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Australian Tree Species Research in China

Proceedings of an international workshop held at Zhangzhou, Fujian Province, PRC, 2–5 November 1992

Editor: A.G. Brown

Australian Centre for International Agricultural Research
Canberra 1994

Contents

Editor's note: Throughout these proceedings specific seedlots are identified by numbers which, with few exceptions, are serial numbers from the Australian Tree Seed Centre of the CSIRO Division of Forestry, Canberra. The Seed Centre can supply more details of the seedlots and, where appropriate, seed from the collections.

Foreword

ACIAR has supported collaborative forestry research between China and Australia since 1985. This workshop is the culmination of that research, enabling those who have participated, both from China and Australia, to draw together the results of many trials undertaken during the last 7 years, and to look to the future in the light of all that has been achieved.

There is no doubt that the research has had remarkable success, and both countries stand to gain significantly from it in the years ahead. Previously untried species and provenances of Australian trees have been shown to perform significantly better than many earlier introductions to China. Experimental plantings are giving rise to full-scale plantations, and the planting of new, more productive species and provenances will gain momentum as newly planted seed orchards start bearing in the years ahead.

It is also gratifying that many Chinese scientists, particularly young researchers, have gained from working beside Australian scientists with many years' experience in selecting and testing Australian trees for particular conditions. This is evident from the real sense of partnership that has developed between scientists from both countries and the higher quality research now emerging from the Chinese side.

This is not the end of ACIAR forestry research in China. Some projects are continuing, new proposals are being developed, and the work of the past 7 years will go on. It has been most rewarding for ACIAR to support the research between the Chinese Academy of Forestry and Australia's CSIRO and other research institutions, and I look forward to seeing the immense gains in China's forestry from the increased use of higher yielding Australian trees.

G.H.L. Rothschild
Director
ACIAR

Research Overview

A.G. Brown*

It is a pleasure to congratulate scientists and managers who over the past 7 years have contributed to the CAF/ACIAR projects which provide the basis for the achievements reported at this workshop. Those achievements include:

- significantly expanded knowledge of adaptation of eucalypt, casuarina and acacia species and provenances (especially acacias);
- assessment of intraspecific variation in seedling morphology and frost resistance of *Acacia mearnsii*;
- elucidation of flowering biology and breeding system of *A. mearnsii*;
- establishment in China of a comprehensive genetic base of promising species;
- development of breeding plans, skills and basic biological information to permit rapid improvement of key species;
- better appreciation of the possible role of mycorrhizal inoculation;
- improved understanding of the dependence of growth of eucalypts on available moisture;
- improved ability to predict likely successful planting sites through climatic analysis;
- establishment in China of facilities and skills to assay tannin and pulpwood quality;
- assessment of product quality (both tannin and wood);
- development of a new tannin-based adhesive for plywood;
- wide dissemination of research results through workshops and literature, including workshop proceedings, books and papers.

The potential economic value of these results has been predicted to provide a return on research investment of 34% per cent per year. It would be of great interest to have a similar economic study in a few years time.

I note with satisfaction Mr Yang Minquan's success in obtaining support of Y400 000 in China's current 5-year plan, to extend the planting of acacias in China. I interpret this as an indication of both the progress we have made in our collaborative research and the importance which the Chinese Government attaches to the application of results.

In Australia, the Government has sponsored an expanded land-care program which, along with other factors, has generated new interest in the potential use of acacias.

Lessons from the Research Program

The effectiveness and efficiency of research are important to all research organisations. I believe that the following significant factors have contributed to the success of the current research:

- effective cooperation between institutions in Australia, enabling the relative advantage of each institution to be captured for the benefit of all participants;
- the development of an effective research network among scientists which extends across historic institutional boundaries;
- the calibre and dedication of staff who have participated in the research, and the stability of staffing throughout the projects;

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- research plans with clear, realistic and mutually agreed objectives;
- commitment by the participating organisations to plans of reasonable duration (i.e., of at least 3 years);
- delegation of responsibility to scientists;
- an appropriate balance between strategic and applied research;
- political and financial support, which has among other things provided adequate operating funds.

I have not listed a large team as important. On some problems a small but talented group is quite adequate; but by contrast marked increases in the number of agricultural scientists in some countries have not been accompanied by increased productivity.

Time and stable funding are necessary but insufficient conditions for building sustainable, productive research programs. They must be factored in with elements from the list above. Even when high rates of return are expected from continuing research, capacity and progress may decline in the absence of perceptive analysis and a determination to nurture the discovery process.

ACIAR support for forestry research with China is changing. A new project to assist predicting growth of different species and provenances in different regions has recently begun. This will build on research carried out as one subproject in the earlier research. We hope to commence a new project in mid-1993, but the scale of this project will be smaller than those now concluding. Despite this, we hope that the momentum which we have built up together over the last 7 years can be maintained. It is a challenging task to attain the leading edge of research, and once attained that position is precarious. The slope leading to the pinnacle is slippery, but we are pleased to have been partners in the climb towards the top.

Impact of Australian Tree Species Research in China: an Update[1]

J.S. Davis*, D.W. McKenney**, J.W. Turnbull* and S.D. Searle***

Abstract

Project 8457 and its replacement 8848 were the focus of a collaborative research effort between CSIRO in Australia and the Chinese Academy of Forestry (CAF). The primary objective of this set of projects was to examine the potential of fast-growing species of *Eucalyptus*, *Acacia* and *Casuarina*. During 1990 an assessment of the expected impact of the research findings was undertaken. Early project trials were used to develop estimates of the expected quantitative impacts of the research. Even with considerable conservatism in developing these estimates it was found that the gains from this research effort were likely to be substantial. Net present values of the gains of $A114 m and internal rates of return of 34% were estimated. This paper uses the information of an additional 2–3 years of results to update the impact assessment. It presents a comparison of the two sets of results and highlights some of the important implications. These additional assessments suggest that the initial estimates of the research impacts have not substantially altered. Research investment returns of around $100 m (in 1990 values) and internal rates of return of about 30% can still be expected.

THIS paper describes the economic impact of a set of collaborative forestry research projects in China, ACIAR Projects 8457 and 8848. The projects deal essentially with the selection of fast-growing species of *Eucalyptus*, *Acacia* and *Casuarina* for planting in southern China.

Due to the long-term nature of forestry, many of the social gains from this research have not yet been realised so this analysis has both an *ex post* and an *ex ante* perspective. This paper updates an earlier assessment (McKenney et al. 1991) by using an additional 2–3 years of research trial information.

Background

Forestry in southern China

Since 1949 the Government of the People's Republic of China has made strenuous efforts to increase forest areas. Early efforts included mobilising the people for massive planting projects but the millions of hectares of plantations which resulted generally had low productivity. The choice of species was dictated primarily by seed availability from local sources. More recent national plans for forestry seek to integrate environmental, commercial-industrial and social considerations and include coastal shelterbelts to control sand drift, revegetation of denuded hills and a large plantation program of fast-growing trees. Social considerations in forestry include reformulation of forest laws to give people greater rights to the trees they plant, and provision of incentives for agroforestry and fuelwood production (Qin 1988).

China's forests cover 113 million ha, about 12% of the land area. More than half of the 100 million cubic metres of wood harvested annually comes from southern provinces, mainly from trees planted by collectives and individuals (Bennett 1988). There is an immense domestic demand for fuelwood, poles and sawn timber and a government policy to increase the amount of wood used for paper pulp. In the ten southern provinces and autonomous regions there are over 25 million ha of deforested land suitable for reforestation and a further 12

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[1] This paper draws intensively on the more detailed paper McKenney et al. (1993)

* Australian Centre for International Agricultural Research, Canberra, Australia

** Forestry Canada, Sault Ste. Marie, Ontario

*** CSIRO Division of Forestry, Canberra, Australia million ha of poorly stocked forest which could be upgraded (Bennett 1988).

An Australian forestry mission to China in 1980 concluded that considerable scope existed for technical improvement of practice in eucalypt plantations to increase growth rates and reduce establishment costs. It also recommended testing new introductions of species and provenances of eucalypts, acacias and casuarinas to increase plantation productivity (Carter et al. 1981).

In 1981 a project to increase forest productivity through demonstrations of different species and provenances and plantation establishment treatments was started in Guangxi Zhuang Autonomous Region under the Australia-China Program of Technical Cooperation for Development. This project, at Dongmen State Forest Farm, showed substantial increases in yield could be obtained through the introduction of new species and provenances of eucalypts and pines and strategic applications of fertiliser (Cameron et al. 1988, McGuire et al. 1988).

A complementary project to test a wider range of Australian species and provenances over a variety of environmental conditions in other provinces where major tree planting activities were planned was supported by ACIAR in 1984 (Project 8457). Implementation began in the following year through the Chinese Academy of Forestry's research institutes in Guangzhou and Beijing, and the CSIRO Division of Forestry, Canberra.

ACIAR Projects 8457 and 8848

The first of these projects commenced in 1985 with the primary objective of identifying Australian eucalypts, acacias and casuarinas which would be more productive than those currently planted in China. A secondary objective was to assist the Chinese in developing scientific research capacity. The project involved introducing from Australia and elsewhere a wide range of species and provenances of known origin. The new material was compared to local selections in field trials on representative sites in different climatic areas. During the first 3 years 19 field trials were established. These were located in Yunnan Province in the cool subtropical, high-altitude plateau areas of southwestern China; in warm subtropical Fujian Province; and tropical Guangdong and Hainan Island provinces. These are areas targeted for eucalypt plantation development.

The trials were designed to test the adaptability of the new introductions. Survival and health were assessed and growth measured. Seedlots from previous introductions were included in the trials as controls for comparative purposes. Statistical considerations suggested a relatively small plot size be used, usually between 9 and 25 trees, which limited the amount of growth data that could be obtained but maximised the number of seedlots that could be screened. It was planned to use the early data as the basis for establishing larger areas of the most promising species and provenances to provide more reliable production data and a source of improved seed. More details of the trials used for estimating the impact of this project are given by Yang et al. (1989), Zhou and Bai (1989), Wang et al. (1989) and Wang (1990) and in papers in these proceedings.

Results and progress

Soon after establishment it became evident that some of the new introductions were growing very much faster than the local species used as controls.

While the experimental data suggest substantial increases in wood production are possible from introduced species, it must be emphasised that some caution is necessary due to the small plot size. There is a potential for the volume estimates in small plots to be inflated due to edge effects. Nevertheless, the results to date do provide an indication of the potential of the new species, especially since the more recent data confirm the early trial results.

The impact of the new information on the plantation program in China is difficult to estimate but it is unlikely that the new species can be fully utilised until reliable sources of seed are available within China. Action has already been taken to establish seed orchards and to prepare breeding programs for further improvement of the most promising species.

China has recently negotiated a loan from the World Bank to undertake extensive planting of forest trees. In southern China, eucalypts feature prominently in this program and the results of the ACIAR trials and the trials in Guangxi (Australia-China Afforestation project) have been highly influential in selecting the species to be used (Ministry of Forestry pers. comm.).

Since the original evaluation of these projects by McKenney et al. (1991) a further 3 years of trial results have become available. This information has been used to update the estimates of wood yields which are expected to be generated if the results of the project are adopted. With some minor variations it has been found that the earlier very encouraging impacts have been confirmed by this additional information, which is used in the rest of this paper to provide revised estimates of the gains expected from this research effort.

Impact Assessment Using a Simple Economic Framework

Assessment framework

The general steps in calculating research payoffs are summarised in Figure 1. Several research evaluation frameworks have been employed in past assessments of the impact of research. Some have used very simple models which estimate the value to society of the research as the expected increase in product output valued at the current or expected price. Others have used welfare-theory based measures of the impact of technology with multi-stage, multi-regional traded good models incorporating research spillovers between regions to estimate the potential value to society of the research. Whether a simple or more complex evaluation framework is chosen depends largely upon the intended use of the information generated. For some decision-making situations the information generated by a simple framework will be all that is required while for others more complex inter-regional interactions will be important.

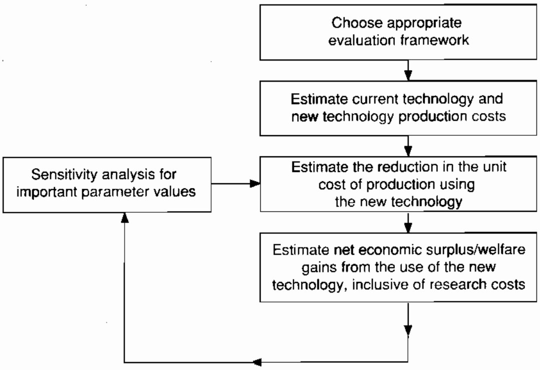

Fig. 1. Steps in evaluating the impact of research.

Even if a simple framework is considered appropriate, care is required in the choice of the framework and especially the estimation procedures adopted. In particular, the estimated value of the expected increase in output should be used with care. Figure 2 illustrates two possible options for a simple measure of the gains from research. A single-region, non-traded good model is represented. The demand for the product is represented by D. Before research the product supply is S_0. After research the cost of producing the product is reduced, shifting the supply to S_1. The welfare-theory based measures of the gains from research suggest that the area 'abde' is a close approximation of society's gains. For a given cost reduction due to research, in this case 'bf', the area 'abfe' will remain the same regardless of the supply and demand characteristics of the product involved. The rest of the welfare gains, here 'bdf', will change depending upon the supply and demand characteristics. In the extreme, this area can be as large as 'bcf'. In most cases this variable area is a relatively small share of the total welfare gain estimate.

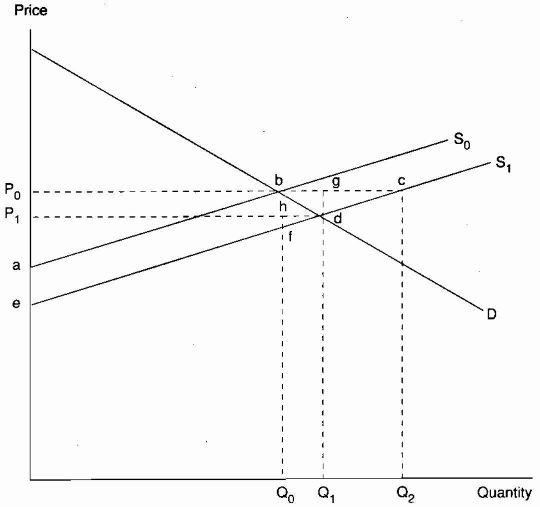

Fig. 2. An illustration of a simple framework for assessing the gains from research.

The second measure illustrated is the value of the change in output. In most studies which include this measure it is rare to find clear specification of the assumptions regarding the supply and demand conditions. Figure 2 illustrates the differences which can occur if different implicit assumptions are made. If it is assumed that the demand is perfectly elastic and the current price is used to value the increase in output, the area 'bcQ_0Q_2' will be estimated. On the other hand, if the demand conditions are as represented in Figure 2 the change in equilibrium output is likely to be significantly less. If the current price is used to value the increase in output the gains from research are 'bgQ_1Q_0'. Alternatively if the after-research expected price is used the gains are 'hdQ_1Q_0'. Clearly the estimate of the gains can be very sensitive to the assumptions regarding the supply and demand conditions. Many studies using the value of output-change measure also estimate the change in output from the research results or researcher controlled (farm) trials. As has been discussed by Davis and Bantilan (1991) additional estimation errors can arise since the relationship between this type of information and aggregate supply and demand conditions is often complex and not incorporated in estimates.

In this study the simple welfare-theory based measure is adopted to estimate the expected gains from research. Apart from the theoretical basis for this measure, in general it is likely to be less sensitive to the often uncertain underlying supply and demand conditions. For reasons highlighted in Davis and Bantilan (1991) the cost reduction, that is 'bf', will be used to estimate the research gains not the output increase ('bc' or 'bg').

This assessment uses only wood values to estimate benefits. Any important non-wood value benefits (or costs) are ignored. Hartman (1976) provides the first formal analytical approach to the economics of forestry when non-wood values enter the decision calculus (see also Bowes and Krutilla 1989). Depending on which non-wood values are important, over- or under-estimates of research gains may result. Clearly for many of the forestry-related problems in China, the planting of any suitable tree species would help, hence it would be inappropriate to attribute all non-wood benefits to the species selection trials analysed here.

The next section outlines the cost analysis which has been developed to assess the impact of the research. This cost analysis is used to provide an estimate of the reduction in unit cost due to research. Project research costs are then summarised and productivity (volume) gains and costs are used to estimate the net worth expected to stem from the project. Since most of the gains are still to be realised, sensitivity analysis using trial results from each year as well as simulations with a range of parameter changes are used to indicate whether the estimates are robust.

Current and new species wood production costs

The economic assessment of gains to wood production from research requires identification of relevant costs for different silvicultural regimes. Since costs and outputs occur through time, a dynamic dimension is needed in the analysis. In forestry such costs may include: site preparation, planting, fertiliser, survival assessments, harvesting activity and an opportunity cost for land. Often land costs are ignored (Samuelson 1976). The following two subsections describe the costs of growing both current and new species of eucalypt, acacia and casuarina in southern China. This cost analysis is separated into the costs of production of the new seedlings and then the plantation costs through to final wood production.

Seed orchard costs in China For China to realise the benefits of increased wood production due to the project species selection trials, some additional costs will be incurred. Among other things these include the costs of adopting the new species (i.e. obtaining seed). If available, the seed could be purchased. However, the Chinese have generally chosen to develop seed orchards for the major species groups in the project. For an economic analysis this cost should be applied to each plantation that utilises the new species. However, note that the cost of doing research that identifies better species should be applied to all plantations that can utilise the improved technology, now and into the future. This approach recognises the permanent nature of technological improvement and is similar to the approach used by McKenney et al. (1989) for evaluating the potential economic benefits of tree breeding.

Table 1 provides a summary of the estimated costs of the relevant seed orchard programs in China. The costs are given in annual terms and as a cost per hectare of plantation. The method of calculating seed orchard costs per hectare of plantation is fully described in McKenney et al. (1989) but can be summarised as follows. All the orchard establishment and management costs (e.g. land costs, site preparation, fertiliser, animal control) over time are converted to an annual cost over the productive life of the orchard. This annual cost is converted to an average cost per hectare of plantation by dividing by the average annual potential planting area the orchard can support.

The potential planting program is contingent on the productivity of the orchard (i.e. how much viable seed it produces), the efficiency of nursery practices (i.e. the number of seeds required to produce a seedling) and the stocking rate of plantations (i.e. the number of seedlings planted per hectare of plantation). Unless nursery practices are very inefficient or the species is a poor seed producer, the seed orchard costs comprise only a small proportion of the plantation establishment costs. The costs ranging from 1.4 to 65.9 yuan/ha are shown in Table 1 and are less than 1% of the plantation establishment costs. Since these costs are so small they have a relatively minor impact on the overall cost of wood production. For the species examined here variations in the initial assumptions of orchard costs and orchard seed yields had little effect on the seed orchard costs per hectare of plantation.

Plantation costs with current and new technology The unit cost of producing wood is calculated by compounding all plantation establishment and management costs forward to the end of the plantation's life and dividing by harvest yield. The costs are then expressed per unit of production (e.g.

yuan per m³). When multiple products are realised from a plantation the issue of cost allocation arises. Here the unit cost of production has been calculated based on total wood yield through time since the allocation of costs among joint products is generally arbitrary and can lead to biased cost estimates for each product (Hof et al. 1985; Bowes and Krutilla 1989).

Table 2 includes the estimates of wood production from existing species plantations which are used as the basis for the cost analysis. Many wood products can potentially be obtained from plantations depending on how they are managed through time (e.g. fuelwood, pulpwood, sawlogs). No attempt has been made to determine whether the research will result in a change to the optimum economic rotation

Table 1. Average seed orchard costs in China.

Species category	Annual cost over productive life of orchard (yuan/ha)[a]	Average annual seed production ('000 seeds/ha of orchard)	Potential plantation area (ha/ha of seed orchard)[b]	Seed orchard cost/ha at plantation (yuan/ha)
Tropical casuarina	959	10 832	677	1.42
Tropical acacia	1827	497	28	66.00
Tropical eucalypt	1084	4 595	342	3.17
Warm subtropical eucalypt	1098	4 506	338	3.25

Notes:
[a] Annual costs estimated using costs compounded at 5% real interest rate
[b] Based on 4 to 1 seed to seedling ratio and initial plantation stocking rates of: 3333 seedlings/ha for *Eucalyptus*, 4444 seedlings/ha for *Acacia* and 4000 seedlings/ha for *Casuarina*; proposed seed orchard sizes are: 30 ha for sub-tropical *Eucalyptus*, 50 ha for tropical *Eucalyptus*, 10 ha for *Acacia* and 100 ha for *Casuarina*
Source: Information provided by scientists in Chinese Academy of Forestry

Table 2. Existing plantation production estimates over time (m³/ha).

Species category and wood product	Total production	Production level each year														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Casuarina equisetifolia	142															
Fuelwood non-coniferous	52			4			8			10						30
Pulpwood	0															
Other industrial roundwood	50															50
Sawlogs for sawn timber	40															40
Acacia auriculiformis	200															
Fuelwood non-coniferous	50										50					
Pulpwood	150										150					
Other industrial roundwood	0															
Sawlogs for sawn timber	0															
Eucalyptus citriodora — tropical	175															
Fuelwood non-coniferous	50			5							45					
Pulpwood	125			25							100					
Other industrial roundwood	0															
Sawlogs for sawn timber	0															
E. citriodora — subtropical	56															
Fuelwood non-coniferous	26			8	8	4	4	2								
Pulpwood	30							30								
Other industrial roundwood	0															
Sawlogs for sawn timber	0															

Source: Estimates by project scientists based on plantation production patterns for existing (control) species, estimated by project scientists length or management regime. The analysis is based on current practices in China. Different flows of products are generated by different species. Some provide early output and each species has its own rotation length. As stated earlier no attempt has been made to determine whether the research will result in a change to the optimum rotation length for these plantations.

The information in Table 2 is used in two ways. The output flows are used as a guide to the annual cost flows for each species. Secondly, the total yield over the full rotation with current technology is adjusted by the yield increases estimated from research trials to give the increased yield resulting from the new technology. This is discussed below.

Table 3 summarises the plantation information used in the cost analysis. Columns [1] and [2] have been taken directly from Table 2. As already indicated the research trial results do not include a completed full plantation rotation. The yield increases seen in trial results have been used to project the expected final wood output changes with the new technology, that is, species and provenance introductions. Therefore the percentage (not absolute) changes observed in the final results are applied to existing plantation production levels. In Table 3 columns [2] and [3] are used to estimate the expected total wood production in column [4].

The Chinese forestry researchers have provided the current level of annual plantings of each species of trees in the areas under consideration. This information is summarised in column [5] of Table 3. The very encouraging early results from project trials have resulted in decisions to establish seed orchards for the species with most promise. Column [6] of Table 3 indicates the expected areas of seed orchard and column [7] provides estimates of the plantation area which could be potentially supported by the seed orchard production. The estimates of plantation area are based on the information provided in Table 1.

Detailed establishment and annual maintenance costs estimates were developed for plantations of each species. Australian and Chinese project

Table 3. Summary of estimates for plantations used in cost analysis for best of the improved species.

Species trial results	Average rotation	Wood yields			Estimates of expected plantings	Area of seed orchard	Potential plantation area from orchard
		Current (m^3)	% Gain	Expected (m^3)	(ha)	(ha)	(ha)
	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Tropical casuarina							
1989	15	142	39	197	10 000	100	67 692
1990	15	142	65	234	10 000	100	67 692
1991	15	142	98	281	10 000	100	67 692
1992	15	142	132	329	10 000	100	67 692
Tropical acacia							
1989	10	200	144	488	1 200	10	277
1990*	10	200	144	488	1 200	10	277
1991*	10	200	144	488	1 200	10	277
1992*	10	200	144	488	1 200	10	277
Tropical eucalypt							
1989	10	175	135	411	33 000	50	17 102
1990	10	175	114	375	33 000	50	17 102
1991	10	175	107	362	33 000	50	17 102
1992*	10	175	107	362	33 000	50	17 102
Warm sub-tropical eucalypt							
1989*	7	56	217	178	10 000	30	10 126
1990	7	56	217	178	10 000	30	10 126
1991	7	56	186	160	10 000	30	10 126
1992*	7	56	186	160	10 000	30	10 126

* Trial results not available; previous or next year's results used

scientists provided these estimates, initially using existing plantation information. This information was adjusted to account for changed costs resulting from the new technology. Examples of the latter include increased seedling costs (see Table 1) and increased fertiliser use to ensure output increases are sustained over several rotations.

Table 4 provides a summary of this cost analysis for each species. The old technology and new technology unit cost of wood production are given in the first two columns. These wood production costs are seen to range from 19 yuan/m^3 to 83 yuan/m^3 for the old technology, falling to between 9 and 48 yuan/m^3 respectively with the significant yield increases expected from the new technologies. Thus the unit cost reductions due to research are seen to range from 9 yuan/m^3 for tropical casuarina to 36 yuan/m^3 for warm subtropical eucalypts. In percentage terms these represent reductions in production cost ranging from 18 to 53%. (Notice these correspond to 39 and 217% production (volume) increases, highlighting the need for caution in assuming a one to one correspondence in these figures, as has sometimes implicitly been the case with some research evaluation studies.) With the additional trial results these estimates of reductions in unit cost do exhibit some changes. In most cases these changes are relatively small. The exception is for tropical casuarina, where the more recent information suggests cost reductions up to double those found with the earlier trial results.

The cost estimates in Table 4 have been calculated by compounding all costs to the end of the rotation and dividing by the total wood production. The compound rate used was 5%; 8% is also used to illustrate the sensitivity of the returns from research to various assumptions. In general, as would be expected, the higher the rate at which costs are compounded the higher the unit cost both with and without the new technology (genetic material). The reduction in unit cost due to research at high interest rates is therefore larger in absolute terms, but not as a percentage.

Table 4. Estimates of unit cost reductions for forestry research in China.

Species trial results by year	Unit cost of production		Unit cost reduction	
	Old (y/m^3)	New (y/m^3)	(y/m^3)	(%)
Tropical casuarina				
1989	51	42	9	18
1990	51	39	12	24
1991	51	36	15	29
1992	51	33	18	35
Tropical acacia				
1989	19	9	10	53
1990*	19	9	10	53
1991*	19	9	10	53
1992*	19	9	10	53
Tropical eucalypt				
1989	38	22	16	42
1990	38	24	14	37
1991	38	24	14	37
1992*	38	24	14	37
Warm subtropical eucalypt				
1989*	83	47	36	43
1990	83	47	36	43
1991	83	48	35	42
1992*	83	48	35	42

* Trial results not available, therefore, the previous or next year's results are used
Note: Annual unit costs are estimated using costs compounded at a real interest rate of 5%

Project research costs

Table 5 summarises the costs of Project 8457 and its follow-up 8848 covering 1985 to 1991. The costs include those incurred by ACIAR, CSIRO and CAF. The research costs for CAF and especially CSIRO are both direct and indirect (e.g. the use of existing buildings and equipment).

Anticipated project net benefits

The gross benefits from the research project are estimated using the unit cost reductions and the framework outlined at the beginning of this section. The present value of these gross benefits is then used with the research cost flows to estimate the net benefits from the project. Since the final wood production plantation has yet to reach the harvesting stage, these benefits are as yet only anticipated. In light of this, several alternative estimates are presented to indicate the sensitivity of the results to different assumptions regarding the impact of the research.

Base-case anticipated project net benefits The base-case project net benefits have been calculated using the information in Tables 2–5 for each year of trial information summed across four trials, using the following assumptions.

- A substantial lag between the start of the research project in 1985, and the harvesting of plantations of the new species. This lag was assumed to be 17–24 years depending on the species. Important components were: completion of the species selection research trials; establishment of seed orchards and production of seed (in this case the trials and orchard establishment overlapped), and establishment of improved plantations which take between 7 and 15 years before harvesting.
- The adoption level of the new species was estimated as the lowest of two possible figures. The first was the levels of current or planned plantings of the new species. The second was the area which could be planted from the seed which is available from the seed orchards being established.
- The demand for the final wood products was assumed to be perfectly elastic, or at least the price was assumed to be unaffected by the increased output due to the research. This can be interpreted in two ways: in China, prices are generally administered; and/or the areas concerned produce a relatively small share of total wood output. The annual gross benefits from research were estimated in two parts: first, the area 'abfe' in Figure 2 using the pre-research output and the unit cost reductions, and second, the area 'bcf', using the with-new-technology output and the unit cost reductions. As indicated in the earlier discussion, care is required in using the second area, 'bcf', although in this case it did not represent a major share of the benefits.
- The interest rate for compounding costs was assumed to be 5%; this being the real rate for forest plantation type of investments. The discount rate for the research investment to estimate net present values was chosen as 10 %. The basis for the different rates for each activity is that plantation activities are commercial investments and therefore warrant a 'private' rate of interest. On the other hand, public sector research investments, apart from being more risky, should be considered from a 'social' discount rate context which is assumed here to be higher than the private rate. The internal rates of return to the research investment are also used for the research assessment analysis. Another justification for the

Table 5. Costs of research projects 8457 and 8848.

Year	ACIAR ($A)	CSIRO and CAF[a] ($A)	Total costs (nominal $A)	Total costs (constant 1990 $A)
1985/86	111 400	101 500	212 900	268 781
1986/87	63 500	85 000	148 500	176 868
1987/88	73 400	84 000	157 400	176 855
1988/89	183 554	245 000	437 544	463 797
1989/90	178 696	250 000	428 696	428 696
1990/91	156 326	250 000	406 326	383 326
Total	766 879	1 024 500	1 791 366	1 898 321

a Chinese Academy of Forestry

Source: Project documents. Nominal research costs are converted to 1990 dollars assuming an inflation rate of 6% p.a.

higher discount rate is that as agricultural research projects show high rates of return, the rate may be viewed as an appropriate opportunity cost of public research funds.

Table 6 summarises the research benefit estimated from 4 years of trial results. The net present value (NPV) of anticipated benefits is estimated at between $A65.3 m and $A71.6 m, depending on the year of the trial results. The associated internal rates of return (IRR) are 32–34%. The NPV is expressed in constant 1990 Australian dollar terms, but discounted to the year of commencement of the project (1986). The equivalent value if compounded to 1990 is $A105.1–115.4 m. By most standards these returns are high, especially given the substantial lags before benefits begin to flow. In addition it is seen that the estimates of benefit have not changed significantly as a result of using information taken from later trial records.

Sensitivity analysis of project benefits Table 6 also includes estimates of research benefits for a range of alternative assumptions for several key parameters. The last three columns present estimates using a compounding rate of 8% for the plantations and seed production costs. This in general results in higher unit costs and therefore greater reductions in unit cost being attributable to research. For example, in the base case the NPV in 1986 is increased by approximately $A25 m, while the IRR increases by 34–35%.

Other situations include: increased plantings by importing additional seed until more seed orchards are established; and alternative lag structures regarding the time from the commencement of the research to its impact on wood production. The lag varied from 4 years less to 4 years longer than the base case. Table 6 indicates that NPVs, in 1986 $A, range from $A35 m to $A143 m and IRRs from 27 to 45%.

Conclusions

A project which investigated the potential improvements in wood production via new introductions of Australian tree species to China was commenced in 1985. Evaluation of the impact of results of this research indicates that substantial social welfare gains to China can be expected to flow from this research by the turn of the century. Valued at the

Table 6. Summary of research benefits analysis.

Case	Costs compounded at 5%			Costs compounded at 8%		
	Net present value ($A million)		Internal rate of return (%)	Net present value ($A million)		Internal rate of return (%)
	In 1986 $	In 1990 $		In 1986 $	In 1990 $	
Base case						
Trial results						
1989	71.6	115.4	33.8	88.3	142.1	35.3
1990	67.3	108.4	33.1	83.3	134.2	34.6
1991	65.3	105.1	32.7	81.3	131.0	34.2
1992	67.6	108.9	32.8	84.7	136.3	34.3
Sensitivity analysis for 1989 trial results as base case						
Extra seed purchase	116.6	187.8	38.0	143.6	231.2	39.6
Base case half unit cost reduction	35.0	56.4	29.0	43.3	69.7	30.4
Base case half unit cost reduction						
Extra seed purchase	57.6	92.8	32.9	71.1	114.5	34.4
Base case lag shortened						
−2 years	87.7	141.3	38.7	104.3	167.9	39.6
−4 years	107.5	173.1	45.3	124.0	199.8	45.8
Base case lag lengthened						
−2 years	57.9	93.2	30.1	71.3	114.9	31.4
−4 years	46.7	75.2	27.2	57.6	92.8	28.3

commencement of the project (1985/86) the net present value of the research is likely to be of the order of $A71 m. This represents an internal rate of return of 34% which, given the long lags assumed in the analysis, is a very attractive social return to the research investment. This estimate of benefit can be viewed with confidence since it is consistent with results obtained in 1990 and is based on a further three years of data from field trials.

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Australian Trees Grown in China

Wang Huoran, Jiang Zeping and Yan Hong*

Abstract

Certain climatic similarities between China and Australia make Australia an important source of useful tree species, of which about 320 species in 45 genera (21 families) have been introduced to China. In particular, *Eucalyptus*, *Acacia* and *Casuarina* play important roles in plantation forestry, soil and water conservation, and landscaping in the tropical and subtropical regions of China. As academic exchanges and collaborative forestry projects develop, Australia's woody flora will be of even greater significance in operational forestry and theoretical biology in China.

AUSTRALIA is a country rich in plant genetic resources. Its native forests mainly comprise species of *Eucalyptus*, *Casuarina* and *Acacia* although the conifers *Araucaria* and *Callitris* are also found. As forestry has developed in the tropical and subtropical regions of the world, Australian tree species, especially *Eucalyptus*, *Acacia* and *Casuarina*, have become more and more important in plantation forestry, soil and water conservation, agroforestry and as a source of fuelwood. In southern China, Australian trees, together with tropical pines, play a key role in wood supply, a trend that has greatly changed the traditional Chinese landscape in rural areas.

Climatic Comparisons

The atmospheric pressure systems governing climate in Australia have a marked seasonal incidence (Gaffney 1973). Weather patterns are strongly influenced by the great anticyclones that travel from west to east, and much of the continent is characterised by low rainfall, high air temperature and high levels of solar radiation (Brown and Turnbull 1986). In winter, northern Australia is influenced by mild dry southeast trade winds and southern Australia experiences cool moist westerly winds. In summer, by contrast, northern Australia comes under the influence of warm moist monsoonal air of the intertropics, resulting in a hot rainy season; in southern Australia fine weather predominates with high temperatures and little rain. Rainfall is erratic and droughts occur frequently. Generally, the rainfall patterns, as outlined by Brown and Turnbull (1986), are strongly seasonal in character with a winter rainfall regime in the south and a summer rainfall regime in the north, and a uniform regime in much of New South Wales, parts of eastern Victoria and southern Tasmania.

China has a great latitudinal range with markedly different climatic types ranging from cold temperate in the north to tropical in the south. The climate in China is predominantly governed by the seasonal winds. In winter the wind, i.e. the cold airmass coming from central Asia and Siberia, extends south over much of China, resulting in dramatic drops in temperature. Compared with other parts of the world with the same latitudes, the temperature of January in China is about 10° lower, so that winter in China is normally very cold and dry. In summer, the climate is influenced by the Pacific monsoon from the southeast which brings high rainfall (Wu Zhengyi et al. 1980; Anon. 1984). There are no exactly equivalent climatic zones in China and Australia.

Because of China's low winter temperatures, few Australian tree species can be successfully grown in the open to the north of Changjiang River (roughly latitude 30°). A few poor specimens of *Eucalyptus gunnii*, *E. perriniana* and *E. camaldulensis* can be seen in the gardens and parks of Shanghai and Wuhan.

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The climatic conditions in the Sichuan Basin and the area south of Nanling Range, i.e. Guangdong, Guangxi and Fujian provinces, are similar to subtropical climates in southeastern Queensland and northeastern New South Wales between latitude 20 and 32 °S (Brown and Turnbull 1986). A sufficiently good match exists between these two regions of China and Australia to permit introduction of Australian trees into China. Many species are potential candidates; examples are *E. grandis*, *E. saligna*, *Grevillea robusta*, *Acacia mearnsii*, *Casuarina* spp. as well as *Araucaria cunninghamii*.

South of the Tropic of Cancer the climate, even though occasionally slightly affected by the cold air currents, is tropical (Wu Zhonglun 1985) and similar to that in northern Queensland and Northern Territory. More tropical species like *E. citriodora*, *E. exserta*, *E. urophylla* (not Australian), *Acacia mangium* and a number of other tropical acacias and casuarinas are successful in this area of China.

The southwest plateau of China, including the adjunct areas of Yunnan, Guizhou and Sichuan provinces, with peak elevations of around 2000 m, has different climatic conditions due to the topography. The climate is typically subtropical with an obvious dry period, strong solar radiation and little temperature difference among seasons, but much between day and night. Rainfall, sometimes affected by the seasonal wind from the Indian Ocean, is still concentrated in summer. Australian species originating only from a habitat with a winter rainfall regime, such as *E. globulus*, *E. nitens* and members of the subgenus *Monocalyptus*, can be grown in this part of China. The cooler summer and mild winter of this area probably compensate for the difference in rainfall regimes (see Figures 1 and 2).

In summary, the main factors which limit species transfer from Australia to China are:

(a) the very hot summer and much lower temperature and humidity in winter in China in areas with the equivalent latitude;

(b) seasonal winds, especially cold air moving southward, that can kill mature trees of exotic species in southern China;

(c) the absence from China of winter rainfall regimes (Mediterranean climate).

Another factor, which may be of general significance, is the difference in microbial associations of the soils.

Comparison of Vegetation

Of the 1701 genera in Australia, 566 are woody plants (Boland et al. 1984). The two largest genera, *Eucalyptus* and *Acacia*, between them dominate almost all the plant associations of the continent. Main forest communities in Australia are:

(a) *Eucalyptus* forests and woodlands, which occupy wetter areas from tropical northern Australia down the eastern coast to cooler Tasmania, and also in the southwestern corner of the continent. In the north vegetative growth is restricted to the summer wet period, Species differ from region to region.

(b) the mallee or many-stemmed shrub eucalypt communities occur in the south in areas receiving a modest, predominantly winter rainfall. Vegetative growth and flowering occur mainly in the cooler months.

(c) *Acacia* and *Casuarina* communities (mainly woodlands and scrubs) occupy the semi-arid and arid zones, except on some fine-textured soils where either tussock grassland or shrublands of *Atriplex* occur.

(d) rainforests now restricted to about half the area which they occupied 200 years ago, in isolated patches in the wetter east from Cape York to Tasmania. Some types are dominated by *Araucaria* spp. in the north and *Nothofagus* spp. in the south.

Australian forests have few deciduous species; *Toona australis* is a notable exception (Beadle 1981).

Of the 2980 genera in China, 1231 are woody plants, 190 are endemic, and 1141 are monotypic or minitypic genera (Wu and Wang 1983). Extensive conifer forests predominate.

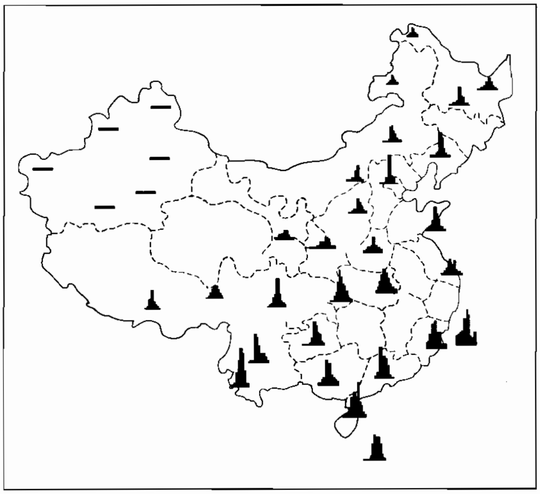

Fig. 1. Rainfall patterns for China.

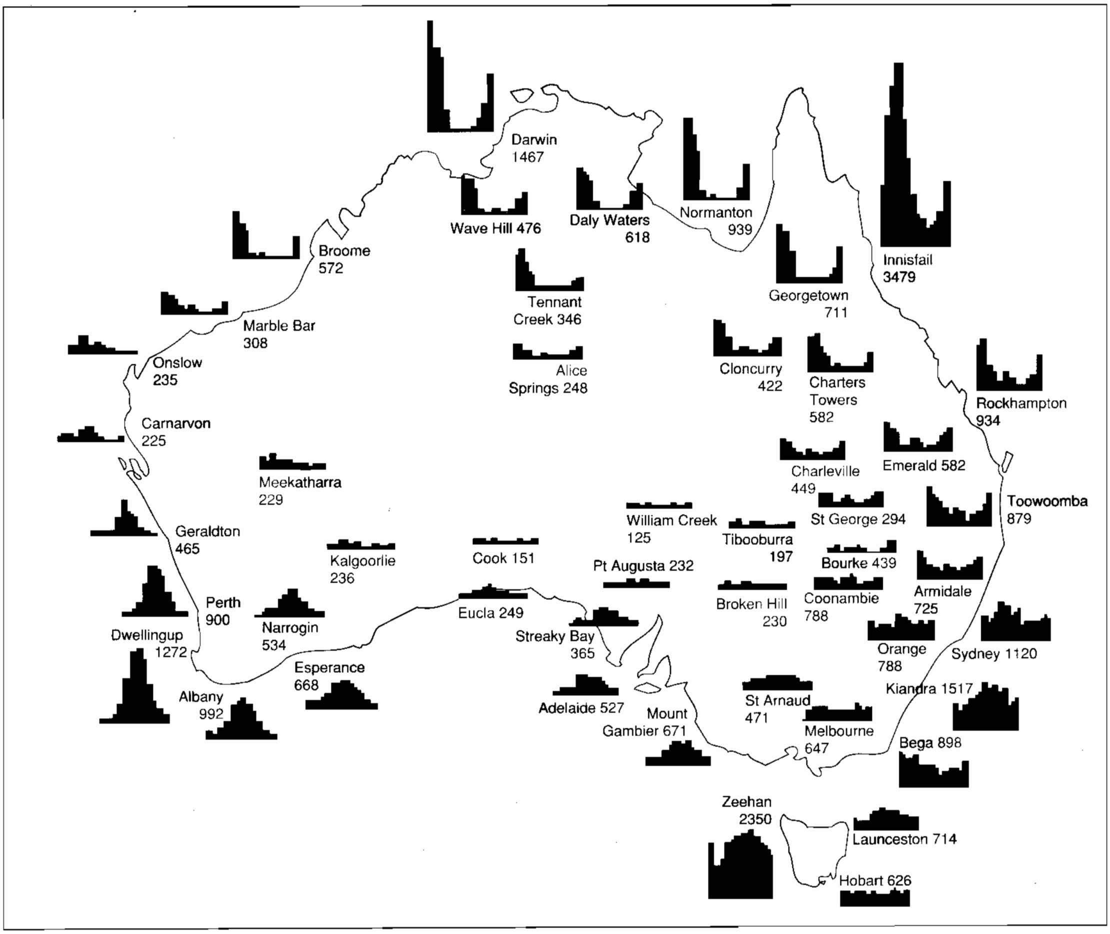

Fig. 2. Rainfall patterns (year-round totals in mm) for Australia (adapted from Beadle 1981).

Pure conifer forests, and conifer-broadleaved mixed forests, occupy vast areas from temperate northeastern to tropical southern China, the species differing from region to region. Deciduous broadleaved forests occur in temperate regions. Evergreen broadleaved mixed forests occupy the northern subtropical zones. Bamboo communities occur sparsely in central and south China. Such types are absent or poorly developed in Australia. Evergreen broadleaved forests occupy the greatest part of central and south China, the equivalent flora in Australia occurring on the east coast from Queensland to Tasmania. Evergreen sclerophyllous forests, in patches in west Sichuan and north Yunnan and southeast Tibet, have their equivalents in Australia's southwest, but with totally different flora. Tropical seasonal rainforests occur only in southern Taiwan, Hainan and southern Yunnan (Wu et al. 1980).

Fossil *Eucalyptus* has been recorded in Sichuan province, Chinese Tibet, dating back to the early Tertiary period (Xu 1981). This may indicate an early connection between Australian and Chinese flora. Similarities can be found in the elements of modern flora, in that there are around 750 plant genera in common between China and Australia (Table 1).

Australian Trees in China

Australian trees were introduced to China more than 100 years ago. Since 1980, collaborative forestry projects between China and Australia have greatly accelerated the introduction of Australian trees to China. Many experimental plantings have been established in southern China for species/provenance selection, and tree breeding programs are undertaken with *Eucalyptus*, *Acacia* and *Casuarina*. In recent years, clonal forestry of *Eucalyptus* has rapidly developed as a business enterprise. Table 2 lists woody genera introduced from Australia.

Eucalyptus

Eucalyptus can greatly contribute towards satisfying demand for paper pulp in China. The first introduction of *Eucalyptus* into China goes back to 1874–1907. Species introduced included *E. globulus*, *E. tereticornis*, *E. camaldulensis* and *E. robusta*. Over 300 species have been tested with an uncertain number of provenances. Wang and Brooker (1991) recorded 102 species in *A Key to Eucalyptus in China*. Only about 10 species (Table 3), however, have or will become important plantation trees in southern China (Wang 1988,1991; Wang et al.1989; Wu and Zhao 1989; Cheng et al. 1990; Wang and Fang 1991; Zhou and Liang 1991). Most species of *Eucalyptus* grown in China belong to the subgenus *Symphyomyrtus*, but species such as *E. regnans*, *E. acmenoides*, *E. radiata* and *E. dives*, in the subgenus *Monocalyptus*, are quite promising in Yunnan Province. It is estimated that about 600 000 ha of *Eucalyptus* plantations have been established in China — mainly *E. exserta*, *E. citriodora*, *E. globulus*, *E. camaldulensis*, *E. tereticornis*, *E. grandis*, *E. urophylla* and some hybrids such as *E. exserta* x *robusta*, *E. saligna* x *exserta*, *E. globulus* x *robusta*, *E. urophylla* x *grandis* etc.

The old plantations of *E. exserta*, *E. citriodora* and so-called *E. leizhou* No.1 are being replaced by more desirable species, such as *E. grandis*, *E. urophylla* and hybrids between the two species. Micropropagation technology is now widely used in operational forestry. More than three million cuttings were produced from tissue culture in 1992.

Although species selections and provenance trials have been conducted for many *Eucalyptus* species, it is necessary to continue *Eucalyptus* introduction, drawing genetic resources from natural populations

Table 1. Genera in common between China and Australia.

Plant taxa		Australia	China	Genera in common Number	Genera in common Percentage
Gymnosperms		15	34	3	6.5
Angiosperms					
	Woody	541	1197	248	16.6
	Non-woody	1145	1749	499	20.8
Total		1701	2980	750	19.1

(Chinese data from Hou 1982, Australian data from Morley & Telken 1983)

Table 2. Woody genera introduced from Australia (numbers in parentheses indicate the total number of species introduced for the genus).

Acacia (c.100)
Actinostrobus (1)
Agathis (3)
Agonis (1)
Allocasuarina (8)
Alstonia (1)
Angophora (2)
Araucaria (4)
Archontophoenix (2)
Banksia (4)
Brachychiton (4)
Callistemon (7)
Callitris (8)
Cassia (3)
Castanospermum (1)
Casuarina (7)
Clianthus (2)
Codiaeum (1)
Cordyline (2)
Dacrydium (1)
Dodonaea (1)
Elaeocarpus (1)
Eucalyptus (c.200)
Eugenia (1)
Flindersia (1)
Gevuana (1)
Grevillea (1)
Hakea (4)
Lagunaria (1)
Livistona (1)
Macadamia (1)
Melaleuca (9)
Metrosideros (5)
Nothofagus (4)
Phormium (1)
Phyllocladus (2)
Pittosporum (2)
Plagianthus (1)
Podocarpus (3)
Ptychosperma (1)
Ranunculus (2)
Sesbania (8)
Sophora (3)
Sterculia (1)
Tristania (1)

in Australia to establish broad genetic bases from which to effect further improvement. Progeny testing has already been set up for some more important species, e.g., *E. globulus*, *E. grandis*, *E. tereticornis*, *E. camaldulensis* and *E. urophylla*, and seed orchards established.

Melaleuca

Species of *Melaleuca* have played an important role in littoral protection in the tropics. They can be used for timber, fuelwood, shelter, protection and landscaping. Nine species of *Melaleuca* have been introduced to China. *M. leucadendron* specimens are planted in Guangdong and Guangxi as street trees.

Callistemon

Most callistemons are salt-resistant shrubs suitable for seaside planting. About seven species have been introduced to southern China. Most are planted in gardens because of their attractive flowers.

Acacia

Acacia species (Table 4) will provide high-quality paper pulp to meet China's demand. In tropical and southern subtropical zones, where the climate is hot and wet, the soils are heavily eroded and leached, and therefore infertile. Research results indicate that multipurpose Australian acacias with nitrogen-fixing capability could succeed on such poor sites.

Acacia mearnsii was introduced into Fujian province in the 1950s. Subsequently more species of *Acacia* were introduced and now about 100 are being tested (Pan et al. 1988, 1989; Wang 1988; Gao et al.1989; Yang 1990; Zheng et al. 1990; Wang and Fang 1991; Yang and Zheng 1991).

Table 3. Major *Eucalyptus* species grown in China for industrial uses.

Species	Main uses	Time of introduction	Number of provenances	Planting areas
E. exserta	Wood, pulp	1960	9	Southern China
E. citriodora	Wood, pulp	1960s	15	Southern China
E. globulus	Pulp, wood, oil	1896	41	Yunnan
E. urophylla	Wood, pulp	1983	17	Southern China
E. camaldulensis	Wood, pulp	1910	92	Tropics & subtropics
E. tereticornis	Wood, pulp	1890	33	Tropics & subtropics
E. grandis	Wood, pulp	1982	44	Southern China, Sichuan
E. smithii	Pulp, wood, oil	1988	4	Yunnan
E. maidenii	Pulp, wood	1964		Yunnan
E. nitens	Pulp, wood	1985	22	Yunnan

Table 4. Good performing and/or promising *Acacia* species grown in China.

Species	Main uses	Time of introduction	Number of provenances	Suitable zones
A. mearnsii	Tannin, soil improvement	1950s	30	Subtropics
A. dealbata	Fuelwood, soil improvement	1950s		Subtropics
A. mangium	Wood, pulp	1979	21	Tropics
A. auriculiformis	Fuelwood, soil improvement	1961	26	Tropics
A. holosericea	Water & soil conservation	1979	5	Tropics
A. cunninghamii	Water & soil conservation	1979		Tropics
A. cincinnata	Wood, pulp		2	Tropics
A. crassicarpa	Wood, pulp	1979	5	Tropics
A. deanei	Wood			
A. melanoxylon	Wood			
A. neriifolia	Wood, pulp			
A. leptocarpa			2	Tropics
A. aulacocarpa	Wood, pulp		5	Tropics

About 60 000 ha of *Acacia* plantations have been established in China. Major species are *A. mearnsii*, *A. dealbata*, *A. mangium*, *A. auriculiformis* and *A. crassicarpa*, some of which have been provenance tested.

Casuarina

Casuarinas (Table 5) were introduced into Fujian province in 1919. They have been widely planted along the coast of southeast China since the 1950s, and have become the preferred species for windbreaks in that area (mainly *C. equisetifolia*, *C. glauca* and *C. cunninghamiana*). More species have been introduced since 1985. Recent research has shown *C. junghuhniana* to be the best performer (National Research Council 1984; Xu and Lao 1984; Wei and Tan 1990; Wang et al. 1992). There are now too many pests and diseases in *Casuarina* forests. *Pseudomonas solanacearum* is especially troublesome.

Grevillea

Grevillea robusta is widely planted in agroforestry systems in south China. It is used as an important roadside tree in cities such as Kunming, Chengdu and Xiamen (Yiqiang 1985).

Coniferae

Of indigenous Australian conifers, three genera, *Araucaria*, *Agathis* and *Callitris* have been planted in China, mainly as garden trees; no commercial plantings have been made.

Problems and Perspectives

Australia is an important source of trees for China. It is crucial to identify appropriate species and provenances for the different regions of China where Australian trees have a potential role in forestry. More research should be carried out on the genetic resources of Australian forests and the theory and methodology of species transfer.

In the last few years, the technology of micropropagation and vegetative propagation by cuttings has rapidly developed, and is now used on a large scale in operational forestry. However, several million cuttings have been produced from only a few clones of *Eucalyptus* and *Casuarina*, an extremely narrow genetic base. In Hainan and Guangdong, all trees in some plantations suffer from the same disease. There is little research on, or application of, long-term breeding strategies in China.

Another serious problem with plantations of Australian species, especially *Eucalyptus* and *Casuarina*, is the decline of site productivity. Little attention has been paid to nutritient cycling and fertilisation. Most plantations of eucalypts and casuarinas are subjected to activities such as the collection of litter for fuel, sometimes at very short intervals. Old windbreak systems of casuarinas on the coast are facing problems of degeneration.

In general, Australian tree species are very important for Chinese afforestation and wood production. *Eucalyptus*, *Casuarina* and *Acacia* are already making great contributions to forestry development, while trees like *Araucaria* spp. and *Toona australis* also have potential.

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Table 5. Important species of *Casuarina* planted in the subtropics of southern China.

Species	Main uses	Time of introduction	Number of provenances
C. equisetifolia	Windbreaks	1919	11
C. glauca	Windbreaks	1950s	9
C. cunninghamiana	Windbreaks	1950s	28
C. junghuhniana	Fuelwood	1985	

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Climatic Analysis Methods to Assist Choice of Australian Species and Provenances for Frost-affected Areas in China

Trevor H. Booth*, Tom Jovanovic* and Yan Hong**

Abstract

The total extent of China subject to frosts is mapped. Three methods to assist species and provenance selection are outlined. The first indicates general regions where particular Australian species will grow in China. The second estimates minimum temperatures at natural provenance sites in Australia and can assist the selection of the most frost-resistant provenances for trials. The third predicts the severity of frost risk at any location in China. Together these methods can help the choice of appropriate species and provenances for specific sites in China.

WORK with *Acacia mearnsii* in ACIAR Project 8458 suggested that frost was a major factor limiting areas suitable for plantations in China. Discussions with Chinese scientists indicated that frost was an important limitation for other Australian species. It also appeared that occasionally severe frosts are more common in China than at locations in Australia with similar long-term mean minimum temperatures. The purpose of ACIAR Project 8849 subproject F was to develop improved methods for assessing frost conditions at any location in China and Australia. This paper shows how the results of this.work can be used to assist the selection of species and provenances for particular sites in frost-affected areas in China.

Mapping General Regions in China Suitable for Particular Species

Selection of species is an important part of any tree introduction program. Webb et al. (1984) described the climatic requirements of 175 tree species suitable for tropical or sub-tropical plantations on the basis of six climatic factors. Using computers to generate maps of the areas which satisfy these requirements has proved to be an effective way of checking and improving these descriptions. For example, Booth (1990) developed a program which could assess conditions at over 15 000 locations around the world. This program showed that the six climatic factors used by Webb et al. (1984) were inadequate to define regions suitable for frost-sensitive species. Information on the absolute (or record) minimum temperature was also needed.

In a previous paper (Booth and Yan Hong 1991) we described how absolute minimum temperature data were added to a microcomputer-based Tree Information and Decision Support Program (TIDSS), which had been developed for China (Yan Hong 1989). Figure 1 shows output from the TIDSS program indicating the very small area of China where the absolute (i.e. record) minimum temperature has never fallen below 0 °C.

TIDSS was used to check and improve descriptions of the climatic requirements of *Acacia mangium* and *A. mearnsii* and to show areas in China suitable for these species (Booth and Yan Hong 1991). Figure 2 shows the area suitable for *Eucalyptus globulus* using the following description of climatic requirements:

Mean annual rainfall	550–1500 mm
Mean max. temp. hottest month	19–30 °C
Mean min. temp. coldest month	2–12 °C
Mean annual temperature	9–18 °C
Absolute min. temp.	> −8 °C

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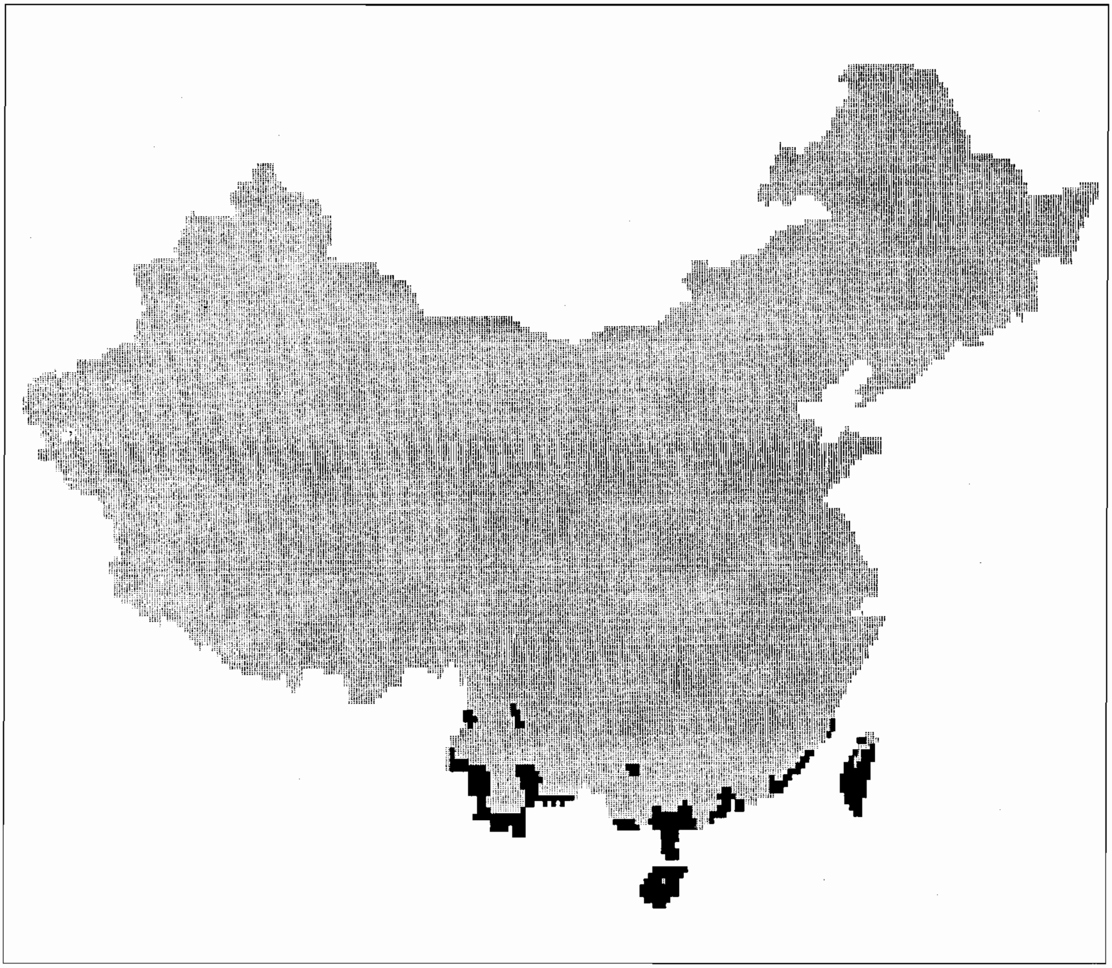

Fig. 1. Frost-free areas in China shown in black shading.

This summary was one of 21 descriptions of eucalypt species' requirements developed for the whole world (Booth and Pryor 1991). The map shows the main region where *E. globulus* is grown in the Yunnan (Turnbull 1981), as well as indicating other areas where it might be suitable. These descriptions or the hundreds of others provided by Webb et al. (1984) or von Carlowitz (1991) provide a first indication of whether a species is likely to be worth trying in a particular area. Mapping the supposedly-suitable area and comparing the output with published or unpublished information provides a good check of the reliability of the information. If trial information is available from other areas in China the description may sometimes be improved, as the descriptions for *A. mearnsii* and *A. mangium* were improved (see Booth and Yan Hong 1991). If trial information from China is not available, then the map provides a first estimate of climatically suitable areas.

Predicting Variation in Frost Resistance between Natural Stands in Australia

Selecting an appropriate species for an area is just the start of the tree introduction process. Selecting the best provenances for a particular site can mean the difference between success and failure. An objective of ACIAR Project 8849 subproject F was to develop interpolation relationships for different monthly minimum temperature measurements in Australia. The purpose was to allow frost conditions

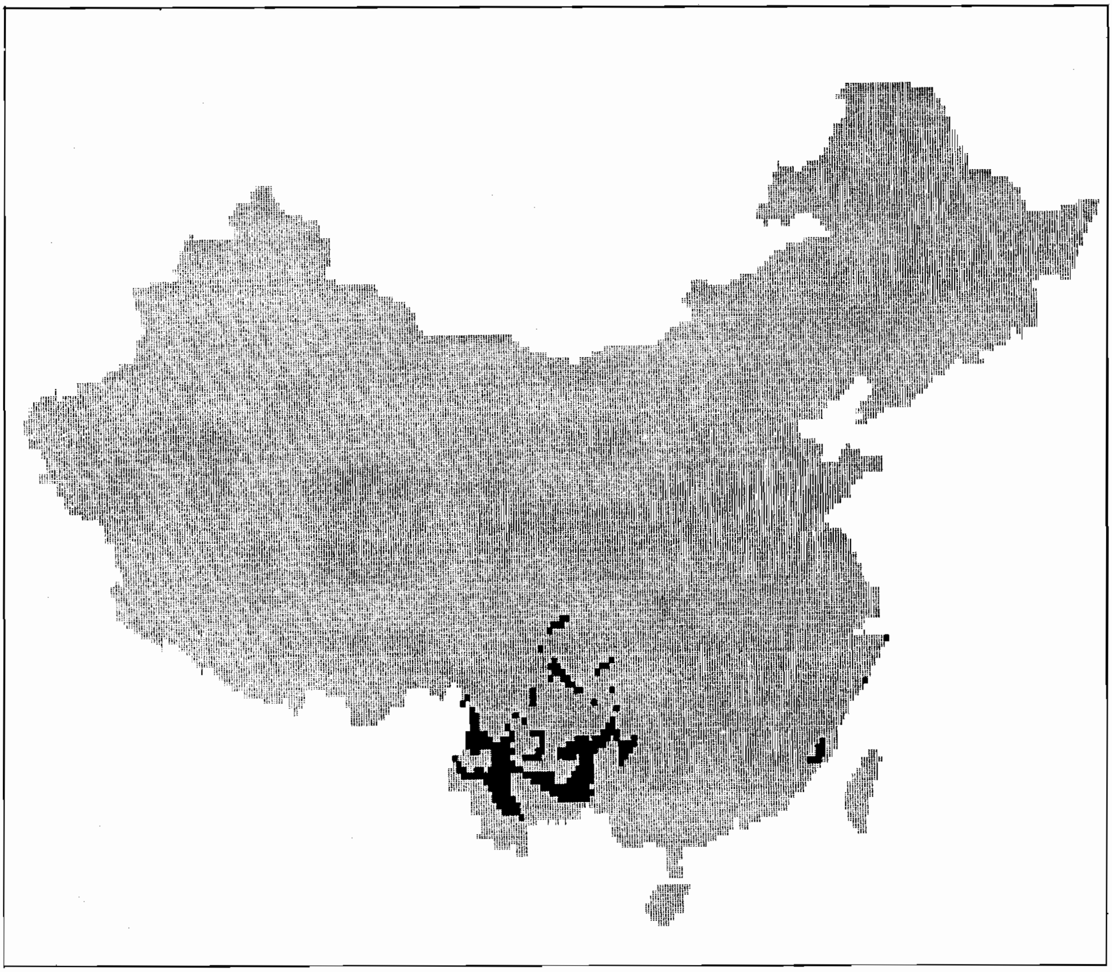

Fig. 2. Areas shown in black are climatically suitable for *Eucalyptus globulus* according to description prepared by Booth and Pryor (1991).

to be estimated for any location in the country. The value of these estimates for predicting the frost hardiness of different provenances could then be assessed.

Monthly minimum temperature measurements are usually available in three forms. For example, if 20 years of data are available for January at a particular location then the *average daily* value would be the mean of 620 values (i.e. the mean of all the measurements). The *average monthly* value would be based on 20 values (i.e. the mean of the coldest January day in each year) and the *absolute* minimum would be based on just one value (i.e. the one coldest January day in all the 20 years). As it is based on only one value the absolute minimum can vary considerably, depending on the number of years of record available.

Interpolation relationships for these different minimum temperature factors were developed using Laplacian smoothing splines (Hutchinson et al. 1984) and data from over 1000 locations in Australia. These relationships allow minimum temperature conditions to be estimated for any location in Australia given its latitude, longitude and elevation. This information can help select appropriate provenances for trials overseas. For example, when looking for frost-resistant provenances overseas researchers sometimes assume that the most southerly locations, such as those in Tasmania, are the most severely frost-affected. This is not always the case, as some of the coldest areas in Australia are in the southeastern area of the mainland.

Using the interpolation relationships we have compared frost damage reported in trials with estimates we have made of minimum temperature conditions at provenances' natural locations. Figure 3 shows the results of comparing the average daily minimum temperature of the coldest month at natural locations of provenances of *Eucalyptus viminalis* with damage recorded on those provenances in a trial at Epsom in South Africa (Nixon 1984). Damage was recorded on a 0–4 scale, with trees very badly damaged or killed by frost scoring 4, for each tree in three replicates of eight trees. The results were expressed as a percentage of the maximum possible.

The relationship between frost damage and estimated minimum temperature ($r^2 = 0.45$) shown in Figure 3 was significantly better than that between frost damage and elevation ($r^2 = 0.27$). However, for some other provenances in the same trial (e.g. 11 provenances of *E. camaldulensis*) the estimated temperature was not a significantly better predictor of damage than elevation.

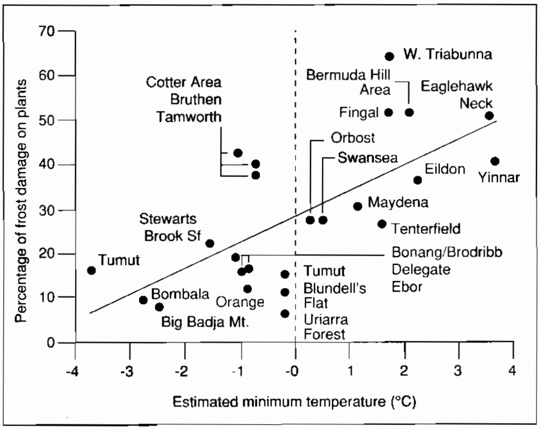

Fig. 3. Relationship between estimated mean minimum temperature of the coldest month at provenances' natural sites and frost damage reported by Nixon (1984) in a *Eucalyptus viminalis* trial.

In other cases (e.g. nine provenances of *E. nitens*) there was no significant relationship between estimated temperature and frost damage. Estimated minimum temperatures of the coldest month were also compared with frost damage results reported in a trial of nine provenances of *A. mearnsii* in South Africa (Hagedorn 1988). The estimated minimum temperatures showed a closer relationship to frost damage ($r^2 = 0.59$) than did elevation ($r^2 = 0.54$), but minimum temperature was not a significantly better predictor.

Some of the most detailed studies of frost damage on Australian species have been carried out in the southeastern United States. We have supplied estimates of minimum temperatures at provenance locations of four eucalypt species to Prof. Don Rockwood (Univ. of Florida). In the first of the analyses to be published using these estimates he suggests that there are complex interactions between frost damage and growth (Rockwood and Meskimen 1991). Fast-growing provenances, which may be relatively susceptible to frost, may grow out of the most vulnerable zone (i.e. near the ground) before slow-growing provenances which are more frost resistant. So, the effects of a frost on a particular set of provenances may be very different if the trees are small seedlings or if they are several metres high.

Further studies using the interpolation relationships may help to clarify the role of frost at natural sites in influencing the frost resistance of particular provenances. For now the interpolation relationships can be used to check that some provenances from colder parts of a species' natural range are included in trials where appropriate.

Predicting Frost Risk at Potential Planting Sites in China

The decision to include provenances from colder regions in trials will depend on the severity of frost likely to be experienced at the trial site. As part of ACIAR Project 8849 Subproject F, interpolation relationships for minimum temperature were calculated to allow frost risk to be estimated for any location in China. Data for 20 years of record were obtained from about 700 meteorological stations across China. Interpolation relationships were developed using Laplacian smoothing splines (Hutchinson et al. 1984). To demonstrate their use the relationships were interrogated to provide estimates of minimum temperature conditions at selected ACIAR Projects 8848 and 8849 planting sites (see Table 1).

The interpolation surfaces were not available when these sites were selected. It is interesting to note that the estimated minimum temperatures at all but one of the Project 8849 trial sites listed are below the −5 °C absolute temperature which was recommended as a minimum for *Acacia mearnsii* by Booth and Yan Hong (1991). Frost damage on *A. mearnsii* plants in a Project 8848 acacia species

Table 1. Minimum temperatures for selected ACIAR trial sites in China estimated using interpolation relationships.

Location		Lat.	Long.	Elev. (m)	Min. temp. coldest month (°C)	Absolute min. temp. (°C)
Forest farm or county	Province					
(Project 8849 trial sites)						
Chenxiang	Fujian	24°49′	117°52′	109	8.5	−1.9
Hubian	Jiangxi	25°51′	114°50′	123	5.0	−6.7
Nandan	Guangxi	24°59′	107°32′	697	4.8	−5.6
Anyuan	Jiangxi	25°59′	115°20′	286	4.3	−7.5
Nanping	Fujian	26°19′	118°10′	92	5.9	−4.3
Wenzhou	Zhejiang	28°1′	120°40′	50	4.2	−6.0
(Project 8848 trial sites)						
Changtai	Fujian	24°40′	117°50′	50	9.0	−1.2
Jindian	Yunnan	25°1′	102°41′	1890	2.1	−5.5
Haikou	Yunnan	24°30′	102°50′	1990	1.8	−6.1
Qionghai	Hainan	19°14′	110°28′	15	15.3	4.8
Bai Shi Ling	Hainan	19°00′	110°15′	20	15.5	4.8
Longdouxie	Guangdong	24°57′	115°5′	480	4.9	−7.1

trial at Longdouxie Forest Farm (Xishing County, northern Guangdong Province) is described in detail by Yan Minquan et al. in these proceedings. The cold period, which occurred in December 1991, was the most severe frost event in the region for fifty years. The lowest temperature previously recorded at the nearest permanent meteorological station was −4.3 °C. The actual minimum temperature recorded on site at Longdouxie was −7.6 °C, which was very close to the predicted value of −7.1 °C given in Table 1. All the *A. mearnsii* trees were seriously injured or killed by the frost, an observation which supports the absolute minimum temperature recommendation of −5 °C made by Booth and Yan Hong (1991). Yang Minquan et al. (these proceedings) also report results from a nearby site where the minimum temperature fell only to −6 °C, but unfortunately *A. mearnsii* trees were not included in that trial.

It will be interesting to see if damage is experienced by *A. mearnsii* at any of the other Project 8848 or 8849 sites in future winters. The estimates of absolute minimum temperature would suggest that the risk is greatest at Anyuan (Jiangxi Province). However, the absolute values shown are estimates of the most extreme value which might be experienced at a site over 20 years and it may be several years before the other sites approach these values. As the trees grow they will also become less susceptible to low temperatures near the ground. Minimum temperatures are also strongly influenced by local conditions, especially topography, so the actual sites may experience somewhat different conditions. Nevetheless, the interpolated estimates provide an indication of the risk at different sites and the interpolation relationships could be used to evaluate frost risk at future planting sites.

Discussion

This paper has described some general methods that can be used to assist the selection of species and provenances for planting in frost-affected areas of China. The methods may assist the selection of agricultural crops as well as forest trees. Enquiries have been received from the FAO/World Bank Red Soils II project to provide advice on frost risks across several provinces of southern China. The interest followed problems during the Red Soils I project when temperatures as low as −15 °C in Jiangxi killed 40% of citrus plantings, as well as causing extensive damage to eucalypt and acacia windbreaks. The team leader wrote that the team considered information on frost risk 'of vital importance in planning a US$300 million investment'. The methods described here could contribute to avoiding serious losses in the future.

Although work on ACIAR Project 8849 Subproject F has now finished the same team of researchers will be contributing to a new ACIAR Project 9127 entitled *'Predicting tree growth for general regions and specific sites in China, Thailand and Australia'*. The new project will continue the development of climatic interpolation relationships and programs, such as that used to produce Figures 1 and 2. The project will also develop more complex mapping programs, which include simulation models of the dynamic influences of climate and soil on tree productivity (see Booth 1991). It will concentrate on selected provenances of *Eucalyptus camaldulensis*, *E. globulus*, *E. grandis*, *Acacia mangium*, *A. mearnsii* and *A. auriculiformis*, though the programs developed will be applicable to any tree species or provenance. The methods developed will further improve our ability to answer the questions: 'Where will it grow?' and 'How well will it grow?'.

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Genetic Improvement of Tropical *Eucalyptus* Tree Species in China

Bai Jiayu*

Abstract

Around 1.5 million hectares of *Eucalyptus* plantations have been established in China, but productivity is much lower than elsewhere (5–10 m^3/ha, compared with up to 100 m^3/ha in Brazil). One reason is that superior species, provenances, families and clones of *Eucalyptus* have not been planted on a large scale. This paper briefly outlines the steps taken for introduction of new lines of *Eucalyptus* and genetic improvement in the ACIAR project *Introduction and cultivation experiments for Australian broadleaved tree species*, undertaken between October 1985 and July 1992.

DURING the 1980s, there has been much progress in selecting *Eucalyptus* species, provenances, and families for plantation improvement in China. The Australian International Development Assistance Bureau (AIDAB) has worked in Dongmen, Guangxi, and ACIAR with the Chinese Academy of Forestry, to select better-performing eucalypts for southern China.

Before this, planting and utilisation trials of natural eucalypt hybrids were undertaken without an overall plan, even though eucalypts had been grown in China for about 100 years. Systematic study began in the 1980s, and now 63 species, 258 provenances and 572 families have been tested. From these many provenances with potential productivity around five times that of the traditional *Eucalyptus citriodora* have been selected.

In recent years the use of interspecific hybrids has increased. Dongmen State Forest Farm, Guangxi, has planted *E. camaldulensis* x *E. urophylla* because it is fast growing on infertile soils and is wind firm. Natural hybrids have been tested for 10 years at Leizhou Forest Bureau, and recently clone no. 8051 has proved a good performer. Genetic improvement has been assisted by vegetative propagation. Qinzhou Research Institute of Forestry (Guangxi), together with Guangdong and Hainan, have worked on tissue culture and cuttings. Annual production is now around 100 000 plants. However, problems remain with the quality and quantity of the planting stock.

Objectives

The overall objectives are to identify the species and/or provenances worth planting and to advance breeding studies through:

1) selection of adaptable, productive new species to replace inferior species presently planted;
2) identification of the best provenances of successful species;
3) progeny testing and selection to supply good reproductive material (seed or cuttings) for establishing seed orchards and plantations;
4) establishment of a gene pool to preserve superior gene resources.

Materials and Methods

Scientists from the CSIRO Australian Tree Seed Centre, aided by climatic analysis of different localities, helped Chinese scientists choose suitable seed for testing. They selected 59 different eucalypt species, and from within these 572 families in 246 provenances (Tables 1 and 2).

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Table 1. List of species/provenances of *Eucalyptus*.

Sp. No.	Seedlot	Species	No. of parents	Locality		Lat. (° ′)	Lon. (° ′)	Alt. (m)
001	15633	*E. acmenoides*	05	Woondum	Qld	26°17′	152°48′	100
002	11060	*E. alba*	03	E of Alligator R	NT	12°22′	133°00′	25
002	12439	"	15	South of Mt Garnet	Qld	18°40′	144°50′	600
002	13119	"	26	Mt Molloy	Qld	16°43′	145°21′	380
003	13942	*E. argillacea*	05	Buchanan Highway	NT	16°39′	132°58′	270
004	15733	*E. bigalerita*	05	Adelaide River	NT	13°15′	131°06′	100
005	12134	*E. botryoides*	08	Meroo Pt Termeil SF	NSW	35°29′	150°24′	9
006	13395	*E. brassiana*	29	West of Morehead	PNG	08°44′	141°25′	25
006	13397	"	27	Woroi to Wipim	PNG	08°51′	143°02′	30
006	13402	"	05	4.6 km S Helenvale	Qld	15°45′	145°14′	140
006	13408	"	10	20.6 km N Musgrave Stn	Qld	14°37′	143°26′	270
006	13409	"	05	11.5 km NE Coen	Qld	13°54′	143°14′	485
006	13410	"	10	44 km N Coen	Qld	13°30′	142°58′	135
006	13411	"	10	3.3 km from Weipa Nth	Qld	12°37′	141°52′	10
006	13412	"	10	6.5 km N Wenlock R	Qld	12°24′	142°37′	90
006	13414	"	10	18 km S Jardine R	Qld	11°18′	142°24′	60
006	13415	"	10	8.8 km NE Bamaga	Qld	10°56′	142°27′	50
006	13542	"	10	18 km NW of Monto	Qld	24°50′	151°01′	390
006	15359	"	20	W of Cooktown	Qld	15°16′	144°25′	50
006	16038	"	33	20 km NW Batemans Bay	NSW	35°35′	150°03′	250
006	16119	"	03	Balamuk-Weremenever	PNG	08°49′	141°20′	20
006	16617	"	05	Wassi Kussa River	PNG	08°55′	142°59′	15
007	B21	*E. camaldulenis*	*	Petford	Qld	17°02′	144°50′	770
007	10666	"	11	Lake Albacutya	Vic	35°44′	142°02′	70
007	12187	"	16	8 km W Irvinebank	Qld	17°24′	145°09′	680
007	12968	"	25	Burdekin R N G'vale	Qld	18°57′	145°03′	410
008	13663	"	21	Wrotham Park	Qld	16°48′	144°10′	230
007	13696	"	10	Leichhardt River	Qld	18°20′	139°53′	20
007	13801	"	27	Katherine	NT	14°27′	132°16′	110
007	13933	"	10	N Fitzroy Crossing	WA	18°06′	125°42′	110
007	13939	"	10	Pentecost River	WA	15°48′	127°43′	60
007	13941	"	05	Victoria River	NT	16°20′	131°07′	100
007	14106	"	09	Gilbert River N	Qld	18°00′	143°00′	150
007	14338	"	12	Region E of Petford	Qld	17°17′	145°03′	500
007	14340	"	01	Emu Ck E Petford	Qld	17°21′	144°57′	460
007	14515	"	10	Mary R Crossing	WA	18°44′	126°48′	270
007	14518	"	10	Tennant Ck	NT	19°34′	134°13′	335
007	14540	"	10	Pentecost River	WA	15°48′	127°53′	10
007	14847	"	20	Emu Ck Petford	Qld	17°10′	145°15′	500
007	14917	"	13	NW of Mt Carbine W	Qld	16°22′	144°43′	400
007	14918	"	15	Laura W	Qld	15°34′	144°27′	90
007	15049	"	10	Bullock Creek	Qld	20°46′	143°55′	400
007	15050	"	07	Gibb River	WA	16°30′	126°10′	400
007	15052	"	07	Isdell River	WA	16°50′	125°32′	250
007	15062	"	08	NE of Katherine	NT	14°23′	132°21′	200
007	16720	"	10	1 km Petford area	Qld	17°24′	145°02′	590
007	16730	"	09	King R/Edith R, Katherine	NT	14°26′	132°03′	190
008	13472	*E. citriodora*	12	ESE of Mt Molloy	Qld	16°42′	145°23′	600
008	13628	"	07	N of Mt Garnet	Qld	17°37′	145°08′	600
008	14703	"	10	W of Mt Carbine	Qld	16°18′	145°05′	940
008	14850	"	34	Irvinebank	Qld	17°26′	145°12′	900
008	14851	"	09	Herberton	Qld	17°23′	145°23′	1000
008	14852	"	18	Mt Garnet	Qld	17°41′	145°07′	850
009	10779	*E. cloeziana*	09	17.7 km E of Gympie	Qld	26°08′	152°50′	150
009	12194	"	10	Coominglah SF Monto	Qld	24°56′	151°00′	560
009	12199	"	10	W Rolleston-Inuune Rd	Qld	24°48′	148°29′	360
009	12202	"	04	Paluma Range SF	Qld	19°01′	146°17′	330

Table 1. Continued

Sp. No.	Seedlot	Species	No. of parents	Locality		Lat. (° ′)	Lon. (° ′)	Alt. (m)
009	12203	″	05	Cardwell	Qld	18°17′	145°58′	75
009	13450	″	10	SE of Gympie	Qld	26°13′	152°55′	150
009	13609	″	18	8 km S of Helenvale	Qld	15°45′	145°16′	500
009	13677	″	40	NW of Cardwell	Qld	26°13′	152°55′	150
009	14127	″	10	S of Ravenshoe	Qld	17°43′	145°29′	950
009	14227	″	10	S of Ravenshoe	Qld	17°43′	145°29′	950
009	14236	″	25	10–25 km W Herberton	Qld	17°20′	145°00′	800
009	14422	″	25	12 km SSW Cardwell	Qld	18°22′	146°01′	30
009	14425	″	25	Gympie	Qld	26°18′	152°48′	100
009	14427	″	25	Blackdown Tableland	Qld	23°48′	149°01′	750
010	13417	*E. crebra*	02	NE of Coen	Qld	13°54′	143°10′	485
011	13406	*E. cullenii*	05	50 km N Laura	Qld	15°21′	144°04′	120
012	13593	*E. decorticans*	05	Taroom–Moura Rd	Qld	25°25′	149°30′	350
013	12325	*E. deglupta*	05	Bulolo	PNG	07°10′	146°40′	0
013	12977	″	20	New Bataan, Philippines		07°38′	126°06′	400
014	13329	*E. dunnii*	10	NW of Kyogle	NSW	28°24′	152°41′	400
015	12171	*E. exserta*	*	32 km E Marlborough	Qld	23°24′	150°30′	10
015	13282	″	*	N of Marlborough	Qld	22°40′	149°54′	30
015	13818	″	07	Mt Douglas	Qld	21°50′	146°00′	580
015	14864	″	16	Herberton area	Qld	17°25′	145°23′	950
016	9541	*E. globulus* subsp. *bicostata*	09	NE of Mansfield	Vic	37°03′	146°20′	850
017	12130	*E. globulus* subsp. *maidenii*	10	Mt Dromedary	NSW	36°17′	150°03′	305
018	13019	*E. grandis*	10	NW of Coffs Harbour	NSW	30°13′	153°02′	135
018	13020	″	10	NNW Coffs Harbour	NSW	30°10′	153°01′	98
018	13289	″	17	Mt Lewis	Qld	16°36′	145°16′	1000
018	13365	″	*	Seed orchard, S Africa		–	100°00′	–
018	13431	″	07	Mt Lewis	Qld	16°36′	145°16′	840
018	13471	″	*	Mt Lewis–Mt Frazer	Qld	16°37′	145°16′	900
018	13965	″	*	Seed orchard, S Africa		–	–	–
018	14210	″	05	27 km SE of Ravenshoe	Qld	17°50′	145°33′	720
018	14393	″	11	25–36 km SE Mareeba	Qld	17°06′	145°33′	900
018	14420	″	20	12 km S Ravenshoe	Qld	17°42′	145°28′	860
018	14423	″	25	Baldy SF 194	Qld	17°18′	145°25′	1000
018	14431	″	25	Belthorpe SF	Qld	26°52′	152°42′	500
018	14509	″	25	Urbenville	NSW	28°31′	152°30′	600
018	14519	″	25	Mt George, Taree	NSW	31°50′	152°01′	230
018	14838	″	07	WNW Cardwell	Qld	18°14′	143°00′	620
018	14849	″	22	NE Atherton	Qld	17°06′	145°36′	1050
018	14860	″	*	EMBRAPA, Brazil		–	100°00′	–
018	15236	″	25	30 km N Coffs Harbour	NSW	30°18′	153°08′	10
018	15358	″	22	24 km NE Atherton	Qld	17°06′	145°36′	1050
019	15356	*E. grandis* x *E. urophylla*	*	Brazil	PI	19°49′	40°16′	50
020	12285	*E. gummifera*	*	Termeil, Nowra	NSW	35°28′	150°23′	30
021	9091	*E. houseana*	01	Prince Regent R Gorge	NT	15°50′	125°30′	45
021	9111	″	*	S Bell Ck Kimberleys	WA	17°10′	125°22′	333
022	13290	*E. intermedia*	10	Julatten district	Qld	16°35′	145°27′	560
023	17244	*E. intertexta*	16	Roe Ck Alice Springs	NT	23°45′	133°50′	500
024	10116	*E. laevopinea*	*	Nullo Mtn E Rylston	NSW	32°48′	149°58′	1070
025	15247	*E. leptophleba*	10	12 km W of Mareeba	Qld	16°58′	145°19′	460
026	6172	*E. maculata*	07	Olney 29 km NW Wyong	NSW	33°08′	151°23′	270
026	13539	″	10	20 km SE of Gympie	Qld	26°17′	152°48′	150
026	13542	″	10	18 km NW of Monto	Qld	24°50′	151°01′	390
026	13576	″	10	E of Dunedoo	NSW	32°04′	149°52′	410
026	14434	″	25	Wondai SF 12	Qld	26°25′	151°56′	400

Table 1. Continued

Sp. No.	Seedlot	Species	No. of parents	Locality		Lat. (° ′)	Lon. (° ′)	Alt. (m)
026	16010	″	05	59.4 km NNW Chinchilla	Qld	26°16′	150°33′	380
026	16360	″	20	SW of Warwick	Qld	28°23′	151°42′	750
026	16757	″	09	Kangaroo SF N Moleton	NSW	30°07′	152°54′	400
026	16899	″	10	Ewingar SF	NSW	29°01′	152°29′	520
026	17511	″	05	Samford/Mt Glorious	Qld	27°21′	152°46′	400
027	15224	*E. melliodora*	02	Pikedale	Qld	28°30′	151°45′	850
028	12795	*E. microcorys*	14	Gallangowan	Qld	26°26′	152°16′	540
028	13535	″	05	10 km W of Beerburrum	Qld	26°57′	152°52′	40
028	13970	″	07	NW of Bulahdelah	NSW	32°19′	152°06′	250
028	13973	″	10	Fraser Island	Qld	25°29′	153°02′	65
028	15362	″	15	Nambour	Qld	26°40′	152°55′	45
028	15527	″	05	Kendall	NSW	31°34′	152°41′	180
028	15607	″	10	11 km W of Beerburrum	Qld	26°56′	152°52′	120
028	15609	″	10	30 km NNE Kempsey	NSW	30°53′	132°55′	30
029	15321	*E. microtheca*	30	Meda & Kimberly Downs	WA	17°25′	124°15′	30
030	15251	*E. miniata*	10	NE of Cooyar	Qld	26°52′	152°00′	400
031	15221	*E. moluccana* subsp. *moluccana*	10	NE of Cooyar	Qld	26°52′	152°00′	400
032	11083	*E. nesophila*	05	40 km S Black Pt, Cobourg	NT	11°19′	132°22′	50
032	11086	″	04	1 km S Raffle Bay, Cobourg	NT	11°21′	132°22′	25
033	11633	*E. ochrophloia*	03	51 km N Yantabulla	NSW	29°18′	140°01′	140
034	13678	*E. orgadophila*	04	N of Clermont	Qld	22°35′	147°39′	274
035	10260	*E. pachycalyx*	02	18 km frm Herberton	Qld	17°23′	145°15′	760
036	13657	*E. paniculata*	05	SW of Nowra	NSW	35°00′	150°30′	120
036	14442	″	11	Coffs Harbour	NSW	29°41′	152°56′	90
037	13924	*E. patellaris*	05	21 km W Katherine	NT	14°37′	132°08′	100
038	11947	*E. pellita*	07	Near Kuranda	Qld	16°14′	145°33′	450
038	12162	″	12	5 km S of Helenvale	Qld	15°45′	145°15′	152
038	13165	″	15	Julatten	Qld	16°35′	145°20′	400
038	13826	″	12	Bloomfield/Daintree	Qld	16°04′	145°19′	200
038	13998	″	12	13.4 km NE of Coen	Qld	13°33′	143°19′	560
038	13999	″	10	71–72 km NE Wenlock	Qld	12°43′	143°08′	100
038	14339	″	18	14.6 km NE Coen	Qld	13°53′	143°17′	580
038	14914	″	15	S of Cessnock	NSW	32°58′	151°21′	250
038	14915	″	10	S of Cardwell	Qld	18°26′	146°08′	15
038	16122	″	10	Between Ggoe-Kiriwa	PNG	08°20′	141°32′	50
039	11038	*E. peltata* subsp. *leichhardtii*	06	Bakerville	Qld	17°24′	145°15′	800
039	11039	″	02	Mount Cottell	Qld	17°22′	145°51′	620
040	11642	*E. peltata* subsp. *peltata*	02	E of Mantuan Downs	Qld	24°25′	147°20′	400
041	13668	*E. phoenicea*	05	W of Cooktown	Qld	15°15′	144°38′	68
042	12803	*E. pilularis*	25	Fraser Island	Qld	25°32′	153°00′	80
042	15528	″	16	16 km WSW of Woolgoolga	NSW	30°10′	150°03′	160
043	15257	*E. polycarpa*	30	NW of Chillagoe	Qld	16°30′	143°22′	
044	11833	*E. propinqua*	21	Kangaroo River SF	NSW	30°07′	152°46′	330
044	12018	″	21	Kangaroo Ck SF	NSW	30°07′	152°46′	335
044	13321	″	04	W of Woolgoolga	NSW	30°04′	153°06′	200
044	15228	″	03	N of Gympie	Qld	26°03′	152°39′	400
045	13265	*E. punctata*	05	Consuelo T'land	Qld	24°56′	148°03′	1100
046	10863	*E. punctata* var. *longirostrata*	05	Barakula SF, Chinchilla	Qld	26°22′	150°26′	350
046	15637	″	27	NW of Monto	Qld	24°49′	150°57′	500
046	16008	″	05	51.5 km NNW Chinchilla	Qld	26°22′	150°27′	330
047	13905	*E. pyrocarpa*	10	Conglomerata SF	NSW	30°07′	153°06′	350
048	15510	*E. raveretiana*	06	Rockhampton	Qld	23°22′	150°31′	5
049	12411	*E. resinifera*	06	14.5 km S Ravenshoe	Qld	17°42′	145°28′	940

Table 1. Continued

Sp. No.	Seedlot	Species	No. of parents	Locality		Lat. (° ′)	Lon. (° ′)	Alt. (m)
049	12418	〃	07	Mt Lewis	Qld	16°36′	145°17′	1100
049	13573	〃	08	Fraser Island	Qld	25°37′	153°00′	55
049	13975	〃	11	NNE of Fendall	NSW	31°43′	152°47′	40
049	13981	〃	10	WNW of Beerburrum	Qld	26°56′	152°50′	40
050	15391	*E. rudis*	09	Gordon R, Albany H'way	WA	34°08′	117°35′	300
051	12978	*E. saligna*	*	Mt Scanzi Kangaroo Valley	NSW	34°45′	150°27′	650
051	13015	〃	08	N of Nelligen	NSW	35°33′	150°11′	30
051	13027	〃	*	SF 175 Mimosa, Blackdown		23°50′	149°05′	760
051	13029	〃	01	NE of Bulahdelah	NSW	32°22′	100°28′	80
051	13263	〃	11	Consuelo T'lands	Qld	24°57′	148°03′	1090
051	13314	〃	10	14 km W of Bulahdelah	NSW	32°24′	152°06′	53
051	13320	〃	10	40 km W of Coffs Harbour	NSW	30°12′	152°49′	600
051	13337	〃	*	E of Glen Innes	NSW	29°48′	152°07′	1000
051	13340	〃	03	NE of Warwick	Qld	27°58′	152°12′	850
051	13341	〃	*	Peters L.A., 274 Connondale	Qld	26°42′	152°34′	700
051	14429	〃	25	Blackdown Tableland	Qld	23°50′	149°05′	780
051	14432	〃	25	Kroombit Tops	Qld	24°25′	151°02′	800
051	14435	〃	26	Kenilworth SF	Qld	26°38′	152°33′	600
051	14507	〃	25	Chaelundi SF	NSW	30°13′	152°46′	640
051	14508	〃	25	Urbenville	NSW	28°34′	152°30′	600
051	14524	〃	26	Armidale	NSW	30°39′	152°08′	900
051	14526	〃	26	Glen Innes	NSW	29°47′	152°09′	1030
051	14527	〃	26	Barrington Tops	NSW	32°00′	151°50′	450
051	15011	〃	45	Kroombit Tops, Monto	Qld	24°51′	151°01′	730
051	15054	〃	25	SE of Tamworth	NSW	31°31′	151°31′	1100
051	15232	〃	20	S of Gympie	Qld	26°25′	152°25′	500
052	11017	*E. signata*	05	S of Maryborough	Qld	25°53′	152°30′	40
053	15233	*E. sphaerocarpa*	03	S of Blackwater	Qld	23°50′	149°05′	760
054	11009	*E. tereticornis*	05	Coominglah SF, Monto	Qld	24°32′	150°58′	400
054	12965	〃	25	SW of Mt Garnet	Qld	18°30′	144°45′	800
054	13303	〃	05	Sale	Vic	38°07′	147°04′	10
054	13304	〃	09	Nerrigundah	NSW	36°13′	149°48′	80
054	13307	〃	08	Windsor	NSW	33°32′	150°50′	100
054	13308	〃	06	Wallaroo SF	NSW	32°39′	151°51′	10
054	13319	〃	06	N of Woolgoolga	NSW	29°55′	153°12′	30
054	13350	〃	10	S of Urbenville	NSW	28°36′	152°24′	400
054	13398	〃	20	East of Kupiano	PNG	10°04′	148°15′	25
054	13399	〃	13	Oro Bay to Emo	PNG	08°57′	148°28′	200
054	13418	〃	20	Sirinumu Sogeri Plat	PNG	09°30′	147°26′	580
054	13442	〃	07	N of Mareeba	Qld	16°55′	145°25′	380
054	13443	〃	10	Kennedy R	Qld	15°26′	144°11′	60
054	13446	〃	04	N of Cardwell	Qld	18°16′	146°00′	40
054	13541	〃	10	9 km SW of Imbil	Qld	26°30′	152°37′	100
054	13544	〃	10	40 km N of Gladstone	Qld	23°44′	151°01′	10
054	13659	〃	25	1 km N of Laura	Qld	15°33′	144°27′	100
054	13661	〃	22	Mt Molloy	Qld	16°41′	145°15′	366
054	13994	〃	15	Crediton SF	Qld	21°00′	148°30′	700
054	14115	〃	30	S of Helenvale	Qld	15°46′	145°14′	120
054	14212	〃	33	5–12 km S Helenvale	Qld	15°45′	145°15′	500
054	14424	〃	30	Ravenshoe	Qld	17°39′	145°21′	700
054	14802	〃	25	Kennedy R	Qld	15°34′	144°02′	140
054	14846	〃	07	S Cardwell	Qld	18°28′	146°06′	10
054	15825	〃	13	Laura R Crossing Pdr	Qld	15°44′	144°41′	140
054	15826	〃	25	Ruth & Quartz Cks Pdr	Qld	15°43′	144°37′	120
054	16541	〃	05	WNW of Dimbulah	Qld	17°09′	145°06′	450
054	16546	〃	05	Palmer River	Qld	16°07′	144°47′	400
054	16547	〃	05	West Normanby R	Qld	15°46′	144°58′	140

Table 1. Continued

Sp. No.	Seedlot	Species	No. of parents	Locality		Lat. (° ′)	Lon. (° ′)	Alt. (m)
054	16549	″	05	Kennedy R	Qld	15°34′	144°02′	140
054	16550	″	05	Morehead R	Qld	15°02′	143°40′	50
054	16558	″	05	Oaky Ck, Springmount	Qld	17°11′	145°20′	540
055	12967	*E. tessellaris*	10	NW of Mareeba	Qld	16°58′	145°15′	450
056	11130	*E. tetradonta*	05	138 km E Goyder R	NT	12°45′	135°54′	30
057	17087	*E. thozetiana*	22	NE Alice Springs	NT	23°31′	134°45′	500
058	14130	*E. torelliana*	07	SSW of Kuranda	Qld	16°53′	145°36′	420
058	14855	″	10	S Helenvale	Qld	15°50′	145°14′	200
058	15263	″	10	S of Cooktown	Qld	15°50′	145°14′	200
058	15265	″	60	SE of Cardwell	Qld	18°28′	146°08′	20
059	10997	*E. trachyphloia*	05	Barakula SF	Qld	26°14′	150°33′	430
060	11143	*E. umbrawarrensis*	04	Katherine area	NT	14°20′	133°40′	150
061	10136	*E. urophylla*	09	Mt Tatamailau	Ind	08°55′	125°30′	2740
061	10140	″	07	E of Hato Bulico Timor	Ind	08°53′	125°32′	2100
061	12362	″	*	S Dili East Timor	Ind	08°37′	125°38′	1100
061	12895	″	23	Mt Mandiri Flores	Ind	08°15′	122°58′	415
061	12898	″	16	Mt Boleng	Ind	08°21′	123°15′	890
061	13828	″	*	Mt Mutis W Timor	Ind	10°35′	123°35′	1200
061	14531	″	50	Mt Egon Flores	Ind	08°38′	122°27′	515
061	14532	″	31	Mt Lewotobi	Ind	08°31′	122°45′	398
061	15089	″	*	Mt Egon Flores	Ind	08°38′	122°27′	500
061	15982	″	14	Mt Wuko Flores	Ind	08°33′	122°35′	800
961	17564	″	31	Mandiri Flores	Ind	08°15′	122°58′	410
061	17565	″	49	Lewotobi	Ind	08°32′	122°48′	375
061	17566	″	08	Wukoh Flores	Ind	08°35′	122°35′	600
061	17567	″	82	Mt Egon Flores	Ind	08°38′	122°27′	450
061	17568	″	01	Kalabhi Alor	Ind	08°19′	122°40′	700
061	17569	″	02	Apui Alor	Ind	08°16′	124°50′	800
061	17570	″	03	Bangat Flores	Ind	08°38′	122°27′	330
061	17571	″	04	Wairteban	Ind	08°38′	122°27′	525
061	17572	″	08	Iling Gele	Ind	08°37′	122°27′	600
061	17573	″	04	Andalan	Ind	08°36′	122°28′	725
061	17574	″	04	Jawagahar	Ind	08°36′	122°28′	550
062	12571	*E. viminalis*	08	Warung SF Coolah	NSW	31°45′	149°59′	1040
063	10996	*E. watsoniana*	06	Barakula SF	Qld	26°15′	150°31′	420
063	17003	″	10	Barakula SF	Qld	26°26′	150°42′	350

R = River
SF = State forest
Plat = Plateau
Pdr = Peninsula development road
Ck = Creek
T'land = Tableland
Pt = Point
Rd = Road
L.A. = Logging area

Table 2. List of *Eucalyptus* families.

Species	Seedlot	Number of collection	N of F.	Location of collection	
E. urophylla	17564	T0000001 ~ T0000031	31	Mandiri Flores	Ind
	17565	T0000032 ~ T0000080	49	Lewotobi	Ind
	17566	T0000081 ~ T0000088	8	Wukoh Flores	Ind
	17567	T0000089 ~ T0000170	82	Egon Flores	Ind
	17568	T0000171	1	Kalabahi Alor	Ind
	17569	T0000188, T0000193	2	Apui Alor	Ind
	17570	T0000194 ~ T0000196	3	Bangat Flores	Ind
	17571	T0000197 ~ T0000200	4	Wairteban	Ind
	17572	T0000201 ~ T0000208	8	Iling Gele	Ind
	17573	T0000209 ~ T0000212	4	Andalan	Ind
	17574	T0000213 ~ T0000216	4	Jawagahar	Ind
	14531	JD1214, JD1215, JD1217 ~ JD1232(a), JD1232(b) ~ JD1235, JD1238, JD1239, JD1249, JD1252, JD1254 ~ JD1256	29	Mt Egon Flores	Ind
	14532	JD1265 ~ JD1266, JD1268 ~ JD1287, JD1290, JD 1291	27	Mt Lewotobi Flores	Ind
E. tereticornis	13308	PSB00047 ~ PSB00052	6	Wallaroo	NSW
	13319	PSB00118 ~ PSB00123	6	North of Woolgoolga	NSW
	13398	JD000921 ~ JD000944	24	East of Kupiano	PNG
	13399	JD000945 ~ JD000957	13	Oro Bay Toemo	PNG
	13418	DS000136 ~ DS000155	20	Sirinumu Sogeri	PNG
	13446	PSB00368 ~ PSB00371	4	North of Cardwell	Qld
	13544	DJ001029 ~ JD001038	10	4 km N of Gladstone	Qld
	13659	BVG00383 ~ BVG00385	3	1 km N of Laura	Qld
	13661	BVG00454 ~ BVG00478	25	Mt Molloy	Qld
	13659	GVB00393 ~ GVB00398	6	1 km N of Laura	Qld
	14212	RS000095 ~ RS000127	33	5-12 km S Helenvale	Qld
	14424	RS000153 ~ RS000182	30	Ravenshoe	Qld
	15826	TREE0001 ~ TREE0025	25	Ruth Quartz Cks	Qld
	16541	JD001540 ~ JD001544	5	WNW of Dimbulah	Qld
	16546	JD001563 ~ JD001567	5	Palmer River	Qld
	16547	JD001568 ~ JD001572	5	West Normanby River	Qld
	16549	JD001583 ~ JD001587	5	Kennedy River	Qld
	16550	JD001588 ~ JD001592	5	Morehead River	Qld
	16558	JD001628 ~ JD001632	5	Oaky Ck Springmount	Qld
	14802	01 ~ 25	25	Kennedy River	Qld
	14212	RS95, RS108, RS113, RS118, RS123	5	5-12 km S of Helenvale	Qld
	13659	BG383 ~ BG391, BG393 ~ BG400, BG403, BG405 ~ BG406	19	1 km N of Laura	Qld
E. camaldulensis	14237		1	Eccles Ck, NE of Petford	Qld
	14256		1	Eccles Ck, NE of Petford	Qld
	14260		1	Eccles Ck, NE of Petford	Qld
	14270		1	Pinnacle Ck, NE of Petford	Qld
	14291		1	Mishap Ck, NE of Petford	Qld
	14295		1	Mishap Ck, NE of Petford	Qld
	14300		1	Eureka Ck, NE of Petford	Qld
	14303		1	Eureka Ck, NE of Petford	Qld
	14307		1	Eureka Ck, NE of Petford	Qld
	14266		1	Theodolite Ck, NE of Petford	Qld
	14267		1	Theodolite Ck, NE of Petford	Qld

Table 2. (continued)

Species	Seedlot	Number of collection	N of F.	Location of collection	
E. camaldulensis	14273		1	20 km NE of Petford	Qld
	14276		1	18 km NE of Petford	Qld
	14343		1	Emu Ck, E of Petford	Qld
	14344		1	Emu Ck, E of Petford	Qld
	14353		1	Emu Ck, E of Petford	Qld
	14388		1	Back Ck, SE of Petford	Qld
	14311		1	Hales Siding, E of Petford	Qld
	14319		1	Hales Siding, E of Petford	Qld
	14333		1	Hales Siding, E of Petford	Qld
	14335		1	Hales Siding, E of Petford	Qld
	14358		1	Emu/Gibbs Ck, SE of Petford	Qld
	14366		1	Gibbs Ck, ESE of Petford	Qld
	14383		1	Oaky Ck, ESE of Petford	Qld
	14386		1	Emu Ck, SE of Petford	Qld
	14777		1	Nolan Ck, SE of Wrotham Pk	Qld
	14778		1	Nolan Ck, SE of Wrotham Pk	Qld
	14779		1	Nolan Ck, SE of Wrotham Pk	Qld
	14780		1	Nolan Ck, SE of Wrotham Pk	Qld
	14781		1	Nolan Ck, SE of Wrotham Pk	Qld
	14782		1	Nolan Ck, SE of Wrotham Pk	Qld
	14783		1	Nolan Ck, SE of Wrotham Pk	Qld
	14784		1	Nolan Ck, SE of Wrotham Pk	Qld
	14785		1	Nolan Ck, SE of Wrotham Pk	Qld
	14786		1	Nolan Ck, SE of Wrotham Pk	Qld
	14787		1	Nolan Ck, SE of Wrotham Pk	Qld
	14788		1	Nolan Ck, SE of Wrotham Pk	Qld
	14789		1	Elizabeth Ck, E of Wrotham Pk	Qld
	14790		1	Elizabeth Ck, E of Wrotham Pk	Qld
	14791		1	Elizabeth Ck, E of Wrotham Pk	Qld
	14792		1	Elizabeth Ck, E of Wrotham Pk	Qld
	14793		1	Elizabeth Ck, E of Wrotham Pk	Qld
	14794		1	Elizabeth Ck, E of Wrotham Pk	Qld
	14795		1	Elizabeth Ck, E of Wrotham Pk	Qld
	14796		1	Elizabeth Ck, E of Wrotham Pk	Qld
	14797		1	Elizabeth Ck, E of Wrotham Pk	Qld
	14798		1	Elizabeth Ck, E of Wrotham Pk	Qld
	14799		1	Elizabeth Ck, E of Wrotham Pk	Qld
	14800		1	Elizabeth Ck, E of Wrotham Pk	Qld
	14801		1	Elizabeth Ck, E of Wrotham Pk	Qld

Representative sites were prepared for the trials. Provenance trials were carried out at two sites on Hainan Island — one at Shangyong, Qionghai County, with high rainfall and one at Lingtou, Ledong County, with dry conditions. Later, 79 ha over 22 sites were planted in tropical and subtropical sites in southern China (see Figure 1). Records of trials in Guangdong and Hainan Provinces are listed in Table 3.

All trials of species and provenances used randomised block designs with four replicates, and 8-16 trees per plot. Progeny tests used randomised block design with single-tree plots and 40 replicates. Measurements for statistical analysis were taken once or twice a year and any damage caused by severe weather was noted. Details of soil and vegetation of the site were noted before the experiments commenced.

Guangdong, Guangxi, Fujian and Hainan were divided into the seven regions in Figure 1 to assist interpretation of trial results.

Table 3. Record of experimental forests.

No.	Trial site	Longitude	Latitude	Time	Sp. N	Pro.	N F. N.	Area (ha)	Trials
02	Shang Yong	19° 14′	110° 28′	1986.6	11	79		4.0	E. sp./pro. (I)
13	Shang Yong Forest Farm	〃	〃	1988.2	46	72		2.3	E. sp./pro. (II)
14	Qionghai County	〃	〃	1988.3	2	9	100	2.0	fami. trial of *camal./tere.*
26	〃	〃	〃	1989.4	1	2	56	0.7	fami. trial of *urophylla*
03	Lingtou, Ledong	18° 42′	108° 52′	1986.6	16	56		2.5	trial of pro.
10	Jianfeng, Ledong	18° 42′	108° 49′	1987.5	11	21		1.0	trial of pro.
05	Bohou, Linggao	20° 00′	109° 40′	1985.5	13	36		2.0	trial of sp./pro.
27	Chunchen Town, Yangchun	22° 08′	111° 46′	1985.5		2	56	0.8	fami. trial of *urophylla*
28	Chunwan Town, Yangchun	22° 30′	112° 04′	1989.4	7			0.67	trial of species
29	Guigang Town, Yangchun	22° 22′	111° 45′	1990.4	1	6		0.12	pro. trial of *microcorys*
30	〃	〃	〃	〃	1	9		0.17	pro. trial of *urophylla*
31	〃	〃	〃	〃	1	8		0.16	pro. trial of *pellita*
32	〃	〃	〃	〃	1	10		0.18	pro. trial of *cloeziana*
33	〃	〃	〃	〃	15			0.27	species trial of eucalypt
34	Pingdong Town, Haifeng	23° 06′	115° 29′	1990.3	2	24		0.39	pro. trial of *camal./tere.*
15	Chenceng, Yangxi	21° 48′	111° 43′	1988.3	16			5.0	species trial
38	Yangjiang For. Ins.	21° 53′	111° 59′	1989.4	2	9		0.4	pro. trial of *urophylla*
35	Base in Yangxi	21° 48′	111° 38′	1991.4	1	11	176	6.6	prog. test of *urophylla*
36	〃	〃	〃	〃	3	36		1.2	provenances trial
37	〃	〃	〃	〃	1	14	100	5.7	prog. test of *tereticornis*
40	Yutong, Yangxi	21° 40′	111° 38′	1991.4	1	18	216	5.33	
42	Dianbai County	21° 30′	110° 00′	1989.5	8			1.0	species trial
04	RITF (Guangzhou)	23° 14′	113° 14′	1986.6	33	158		0.8	gene collection
17	Tanshui, Huiyang	22° 52′	114° 20′	1988.6	9			1.0	provenances trial
41	Sannian, Huizhou	23° 05′	114° 25′	1991.4	1	18	180	6.67	prog. test of *tereticornis*
19	Lake Town, Boluo	23° 11′	114° 17′	1988.6	7			0.8	progeny test
20	Potang, Boluo	23° 11′	114° 17′	1989.4	2	9		10.0	seed base of *tereticornis*
39	Dogan Town, Enping	22° 11′	112° 21′	1990.8	1	11	188	10.0	seed base of *tereticornis*
43	Longjie, Lianping	24° 22′	114° 29′	1989.6	9			7.5	species trial
All								79.26	

pro.: provenance
sp.: species
camal.: *camaldulensis*
tere: *tereticornis*

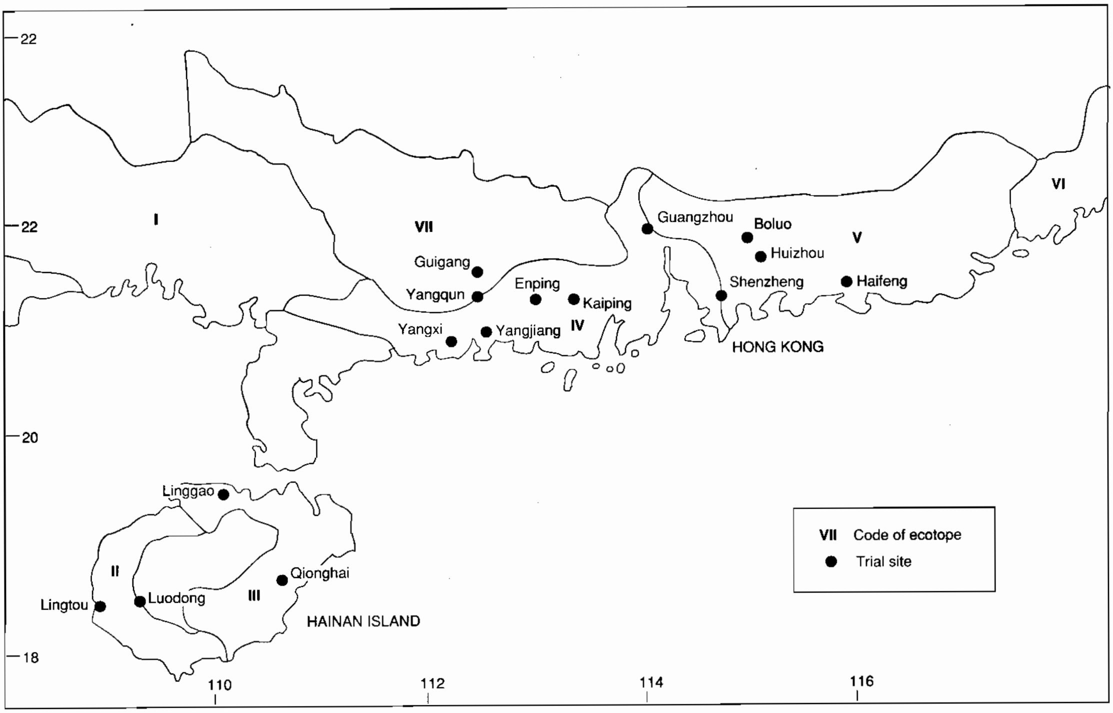

Fig. 1. Distribution of trial sites in China.

Results and Analysis

Selection of species and provenances

Areas with frequent typhoons Severe typhoons occur more than once a year in eastern Hainan province (region III in Fig.1). Most tree species tested except *E. camaldulensis* and *E. tereticornis* had poor survival (Table 4). *E. urophylla* had good volume growth; the best provenance (12895) was from Mt Mandiri, Indonesia (average 13.8 m in height, 12.5 cm dbh and 128 m^3 volume in the fifth year after planting, but only 69% survival). Provenances 15089 and 12362 were not as good as 12895 but better than others (Table 5).

E. camaldulensis had the best survival; most provenances were better than 90% and one from Katherine, Northern Territory, was 100%. The 41-month result of provenance trial No. 13 showed that 12187, 13196 and 12198 of *E. camaldulensis*, 15825 and 14826 of *E. tereticornis* and 14195 of *E. pellita* were able to withstand wind — less than 20% were blown down and they also showed superior growth. Height, dbh and volume of trial stands were classified into seven types by cluster analysis, and the four best types are listed in Table 4.

Arid areas The adaptability and growth of some species tolerant to drought could be judged by results of experiment No. 3 which is located in dry, hot areas of south-western Hainan Island (annual rainfall about 700 mm with a 6-month dry season, due to the foehn, a warm dry wind from Laos) (region II in Fig. 1). Besides *E. camaldulensis* (including 15052, 14106,14918) and *E. tereticornis* (13544 and 13443) most of the species in the trial performed poorly or died. Most provenances of *E. urophylla* died, except 14532 which had survival of 40% and a growth rate equivalent to that of *E. tereticornis* 13443.

Plains and plateau of western Guangdong Western Guangdong also experiences typhoons, but not as much as Hainan. Annual rainfall is moderate and well distributed and the soil is quite fertile. Results of trials in Yangjiang City (region IV in Fig. 1) show that *E. urophylla* was the best species, with provenances 14532 and 12895 the best and second-best performers respectively.

Hills and low mountains Trial sites were 50–100 km from the coast at an altitude greater that

100 m (region VII in Fig.1), where the soil is fertile, temperature lower than that of coastal areas and site preparation is difficult due to steep slopes. *E. urophylla* 14532 performed better than *E. camaldulensis* and *E. tereticornis*, while other species performed less well.

Areas of eastern Guangdong The recent trial results show that *Eucalyptus* is suitable for eastern Guangdong, though it had rarely been planted in the past. The results of the 15-month trials show that *E. urophylla*, *E. camaldulensis* and *E. tereticornis* were good performers, and the height of the best provenances was above 5 m. Provenances recommended for wider planting in eastern Guangdong are: 12895 and 14532 for *E. urophylla*; 14338 and 12187 for *E. camaldulensis*; and 13448 for *E. tereticornis*.

Provenances suited to different site types From the experiments above, as well as from results at Dongmen and Zhangzhou, Fujian, it is evident that provenance 14532 of *E. urophylla* is adaptable and grows well on all sites. Others worth planting on a large scale are *E. urophylla* 12895 and 15089; *E. camaldulensis* 15062, 14918 amd 12187; and *E. tereticornis* 15825 and 13443 (Table 6).

The analysis of trial results has enabled the research team to list recommended species and provenances (Table 5). Although from stands only 5 years old, the trial data were relevant and valuable for short rotation *Eucalyptus* plantings.

Progeny testing Progeny tests were established for key tree species including *E. camaldulensis*, *E. tereticornis* and *E. urophylla*.

Results of *E. camaldulensis* trials at 4 years show that, of the families listed in Table 7, numbers 4, 9, 23 and 27 grew fastest and the difference between families was significant.

Four years' results of *E. tereticornis* trials listed in Table 8, show that the best performers were all from Laura in Queensland, while the second-best came from Kennedy River in Queensland.

Progeny testing of *E. urophylla* was carried out in Qionghai county, Hainan, and in Yangqun City, Guangdong, the same year. Results showed that provenances from Mt Egon and Mt Lewotobi contained the best families. Furthermore, top families in Qionghai differed from ones in Yangqun and 10 good families performed differently at each site, except No. 52 from Lewotobi, which ranked the first at Yangqun and fifth at Qionghai (Table 9).

Analysis for the best locality Provenances of *E. urophylla* from Lewotobi, Egon and Mandiri in Flores, Indonesia, were good performers. These localities are all between 8°15–8°38 E and 122°27–122°58 N, with altitude 415–500 m (Table 10).

Good provenances of *E. camaldulensis* and *E. tereticornis* came from Laura, Kennedy River and Irvinebank in Queensland, Katherine in the Northern Territory and Isdell River in Western Australia. The species are distributed widely across Australia north of 17° where rain falls in summer and there is a 6-month drought in the cooler months as in Hainan Island and western Guangdong.

Table 4. Performance of species/provenances in typhoon areas.

I	II	III	IV
E. urophylla	*E. grandis*	*E. camaldulensis*	*E. camaldulensis*
12895	14849	14918	13663
	14420	*E. exserta*	15062
	14210	13282	13941
	13431	*E. tereticornis*	15052
	E. urophylla	13418	15050
	15089	13541	14917
	14532	13544	14847
	13828	14424	*E. tereticornis*
	12898	12965	14115
	12362	13319	13442
			13446
			13994

Table 5. Species/provenances recommended for planting.

Species	Seedlot	Locality		Suitable sites	Note
E. urophylla	14532	Mt Lewotobi	Ind	all site types	better performance
	12895	Mt Mandiri Flores	Ind	all sites except arid area	grows fast, wind-resistant
	15089	Mt Egon Flores	Ind	"	unable to withstand wind
	12362	S Dili East Timor	Ind	"	"
	14531	Mt Egon	Ind	"	grows fast
	13010	Ulanur Alor	Ind	moderate site	"
E. grandis	14420	12 km S Ravenshoe	Qld	moderately fertile	
	13431	Mt Lewis	Qld	"	
	14210	27 km SE of Ravenshoe	Qld	"	
	14849	NE Atherton	Qld	"	
	14860		Brazil		
E. camaldul.	15062	NE of Katherine	NT	typhoon & arid areas	100% survival
	14918	Laura	Qld	typhoon often	grows fast, wind resistant
	12187	8 km W Irvinebank	Qld	all site types	fast height growth
	14917	NW of Mt Carbine	W Qld	typhoon prone	
	15052	Isdell River	WA	"	
	14106	Gilbert River	NT	arid areas	
	14847	Emu Ck Petford	Qld	moderate site	
E. tereticor.	15825	Laura R Crossing Pdr	Qld	all site types	grows fast & wind resistant
	13418	Sirinumu Sogeri Plat	PNG	"	drought-tolerant, grows fast
	13443	Kennedy River	Qld	"	"
	13544	40 km N of Gladstone	Qld	"	wind-resistant
	13541	9 km SW of Imbil	Qld	"	"
E. grandis x *E. tereticornis*	15356		Brazil	moderately fertile	
E. pellita	14915	S of Cardwell	Qld	moderate site	rather wind-resistant
	14339	14.6 km NE Coen	Qld	"	
E. citriodora	13472	ESE of Mt Molloy	Qld	moderately fertile	unable to withstand wind
	14703	W of Mt Carbine	Qld	"	"
E. maculata	13539	20 km SE of Gympie	Qld	moderate site	
E. brassiana	13409	11.5 NE Coen	Qld	"	
		Woroi to Wipim	PNG	"	

Table 6. Species/provenances for planting in Guangxi, Guangdong, Hainan Island and southern Fujian

Planting areas	Species/provenances recommended				Forest age	Height	Dbh	Volume	Note
	Species	Seedlot	Locality		(yr)	(m)	(cm)	(m^3/ha)	
I (Dongmen)*	*urophylla*	13010	Ulanu R Alor	Ind					
	〃	14534	Mt Egon Flores	Ind	3.5	15.02	10.05	61.11	
	tereti.	13443	Kennedy River	Qld	3.5	15.32	8.34	41.43	
	camaldu.	B21	Petford	Qld	3.5	15.26	8.11	39.98	
	〃		Katherine	Qld					
	grandis	84, 86	Mt Lewis	Qld	3.5	12.94	9.32	37.61	
II (Semi-arid areas of south-western Hainan)	*tereti.*	13443	Kennedy River	Qld	5	10.6	8.76	80.47	high growth/survival
	camaldu.	14106	Gilbert River	Qld	5	10.34	8.77	77.98	〃
	〃	15062	NE of Katherine	Qld	5	10.02	8.32	72.10	〃
	〃	14847	Emu Ck Petford	Qld	5	10.54	8.42	71.35	〃
	〃	14918	Laura	Qld	5	10.27	8.60	70.65	〃
III (Typhoon areas of eastern Hainan)	*urophylla*	12895	Mt Mandiri	Ind	5	13.82	12.54	128.34	high growth &
	〃	15089	Mt Egon Flores	Ind	5	13.26	11.79	91.69	unable stand wind
	〃	12362	S Dili East Timor	Ind	5	11.96	11.10	89.51	〃
	grandis	13431	Mt Lewis	Qld	5	12.15	10.83	81.80	〃
	camaldu.	14918	Laura	Qld	5	12.38	8.69	77.71	wind-resistant
	tereti.	13418	Sirainumu Sogeri Plat	PNG	5	11.48	9.05	74.04	〃
	〃	13443	Kennedy River	Qld	5	12.66	8.24	69.26	〃
IV (Hills & plateau of western Guangdong)	*E. grandis* x *E. urophylla*			Brazil	2	9.65	8.72	104.02	
	urophylla	12362	S Dili East Timor	Ind	2	9.05	7.73	72.09	
	〃	15982	Mt Wuko Flores	Ind	2	8.83	7.84	71.95	
	〃	12895	Mt Mandiri	Ind	2	8.70	7.78	66.65	
	〃	12898	Mt Boleng	Ind	2	8.25	7.52	59.88	
V (Eastern Guangdong)	*camaldu.*	12187	8 km W Irvinebank	Qld	1.3	5.21	4.29		
	〃	13801	Katherine	NT	1.3	5.09	4.35		
	〃	14338	Region E of Petford	Qld	1.3	5.07	4.21		
	tereti.	13443	Kennedy River	Qld	1.3	5.20	4.04		
	〃	13544	40 km N of Gladstone	Qld	1.3	4.45	3.83		
	urophylla				4	10.2	8.89	87.45	
	pellita				4	8.8	7.66	62.66	
VI ** (Zhangzhou, Fujian)	*camaldu.*	14918	Laura	Qld	5	13.5	11.1		
	〃	15062	NE of Katherine	NT	5	13.4	10.2		
	〃	14847	Emu Ck Petford	Qld	5	12.9	9.2		
	grandis	14860	EMBRAPA	Brazil	5	14.5	11.6		
	〃	14849	NE Atherton	Qld	5	14.1	11.7		
	〃	13019	NW of Coffs Harbour	NSW	5	13.9	11.7		
	〃	14210	27 km SE of Ravenshoe	Qld	5	13.9	11.8		
	〃	14431	Belthorpe SF	Qld	5	13.8	11.6		
	urophylla	15089	Mt Egon	Ind	5	13.9	11.9		
	〃	12895	Mt Mandiri	Ind	5	13.2	11.2		
	〃	14532	Mt Lewotobi	Ind	5	12.9	11.9		
VII (Hills of western Guangdong)	*urophylla*	14532	Mt Lewotobi	Ind	1.2	5.01	4.04		
	gran. x *uro.*	15356		Brazil	1.2	5.03	4.04		
	camaldu.	B21	Petford	Qld	1.2	5.44	3.47		
	tereti.	15825	Laura R Crossing	Qld	1.2	5.00	3.32		
	camaldu.	14918	Laura	Qld	2	6.10	4.33		
	tereti.	13443	Kennedy River	Qld	2	5.96	4.19		
VIII (Tableland of north-west	*urophylla*	12895	Mt Mandiri	Ind	4	11.42	10.66	129.26	
	tereti.	13660	Helenvale	Qld	4	10.44	9.10	100.51	

* Data cited from trial results of Dongmen

** Data offered by Mr Wang Huoran

Table 7. Fifty-month result of progeny testing of *E. camaldulensis* in Qionghai, Hainan Island.

	Time of planting: March 1988		Time of measuring: May 1992		
No. of family	Location	Height (m)	Dbh (cm)	Volume (m^3)	Survival (%)
4	Dimbulah	9.6	7.6	0.020	76
9	Dimbulah	9.1	7.3	0.018	96
23	Irvinebank	9.0	7.1	0.017	92
7	Dimbulah	9.4	7.0	0.017	80
26	Nolan Creek	9.5	7.0	0.017	78
20	Irvinebank	9.1	7.1	0.017	100
42	Elizabeth Creek	9.5	6.8	0.017	73
47	Elizabeth Creek	9.9	6.9	0.017	96
3	Petford	9.5	6.8	0.016	76
1	Petford	9.1	6.9	0.016	92
32	Nolan Creek	9.4	6.7	0.016	96
16	Petford	9.8	6.8	0.016	96
44	Elizabeth Creek	8.9	6.7	0.016	85
30	Nolan Creek	9.3	6.8	0.016	96
29	Nolan Creek	9.3	6.7	0.016	88
31	Nolan Creek	8.9	6.8	0.015	85
18	Irvinebank	8.8	7.0	0.015	85
28	Nolan Creek	9.1	6.8	0.015	96
17	Petford	9.4	6.6	0.014	88
40	Elizabeth Creek	9.7	6.3	0.014	67
27	Nolan Creek	8.8	6.4	0.014	92
19	Irvinebank	8.8	6.5	0.014	85
5	Dimbulah	9.1	6.3	0.013	76
43	Elizabeth Creek	9.3	6.4	0.013	96
13	Petford	9.0	6.2	0.013	96
25	Petford	8.6	6.3	0.013	92
48	Elizabeth Creek	8.4	6.3	0.012	81
46	Elizabeth Creek	8.4	6.3	0.012	92
50	Elizabeth Creek	8.5	6.4	0.012	96
37	Nolan Creek	9.0	6.2	0.012	88
8	Dimbulah	8.9	5.9	0.012	80
24	Petford	8.9	5.9	0.012	92
2	Petford	8.5	5.7	0.012	40
34	Nolan Creek	8.5	6.2	0.012	88
39	Elizabeth Creek	8.6	6.0	0.011	92
15	Petford	8.5	6.1	0.015	88
6	Dimbulah	8.5	5.9	0.011	72
35	Nolan Creek	8.5	5.9	0.011	88
45	Elizabeth Creek	8.2	5.8	0.011	88
33	Nolan Creek	8.3	5.9	0.011	100
11	Petford	8.6	6.0	0.010	68
49	Elizabeth Creek	8.3	5.9	0.010	85
38	Elizabeth Creek	8.4	5.5	0.010	88
21	Irvinebank	8.1	5.6	0.009	92
14	Petford	8.5	5.5	0.009	85
10	Petford	8.5	5.5	0.009	73
36	Nolan Creek	8.0	5.4	0.009	92
12	Petford	7.8	5.3	0.008	92
41	Elizabeth Creek	7.3	5.1	0.007	81
22	Petford	7.7	4.8	0.007	74
Mean		8.8	6.3	0.013	86

Table 8. Fifty-month result of progeny test of *E. tereticornis* in Qionghai, Hainan Island.

	Time of planting: March 1988		Time of measuring: May 1992		
No. of family	Location	Height (m)	Dbh (cm)	Volume (m^3)	Survival (%)
15	Laura	10.3	8.4	0.026	88
4	〃	10.3	8.1	0.025	100
16	〃	10.1	8.1	0.024	92
20	〃	9.9	8.0	0.023	96
9	〃	10.2	7.9	0.023	81
5	〃	9.6	7.6	0.022	85
7	〃	10.1	7.8	0.022	80
13	〃	10.2	7.6	0.021	100
8	〃	9.7	7.8	0.021	73
17	〃	9.5	7.7	0.021	96
10	〃	9.8	7.6	0.021	79
3	〃	9.8	7.6	0.020	92
14	〃	9.8	7.6	0.020	85
18	〃	9.5	7.4	0.020	89
41	Kennedy River	10.1	7.1	0.020	81
43	〃	10.4	7.2	0.019	100
12	Laura	10.0	7.3	0.019	81
24	Kennedy River	10.1	7.3	0.019	88
1	Laura	8.7	7.1	0.018	87
6	〃	9.4	7.0	0.017	70
2	〃	9.2	7.2	0.017	96
19	〃	9.2	6.8	0.016	95
35	Kennedy River	9.4	6.8	0.016	92
47	Helenvale	8.2	7.3	0.016	79
27	Kennedy River	9.6	6.8	0.016	96
38	〃	9.7	6.7	0.016	86
44	〃	10.1	6.7	0.016	88
36	〃	9.6	6.5	0.015	68
40	〃	9.6	6.6	0.015	79
22	〃	9.6	6.6	0.015	78
37	〃	9.8	6.2	0.015	81
49	Helenvale	7.5	6.5	0.013	82
23	Kennedy River	9.2	6.0	0.013	92
29	〃	9.2	6.3	0.013	92
39	〃	9.3	6.0	0.013	76
21	〃	8.4	6.0	0.013	84
30	〃	9.2	6.0	0.012	88
31	〃	8.4	5.9	0.011	74
33	〃	8.7	5.9	0.011	81
42	〃	7.8	5.6	0.011	81
32	〃	8.8	5.8	0.011	75
28	〃	8.7	5.7	0.010	84
25	〃	8.8	5.6	0.010	81
26	〃	8.5	5.2	0.009	92
34	〃	8.3	5.2	0.009	89
11	Laura	8.2	5.1	0.008	46
48	Helenvale	5.9	5.0	0.008	46
46	〃	5.6	5.3	0.007	65
45	Kennedy River	7.8	4.8	0.007	69
50	Helenvale	5.2	4.7	0.005	52
Mean		9.2	6.7	0.016	83

Table 9. Twenty-seven month result of progeny test of *E. urophylla* in Qionghai, Hainan Island.

Time of planting: April 1989 Time of measuring: July 1991

No. of family	Location	Height (m)	Dbh (cm)	Volume (m^3)	Survival (%)	Rate of* down (%)
13	Mt Egon	7.7	8.5	0.025	75	22
58	Mt Lewotobi	7.7	8.2	0.021	77	62
26	Mt Egon	7.3	8.0	0.021	76	74
50	Mt Lewotobi	7.3	7.9	0.021	85	75
52	〃	7.5	7.8	0.021	96	87
35	Mt Egon	7.5	8.0	0.020	80	42
65	Mt Lewotobi	7.6	7.6	0.020	78	65
22	Mt Egon	7.5	7.9	0.020	87	52
49	Mt Lewotobi	7.8	7.7	0.020	96	39
10	Mt Egon	7.6	7.9	0.020	96	62
02	〃	7.5	7.6	0.020	92	30
11	〃	7.4	8.0	0.020	92	39
67	Mt Lewotobi	7.9	7.6	0.019	75	68
40	Mt Egon	7.1	7.9	0.019	80	65
71	Mt Lewotobi	7.4	7.3	0.019	83	55
74	〃	7.5	7.6	0.019	70	53
47	〃	7.5	7.5	0.019	88	56
15	Mt Egon	7.3	7.7	0.018	84	62
59	Mt Lewotobi	7.3	7.5	0.018	76	83
08	Mt Egon	7.4	7.8	0.018	68	65
17	〃	7.4	7.7	0.018	84	52
23	〃	7.3	7.3	0.018	81	60
56	Mt Lewotobi	7.1	7.4	0.018	91	43
69	〃	7.4	7.1	0.018	77	40
53	〃	7.3	7.3	0.018	88	77
39	Mt Egon	7.2	7.6	0.018	84	9
37	〃	6.6	7.5	0.017	60	73
57	Mt Lewotobi	7.1	7.5	0.017	87	43
55	〃	7.6	7.4	0.017	77	65
12	Mt Egon	7.0	7.2	0.017	67	69
14	〃	6.8	7.2	0.016	100	56
51	Mt Lewotobi	7.0	7.0	0.016	80	65
07	Mt Egon	6.7	7.4	0.016	72	61
01	〃	7.2	7.0	0.016	92	39
05	〃	6.7	7.2	0.016	88	45
75	Mt Lewotobi	7.1	7.0	0.016	68	94
16	Mt Egon	6.6	7.0	0.016	87	63
62	Mt Lewotobi	6.8	7.1	0.015	69	72
19	Mt Egon	6.8	7.2	0.015	96	45
64	Mt Lewotobi	7.0	6.8	0.015	69	73
68	〃	6.9	6.7	0.015	58	93
61	〃	6.8	6.7	0.015	59	71
06	Mt Egon	7.0	7.0	0.015	64	44
70	Mt Lewotobi	6.9	6.5	0.014	60	80
48	〃	6.7	6.9	0.014	70	62
18	Mt Egon	6.8	6.9	0.014	84	71
60	Mt Lewotobi	6.8	6.6	0.014	95	81
04	Mt Egon	6.4	7.0	0.014	75	74
20	〃	6.6	6.6	0.014	87	48
09	〃	6.4	7.1	0.014	83	60
54	Mt Lewotobi	7.0	6.5	0.014	77	68
41	Mt Egon	6.6	6.6	0.014	80	70
66	Mt Lewotobi	6.5	6.6	0.013	85	77
63	〃	6.7	6.2	0.012	60	67
27	Mt Egon	6.4	6.5	0.011	85	64
21	〃	6.1	6.1	0.011	80	60
Mean		7.1	7.3	0.017	80	61

* Including stem-down and branches broken

Table 10. Twenty-five month result of progeny test of *E. urophylla* in Yangchun, Guangdong.

Time of planting: May 1989 Time of measuring: June 1991

No. of family	Location	Height (m)	Dbh (cm)	Volume (m^3)	Survival (%)
52	Mt Lewotobi	12.0	9.9	0.049	81
64	"	11.0	9.8	0.048	54
61	"	11.0	9.7	0.046	83
06	Mt Egon	11.1	10.1	0.046	83
63	Mt Lewotobi	10.8	9.9	0.045	71
74	"	11.1	9.4	0.044	75
17	Mt Egon	11.0	9.7	0.043	90
69	Mt Lewotobi	11.0	9.5	0.043	90
16	Mt Egon	11.1	9.5	0.042	83
23	"	11.5	9.4	0.042	83
19	"	10.4	9.5	0.041	62
67	Mt Lewotobi	11.0	9.0	0.041	86
60	"	10.7	9.3	0.040	83
13	Mt Egon	10.7	9.1	0.039	97
02	"	10.2	8.8	0.039	90
21	"	10.4	8.9	0.037	83
22	"	10.5	9.1	0.036	72
35	"	10.0	8.3	0.035	50
18	"	10.7	8.7	0.035	90
71	Mt Lewotobi	9.6	8.4	0.035	86
20	Mt Egon	10.5	8.7	0.035	79
10	"	10.3	8.8	0.035	93
37	"	10.1	8.6	0.034	76
01	"	10.9	8.8	0.034	87
59	Mt Lewotobi	10.0	8.3	0.034	77
07	Mt Egon	9.8	8.6	0.034	86
15	"	10.1	8.8	0.034	71
11	"	10.6	8.8	0.034	83
65	Mt Lewotobi	10.4	8.4	0.033	79
75	"	10.4	8.4	0.033	76
04	Mt Egon	10.0	8.7	0.033	72
09	"	10.4	8.7	0.033	83
58	Mt Lewotobi	9.9	8.2	0.032	60
70	"	10.0	8.1	0.032	67
05	Mt Egon	10.0	8.5	0.319	83
57	Mt Lewotobi	10.1	8.2	0.032	65
39	Mt Egon	9.5	8.3	0.031	75
27	"	9.5	8.1	0.028	90
14	"	9.6	7.8	0.027	97
62	Mt Lewotobi	9.9	7.8	0.027	75
Mean		10.4	8.9	0.037	79

Discussion and Recommendations

- Species and provenances that have already been successful in southern China require further trials to identify the best performers. These species include *E. pellita*, *E. citriodora*, *E. maculata*, *E. brassiana* and *E. cloeziana*.
- Good provenances of *E. urophylla* are mainly from Flores Island in Indonesia. Seed of superior trees should be sought to improve the breeding population. Meanwhile, consideration should be given to genetic resources from the other islands in Indonesia where the species occurs.
- The successful performance of provenances of *E. tereticornis* and *E. camaldulensis* from north of 17°S in Australia, where the climate is similar to that of Hainan and western Guangdong, demonstrates that climate analysis is useful in identifying potentially successful introductions.
- Management should be strengthened for forests which have been established through progeny testing, in order to offer the best advice on population studies.
- Since there have been significant differences between families, further regional trials of families should be carried out to identify superior families and individuals for operational plantings, for example as clones.

Valuable results have been obtained through 6 years of experiments. Essential genetic improvement in *Eucalyptus* for tropical and subtropical China can, however, only be obtained by consistent application of an appropriate breeding strategy.

Acknowledgment

This is a report of research in genetic improvement of tropical *Eucalyptus* species, part of the project *Introduction and cultivation experiments for Australian broadleaved tree species* involving ACIAR, CSIRO and the Chinese Academy of Forestry. Research objectives were achieved by all in the work group during the 6 years of the project, for which great thanks are due to Wu Kunming, Zhou Wenlong, Wu Juying, Liang Kunnan and Xu Jianmin.

Introduction and Provenance Trial of *Eucalyptus nitens* and its Potential in Plantation Forestry in China

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Abstract

A trial comprising 10 provenances of *Eucalyptus nitens* and four related species — *E. globulus, E. maidenii, E. bicostata* and *E. viminalis* — was established in July 1986. Local seedlots of *E. globulus* and *E. maidenii* were included as controls. Four-year results indicate that there were significant differences between species and between provenances in growth of height, diameter and volume. The *E. nitens* provenance from Federation Range (12401) had the highest growth rate while the provenance from Marshalls Spur (15015) had the lowest. The volume of provenance 12401 was 2.5 times larger than 15015. At age 4, the volume of *E. nitens* was 23% and 45% larger than that of local *E. globulus* and local *E. maidenii* respectively. Bioclimatic analysis shows that *E. nitens* appears to have great potential in plantation forestry in the Yunnan-Guizhou Plateau. It would also be promising in limited areas of south-central Jiangxi and Hunan Province as well as southern Jiangsu and northern Zhejiang Province.

CLOSELY related to *E. globulus* Labill. and *E. viminalis* Labill., *E. nitens* taxonomically belongs to section *globulus* of subgenus *Symphyomyrtus*. It is a dominant species in the tall open eucalypt forests in Australia and usually attains 40–70 m (occasionally 90 m) in height and 1–2 m in diameter with a round and straight stem (Boland et al. 1984).

E. nitens has a markedly discontinuous distribution from northern New South Wales to southern Victoria (Pryor and Johnson 1971). It mostly occurs in four large isolated areas (Fig. 1). Wide geographic variation exists in its morphology, especially of its juvenile leaves. Latitudinal range is 30–38 °S and altitudinal range is 600–1600 m. The best stands occur between 1000 and 1300 m altitude (Pederick 1977).

In its natural range the climate is from cool to warm and humid to semi-humid. The mean maximum temperature of the hottest month is 21–26 °C and the mean minimum temperature of the coldest month is −5–2 °C. The mean annual rainfall is 750–1750 mm, and 50–150 days per year are frost-free. Snow occurs throughout most of the natural range. It is usually associated with *E. regnans* and *E. delegatensis.*

It can grow on a wide range of moderately fertile soils, especially if there is clay in the subsoil, but the best growth is on moist loams. It has fast early growth.

It is one of the most frost-tolerant of the fast-growing commercial eucalypts. Temperatures drop to −12 °C in its natural range and it has survived temperatures as low as this in exotic plantations. It is sensitive to hot, dry winds and drought conditions. It has so far shown little incidence of endemic insect pests (Turnbull and Pryor 1984).

The heartwood is pale pink. It is one of the lighter eucalypt timbers with a lower basic density. It has a straight grain and is not difficult to work. The wood is used for general building construction, house and floor decoration, panelling and pulping.

E. nitens is now an important species in plantations in temperate areas in Australia. In Victoria it has grown faster than *E. regnans* when planted in areas 350 m below its natural range. In northern

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Tasmania it has shown greater vigour than *E. delegatensis* on sites above 500 m receiving annual rainfall in excess of 2000 mm. Since the 1970s, many countries have been planting *E. nitens*: New Zealand, South Africa, Zimbabwe and Iran have planted *E. nitens* in humid mountain areas. In the former Soviet Union, it was managed as coppice forest in areas where the temperature ranges from − 14 to 15 °C (Turnbull and Pryor 1984).

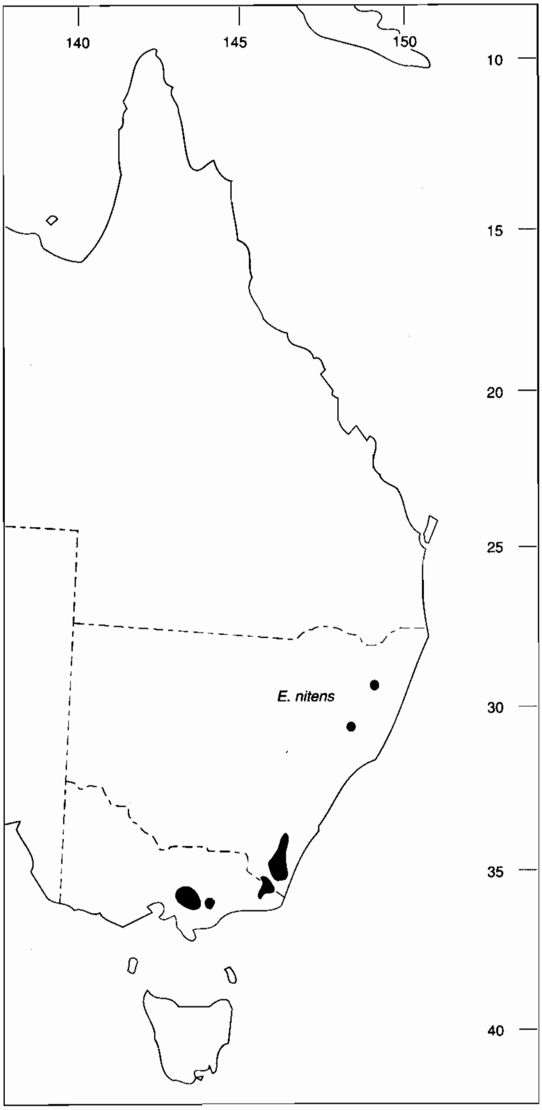

Fig. 1. The natural distribution of *E. nitens*, NSW and Victoria, Australia.

Since the ACIAR-CAF project started in 1986, *E. nitens* has been introduced in Yunnan Province. In the World Bank-funded National Afforestation Program, it has been selected as a major species for eucalypt plantations in Yunnan.

This paper presents a study of the provenance variation of *E. nitens* and its potential in plantation forestry in China.

Materials and Methods

Field trial

Seeds collected from open pollinated natural stands and provided by the Australian Tree Seed Centre were bulked (see Table 1 for details). The trial is located at Jindian, 8 km north-east of Kunming. There were nine trees in row plots and eight replicates in an incomplete block design. Tree spacing was 2 × 2 m.

The natural environment of the trial site, experimental design and silvicultural methods were described in detail by Wang et al. (1989).

All data were manipulated and analysed with Datachain and Genstat 5. The formula $V = 1/12\pi D^2H$ (m^3/tree) (Zhou and Liang 1991) was used to calculate standing volume overbark. Plot means were calculated on five dominant trees in a plot.

Bioclimate analysis

Key conditions for growth and survival of *E. nitens*, derived from the climate of its natural range and planting areas in China and other countries, are:

i) Mean annual temperature: 9–18 °C
ii) Mean minimum temperature: − 1–7 °C
iii) Mean maximum temperature: 20–30 °C
iv) Absolute minimum temperature: ≥ − 10 °C
v) Mean annual rainfall: 750–1500 mm
vi Dry season (rainfall < 40 mm): 0–6 months

Areas suitable for growing *E. nitens* were delineated by the Tree Introduction Computer Decision Support System with the above data (Yan 1989). Climates typical of donor and recipient sites were compared using Gaussen's method. The similarity of meteorological stations representing donor and recipient sites was assessed by cluster analysis, and results used to select further provenances for specific conditions.

Table 1. Geographic localities of *E. nitens* provenances.

Seedlot	Parent trees	Locality	Lat.	Long	Alt. (m)
15015	20	Marshalls Spur, Vic	37°50′	146°21′	1165
14454	31	Toorongo Plateau, Vic	37°47′	146°16′	900
12401	3	Federation Range, Vic	37°27′	147°57′	1100
15016	6	Barneweel Plains, Vic	37°27′	147°57′	1100
12867	5	Bonang SF, Vic	37°12′	148°42′	800
14455	7	Brown Mt, NSW	36°38′	149°24′	1130
14437	6	Tallaganda SF, NSW	35°54′	149°30′	1300
14449	19	Tallaganda SF, NSW	35°31′	149°33′	900
13281	11	ENE of Armidale, NSW	30°28′	152°15′	1277
14450	23	Barrington Tops, NSW	30°00′	151°30′	1500

Results

Species/provenance trial

Difference between the species Four-year results indicated that *E. nitens* has grown faster than *E. viminalis*, *E. globulus* and local landraces of *E. globulus* and *E. maidenii*, especially in diameter and volume.

The mean volume of *E. nitens* is 0.022 m^3/tree, which is 23 and 45% larger than that of the local *E. globulus* and the local *E. maidenii* respectively and 84% larger than *E. viminalis*. Its survival was lower than that of the local controls but higher than that of newly-introduced *E. globulus* and *E. viminalis* (Table 2).

Provenance variation Ten provenances of *E. nitens* were included in the trial. At age 4, significant variation was found between provenances in both growth rates and adaptability to the new environment. Provenance 12401 had significantly greater volume than all the others: it attained 9.9 m in height, 11.1 cm in diameter and 0.033 m^3/tree in volume. Provenance 15015 had the lowest growth rate, close to the local *E. maidenii* but significantly inferior to the others. The volume of provenance 12401 was 2.5 times larger than that of 15015. These two provenances are from western Victoria. Provenances from the rest of Victoria were not significantly different from the local *E. globulus*. Growth rates of all the NSW provenances exceeded all except 12401 from Victoria. No significant differences exist between the provenances of NSW themselves except 14437. Provenance 14449 from Tallaganda, NSW had the highest survival of 86%, while 15015 from western Victoria with lowest growth rates has the lowest survival of 71% (Table 3).

Table 2. Comparison of growth of *E. nitens* with that of related species at age 4 years.

Species	Ht (m)	Dbh (cm)	V (m^3)	Sv (%)
nitens	8.0	9.7	0.022	82
ck-g	8.1	8.6	0.018	87
ck-m	7.6	8.3	0.015a	83
globulus	7.5	7.5	0.013ab	76
bicostata	7.6	7.8	0.013ab	82
maidenii	7.8	7.6	0.013ab	85
viminalis	7.7	6.9	0.012b	75

Ht: height V: volume Sv: survival
Dbh: diameter at breast height
ck-g: local *E. globulus*
ck-m: local *E. maidenii*

Table 3. Growth of provenances of *E. nitens* at age 4 years.

Seedlot	Ht (m)	Dbh (cm)	V (m^3)	Sv (%)
12401	9.9	11.1	0.033	79
14455	8.5	10.1	0.025a	83
13281	8.7	10.1	0.025a	82
14450	7.8	10.6	0.024a	81
14449	8.2	10.2	0.023ab	86
14437	7.7	9.8	0.021b	76
15016	7.6	9.4	0.019c	85
14454	7.6	8.9	0.018c	85
ck-g	8.1	8.6	0.018c	88
12867	7.6	9.0	0.017c	84
ck-m	7.6	8.3	0.015d	83
15015	6.6	8.0	0.013d	71

There were no significant correlations between growth of provenances and their original latitude, longitude and altitude (Table 4).

Table 4. Correlation coefficients between growth in China and latitude, longitude and altitude of seed sources.

	Height	Diameter	Volume	Survival
Latitude	0.34	0.62	0.43	0.21
Longitude	0.17	0.48	0.28	0.06
Altitude	0.04	0.36	0.24	0.48

Growth features Fig. 2 shows the monthly growth of *E. nitens* at Kunming. The growth peak is from May to November, matching the pattern of rainfall in Kunming (Fig. 3).

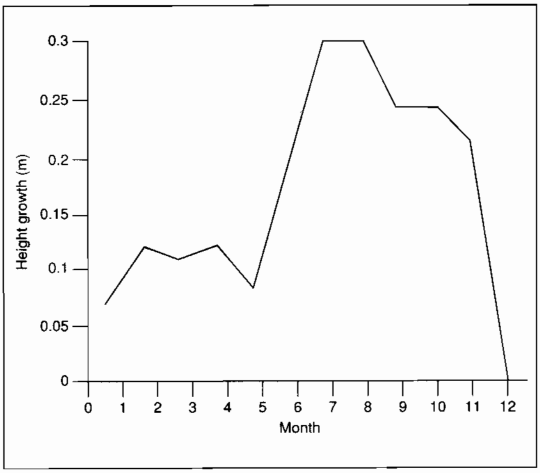

Fig. 2. Monthly height growth of *E. nitens* at Kunming.

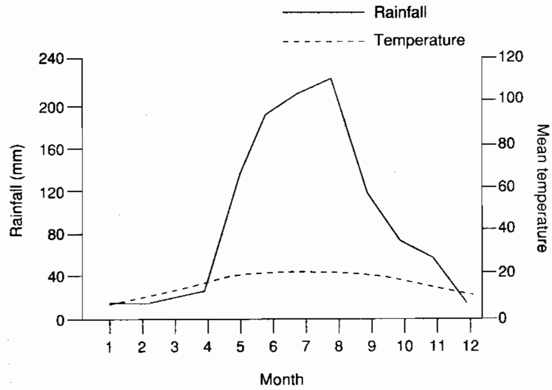

Fig. 3. Yearly rainfall and temperature at Kunming.

Table 5 presents correlation coefficients between successive yearly measurements of height and diameter. Growth in the first year was not closely related to subsequent development.

Table 5. Correlation coefficients between successive yearly measurements of height and of diameter. (The values for height are in the lower left half of the table, and for diameter in the upper right half.)

	Year 1	Year 2	Year 3	Year 4
Year 1		0.57	0.42	0.46
Year 2	0.66*		0.95**	0.88**
Year 3	0.72*	0.91**		0.97**
Year 4	0.27	0.64**	0.81**	

Potential in plantations

Zoning introduction areas Fig. 4 shows areas suitable for *E. nitens* as outlined by the Tree Introduction Computer Decision Support System. The darker shading in the figure indicates that the best areas for growing *E. nitens* are the Yunnan-Guizhou Plateau, Chengdu Basin and coastal areas of Zhejiang Province, where climatic conditions meet the biological requirements of the species. The lighter shading in the figure represents potential areas for *E. nitens* in eastern Sichuan, southern central Hunan, southern Jiangsu and northern coast of Zhejiang provinces, where the mean maximum temperatures of the hottest month are high (Table 3) and are the main constraint to growth, although adequate rainfall and a short dry season are also desirable.

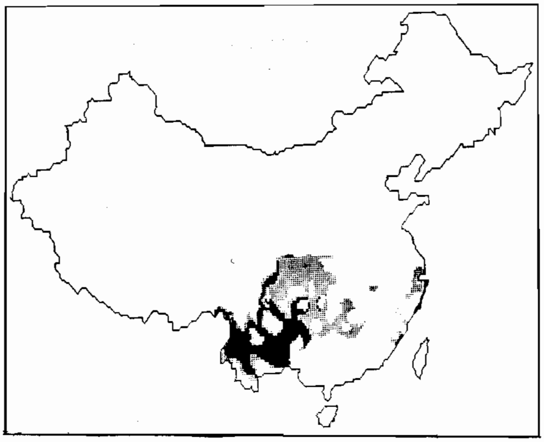

Fig. 4. Potential distribution of *E. nitens* in China.

Typical climate comparison Kunming, a recipient location, has summer rainfall, while the three meteorological stations near the natural populations — Woods Point in Victoria, Bondi in NSW and Armidale in northern NSW — have winter, uniform and summer rainfall patterns respectively. Kunming is thus climatically closest to Armidale.

Cluster analysis Fig. 5 shows the results of cluster analysis on the above factors and quantified rainfall type. The stations can be grouped into three clusters. One represents the Yunnan, Guizhou and Sichuan region, where the dry season is distinct. The second represents Zhejiang in China and northern NSW in Australia, which do not have distinct dry seasons. The third consists of two Australian provenances, Bondi S.F. and Woods Point, whose rainfall patterns differ from the other two groups.

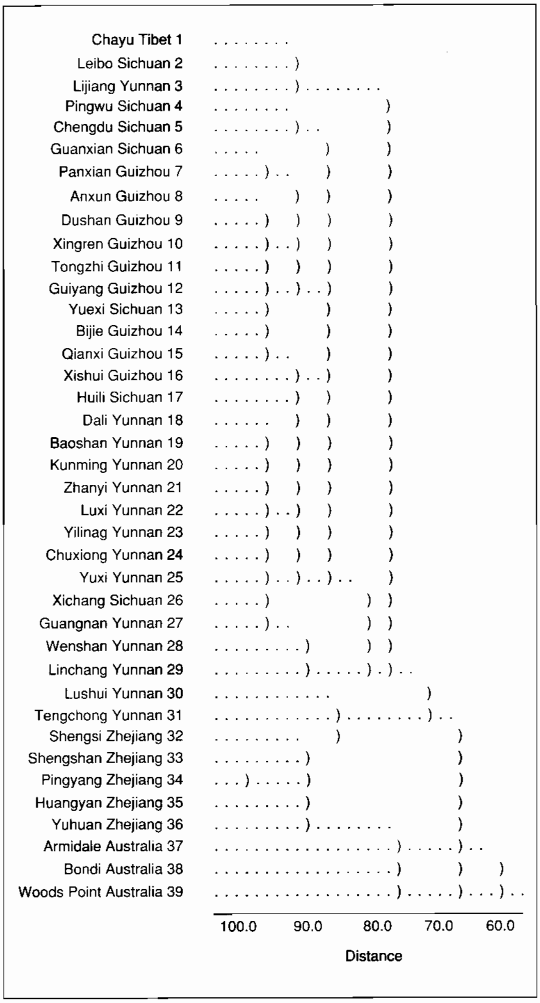

Fig. 5. Cluster analysis of growth and climatic factors

Large areas suitable for growing *E. nitens* in China are mainly in the cool subtropics on the southwest plateau. The main difference between the donor and the recipient climates is the rainfall pattern. Provenances from northern NSW are the most climatically suited for coastal areas, especially in Zhejiang Province.

Discussion and Conclusion

In another study, *E. nitens* was also introduced to the Baoshan area, Yunnan Province. At age 3.3 years it attained 7.7 m in height and 7.7 cm in dbh, exceeding *E. grandis*, *E. bicostata* and *E. maidenii* (Zhang and Yang 1988). These results, together with those from this trial, lead to the conclusion that the introduction of *E. nitens* has been successful and that it is a most promising species in eucalypt plantations in China.

Both the best and the worst provenances are from western Victoria, indicating that genetic differences and potential for provenance selection exist in that area. This variability is the reason why the growth of *E. nitens* in China did not significantly correlate with latitude or elevation of origin.

Generally speaking, provenances from NSW grew faster than those from Victoria. This is consistent with results from South Africa and Australia (Shepherd et al. 1976; Darrow 1983). Because provenances from NSW come from areas with similar rainfall patterns to those of the planting areas in China and South Africa, the difference among NSW provenences could be attributed to either the climatic adaptation or quantitative genetic variation (Pederick 1979). Therefore it is safe to select the provenances from NSW, especially from coastal areas.

E. nitens grows well in cool humid conditions but not in dry hot conditions. In comparison with Australia, the climate of China displays a greater annual range in important factors. Because of the influence of continental seasonal winds, the introduction areas in China have cold, dry winters and hot and humid summers. Fig. 4 shows that the height growth of *E. nitens* was obviously constrained during the dry season. In spite of the high summer temperatures in China, the growth of *E. nitens* was not seriously affected because rainfall is concentrated in the same season, and thus a favorable moisture balance is maintained. Although no dry season exists in the areas with uniform and winter rainfall in the natural range, water stress may still occur because the rainfall in summer does not increase, and may even decrease when temperatures are high. In addition, the soils are poor. With careful selection of local ecological conditions and suitable provenances, *E. nitens* appears to have great potential in plantations in China, especially in coastal areas with a short dry season.

Because of the complicated ecological and geological conditions in the potential planting area, as well as large variation within the species, it is essential to establish multi-site experiments to determine the genotype-environment interaction (GEI) and to select the best provenances for different areas.

Acknowledgments

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Stomatal Conductance of *Eucalyptus globulus* and *E. nitens* in Irrigated and Rainfed Plantations

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Abstract

Stomatal conductance of *Eucalyptus globulus* and *E. nitens* was measured throughout several days between September 1991 and March 1992 in a 2-ha plantation in southeast Tasmania which included irrigated control and rainfed plots. During this period three drying cycles and two periods of rehydration were experienced by the rainfed trees. The plantation was established in August 1990 on a site where it was anticipated that water availability would limit growth. Stomatal conductance was measured for three canopy layers and two aspects (east and west) and was supported by measurements of soil water deficit and pre-dawn water potential. During both drought cycles stomatal conductance was higher in irrigated *E. nitens* than in irrigated *E. globulus*, while in the rainfed plots it was lower for *E. nitens* than *E. globulus*. At the end of the second drought cycle 100 mm of irrigation was applied to the rainfed plots. After 2 weeks stomatal conductance of both species was still lower in the rainfed plots than the irrigated controls despite pre-dawn water potential increasing to pre-drought levels. After a further month stomatal conductance of *E. nitens* was still depressed. In summer only 25% of evaporative demand in this managed plantation was met by rainfall. This study suggests that in most places where they are planted the growth of *E. globulus* and *E. nitens* is limited by available water. In southern Australia this limitation is most severe when the capacity for growth is greatest.

THE effect of trees on catchment water yield is an important environmental consideration for plantation establishment programs. Conversely the effect of available water on plantation yield might be used as a criterion for selecting prospective sites or for matching species to sites.

In South Africa, the reduction of catchment yields by plantations of *Eucalyptus grandis* and *Pinus patula* (van Lill et al. 1980) has given rise to interest in screening clones of both species of water-use efficiency (Dye 1987). In India, similar concerns have led to studies comparing water use by plantations of *E. teretecornis* and *E. camaldulensis* to that of agricultural crops and native vegetation (Roberts et al. 1992). In Yunnan province, China, significant areas of *E. globulus* are planted in areas where available water limits growth.

In Australia, the Commonwealth seeks an expansion of the hardwood plantation estate. At present *E. globulus* and *E. nitens* are favoured by industry for the production of wood fibre. Expansion of the estate on the scale envisaged will inevitably involve planting these species on sites where available water limits growth. In August 1990 an experimental plantation incorporating these two species, which included irrigated controls, was established on a dry, inherently fertile site in southeast Tasmania. This paper describes seasonal and diurnal variation in the stomatal conductance (g_s) of both species under irrigated and rainfed conditions. The influence of aspect, canopy layer and soil water content on the magnitude and patterns of g_s is considered.

Materials and Methods

Site

A 2-ha plantation was established in August 1990 (Prosser sheet 8412, DN501602, Lat. 42°49′S, Long. 147°36′E). A survey on a 20 m grid indicated an average soil depth to bedrock or rock floaters

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of 66 and 57 cm in the western and eastern halves respectively. The profile consists of a 25 cm red-brown to brown loam A horizon which gives way abruptly to a red-brown light medium clay B horizon occasionally overlaying light yellow-brown gritty loam from decomposing rock (Type: chocolate soil — Stace et al. 1968; Mapping unit: Stoneleigh clay loam — Loveday 1957). The parent material is basalt with a bench of mudstone underlying the south-west corner. The site is inherently fertile with the main restrictions on growth being low rainfall and available soil water (<100 mm between field capacity and permanent wilting point).

Experimental design

A split-plot design comprised three irrigated (I) controls adjacent to three rainfed (R) replicates. Within each replicate four seedlots were planted, two each of *E. globulus* and *E. nitens*. Seedlings were planted at a spacing of 3.5 × 2.0 m. Physiological measurements were centred on one seedlot from each species (*E. globulus* four single families ex. King Island and *E. nitens* seed orchard ex Forest Resources; see Table 1 in White et al. (these proceedings).

Treatments

Five weeks after planting, 120 kg/ha of elemental phosphorus was applied as triple superphosphate. In the first two years after planting 90 and 135 kg/ha of elemental nitrogen was applied as urea.

In November 1991 irrigation commenced in the replicates designated as controls. Water levels were maintained to ensure that soil water content did not limit growth (soil water deficit <25 mm).

The rainfed treatments were subjected to three stress cycles between November 1991 and May 1992. In the first cycle to 20 December 1991 soil water deficits under the rainfed plots did not exceed 50 mm. From 20 December to 2 January 1992, 40 mm of rain fell. A second stress cycle to 3 February induced soil water deficits of between 90 and 100 mm. The rainfed plots received 100 mm of water from a travelling irrigator. This reduced these deficits to less than 10 mm. On 23 March soil water deficits reached 70 mm (Fig 1a).

Measurement

Thirty-six access tubes for a neutron moisture meter (CPN 503, Pacheco, California) were installed. Three were placed within each plot, one each at 0.5, 1.0 and 1.75 m from the rip-line, immediately opposite the midpoint between a pair of trees selected randomly. The first two tubes were advanced to soil depth and the last to 3 m. Soil water content (θ) was measured at 0.15 m intervals down to 1.5 m and at 0.30 m intervals below that. Soil water deficit (ΔW) and daily evapotranspiration (E_t) were calculated (Honeysett et al. 1992).

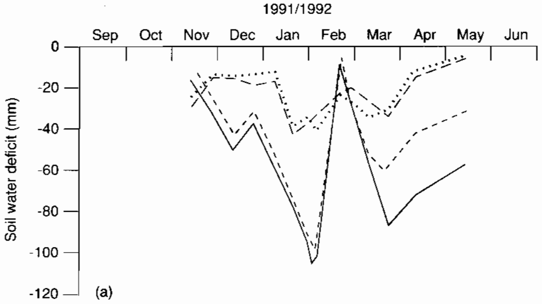

Fig. 1a. Soil water deficits (ΔW) during three stress cycles. The first cycle commenced on 6 November 1991.

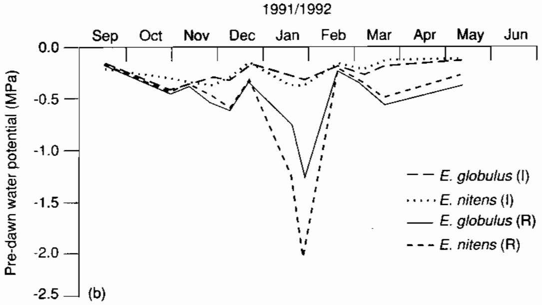

Fig. 1b. Pre-dawn water potential (ψ_{max}) throughout the period of measurement.

Pre-dawn water potential (ψ_{max}) was measured using a pressure chamber (Model 1002, PMS Instrument Co., Corvallis, Oregon). Leaves were selected from a 3 × 3 group of 9 trees in the irrigated and rainfed plots of *E. globulus* and *E. nitens*. On most occasions ψ_{max} was measured on the same day as ΔW.

Stomatal conductance (g_s) was measured on three trees randomly selected from each of the nine used for ψ_{max}. For each tree g_s was measured on the abaxial and adaxial surfaces of six juvenile leaves. One leaf from each of three canopy layers was selected in both the eastern and western halves of the tree. An Li-1600 (Li-Cor Inc., Lincoln, Nebraska) steady-state porometer was used to measure g_s. Instantaneous measurements of quantum flux density (Q) were made simultaneously. Stomatal conductances for the abaxial and adaxial surfaces of each leaf and Q incident on both surfaces were summed.

An Assman psychrometer (Casella, London) mounted in a screen was used to make regular measurements of ambient relative humidity and dry bulb temperature in the plantation throughout days when gs was measured. A weather station established adjacent to the plantation included a manual rain gauge and class A pan evaporimeter. Only rainfall (P) and evaporation (E_0) are presented here.

Results

Water balance

In the 12-month period from 1 July 1991 pan evaporation (E_0) was 1385 mm, and 433 mm of rainfall (P) was recorded. For six consecutive months from October 1991 Eo was >160 mm (Fig. 2). E_0 was lowest in July 1991 at 30 mm.

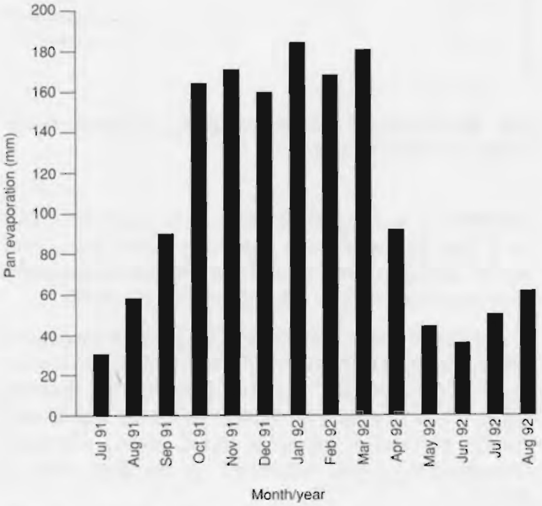

Fig. 2. Monthly pan evaporation, E_0.

During the same 12-month period E_t of *E. globulus* (I) was 903 mm or 65% E_0. It was therefore necessary to supplement rainfall with 470 mm of irrigation (Fig. 3) to meet evaporative demand and maintain controls at $\Delta W < 25$ mm. Thus only 40% of the water necessary to meet this demand fell as rain. In summer (1 December 1991 to 29 February 1992), autumn (1 March to 31 May) and winter (1 June to 31 August) rainfall met 25, 40 and 89% of evaporative demand respectively.

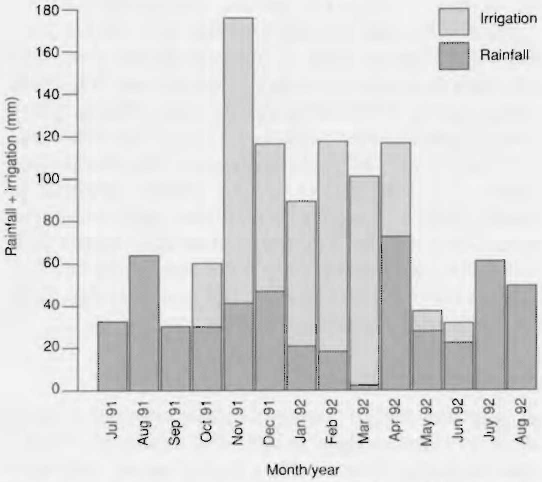

Fig. 3. Monthly pattern of rainfall, P from March 1991 and of supplementary irrigation to the irrigated controls from October 1991.

Diurnal and seasonal changes of stomatal conductance

On 27 September 1991, one month before irrigation commenced, mean g_s was similar in the irrigated (I) and rainfed (R) treatments of both species throughout the day (Fig. 4). Pre-dawn water potential (ψ_{max}) in all treatments was greater than -0.2 MPa (Fig. 1b). Maximum conductance was less than 0.5 cm s^{-1} for both species and was recorded at approximately 0900 h. Stomatal conductance was closely correlated with quantum flux density (Q) with no significant differences evident between treatments. In *E. nitens* (R) a reduction in g_s shortly after 1000 h coincided with a similar decrease in Q (Fig. 4).

Following commencement of irrigation ψ_{max} was maintained at greater than -0.5 MPa in the irrigated controls (Fig. 1b). On 11 December 1991, when ΔW had reached 41 and 49 mm under *E. nitens* (R) and *E. globulus* (R) respectively, ψ_{max} had fallen to approximately -0.6 MPa (Figs 1a, b). Although ψ_{max} was only 0.25 MPa lower in rainfed than irrigated trees, maximum g_s was 40% lower in rainfed (0.28 cm s^{-1}) than irrigated (0.51 cm s^{-1}) *E. nitens* (Fig. 5). In contrast maximum g_s was only marginally lower in rainfed (0.36 cm s^{-1}) than irrigated (0.41 cm s^{-1}) *E. globulus*. In the irrigated controls g_s was slightly lower in *E. globulus* than *E. nitens* while in the rainfed trees the order was reversed.

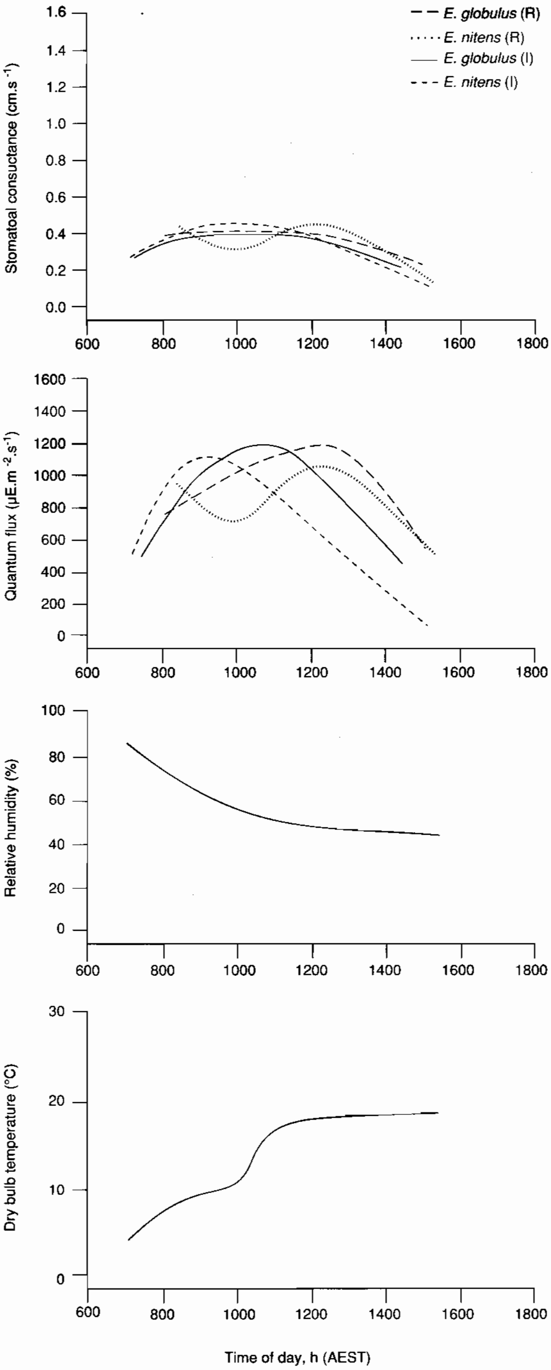

Fig. 4. Diurnal changes in stomatal conductance, quantum flux density, relative humidity and dry bulk temperature on 27 September 1991, prior to the commencement of irrigation.

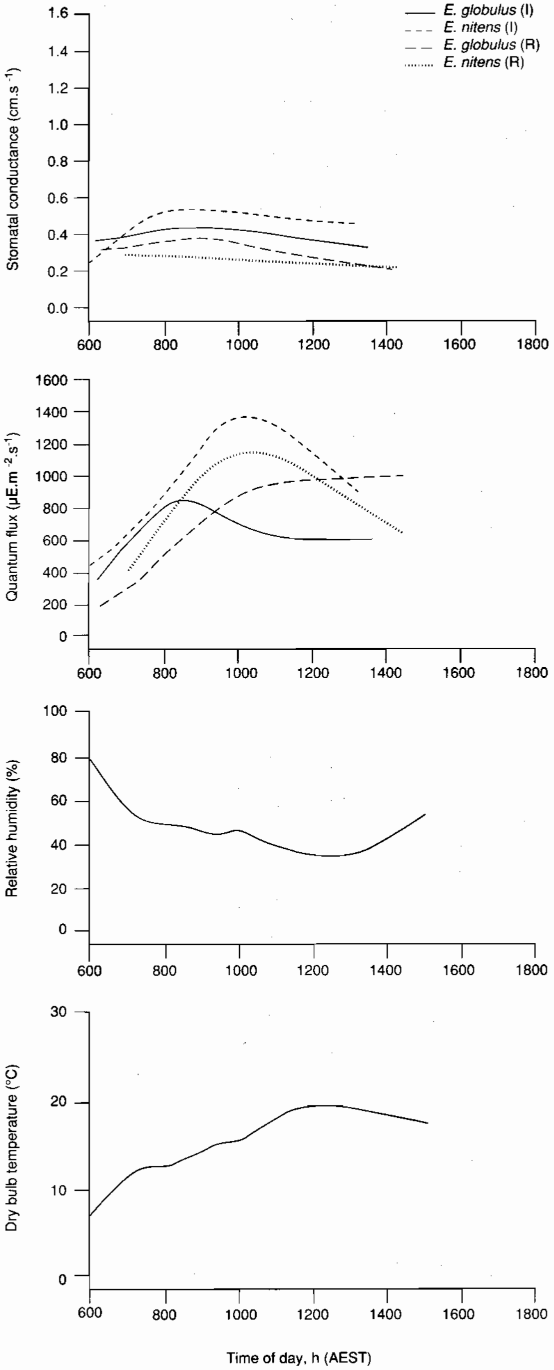

Fig. 5. Diurnal changes in stomatal conductance, quantum flux density, relative humidity and dry bulb temperature on 11 December 1991, during the first stress cycle.

At the start of the second stress cycle, soil water deficit (ΔW) was 31 and 37 mm under *E. nitens* (R) and *E. globulus* (R) respectively (Fig. 1a). As a result $\psi_{\max}$ increased to approximately -0.3 MPa in the rainfed plots of both species (Fig. 1b). By 3 February 1992 ΔW under both species exceeded 90 mm and $\psi_{\max}$ in *E. nitens* (R) and *E. globulus* (R) was -2.0 and -1.3 MPa respectively. The ranking of maximum g_s was the same as on 11 December 1991 but the differences between the irrigated and rainfed treatments of both species were more pronounced (Fig. 6) reflecting the greater differences in ΔW and $\psi_{\max}$. Maximum g_s of *E. nitens* (I) and *E. globulus* (I) was 1.49 and 1.22 cm s^{-1} and the stomata had to all intents and purposes closed: g_s of *E. globulus* (R) was still 0.23 cm s^{-1}.

Two weeks after irrigation of the rainfed treatments $\psi_{\max}$ of both species had increased to -0.3 MPa and ΔW had decreased to 5 and 8 mm under *E. nitens* (R) and *E. globulus* (R) respectively. Despite the recovery of $\psi_{\max}$, g_s remained depressed throughout the day in the rainfed treatments of both species compared to the irrigated controls. Maximum g_s was greater in irrigated *E. nitens* (0.79 cm s^{-1}) than irrigated *E. globulus* (0.63 cm s^{-1}) and rainfed *E. globulus* (0.49 cm s^{-1}) or *E. nitens* (0.43 cm s^{-1}) (Fig. 7). By 10 March daily E_t was 4.18 mm in rainfed *E. globulus* (R) compared with 3.15 mm by *E. nitens* (R). As a result ΔW under *E. nitens* (R) increased more slowly than in *E. globulus* (R) until by 23 March 1992 ΔW was 84 mm under the latter compared to 56 mm under the former species (Fig. 1a). Maximum g_s was again highest in irrigated *E. nitens* (0.71 cm s^{-1}) and for the other three treatments approximately 0.35 cm s^{-1} (Fig. 8).

Aspect and canopy layer (data not shown)

On 11 December 1991 in the irrigated plot of both species g_s was highest in the eastern half of the tree in the morning and in the west after midday. This was also true in *E. globulus* (R). In the *E. nitens* (R), g_s became greater in the westerly leaves in mid to late morning. On February 3 g_s was higher in the west for *E. globulus* (I) throughout the day while the trend in all other treatments was the same as for December. After the rainfed plots were watered g_s was higher throughout the day for leaves in the western half of the trees than for those in the east. By 23 March conductance in the eastern half of the tree was higher again in the morning.

The effect of canopy layer on g_s was inconsistent. While mean g_s mostly decreased with depth in the canopy, the middle and bottom layers frequently showed the highest g_s in all treatments.

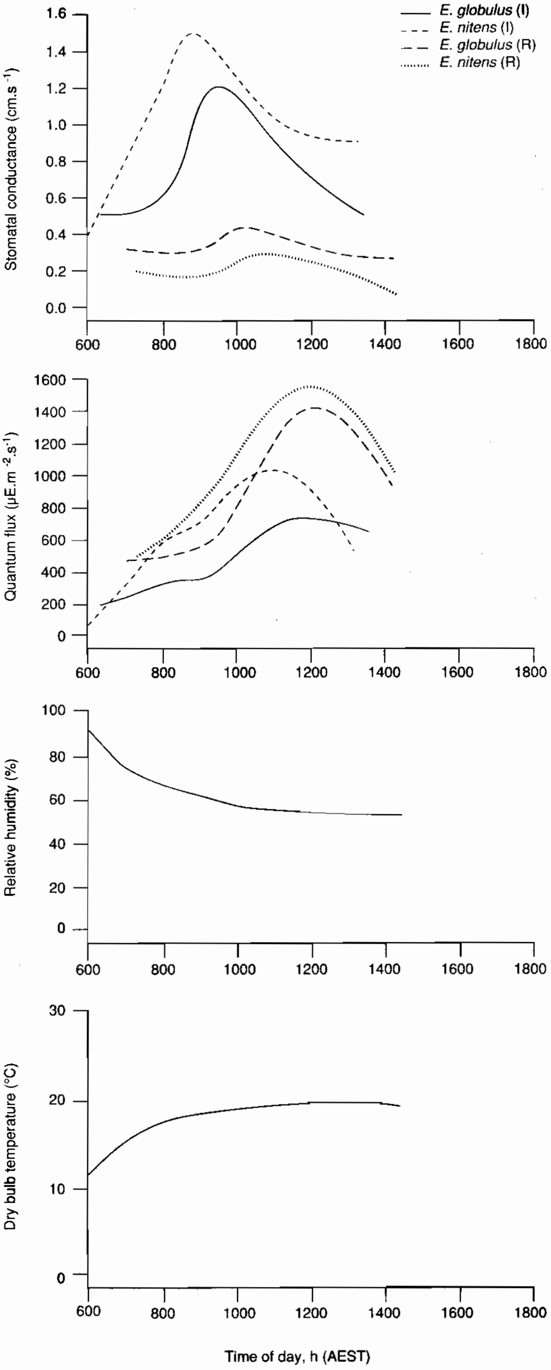

Fig. 6. Diurnal changes in stomatal conductance, quantum flux density, relative humidity and dry bulb temperature on 3 February 1992, during the second stress cycle.

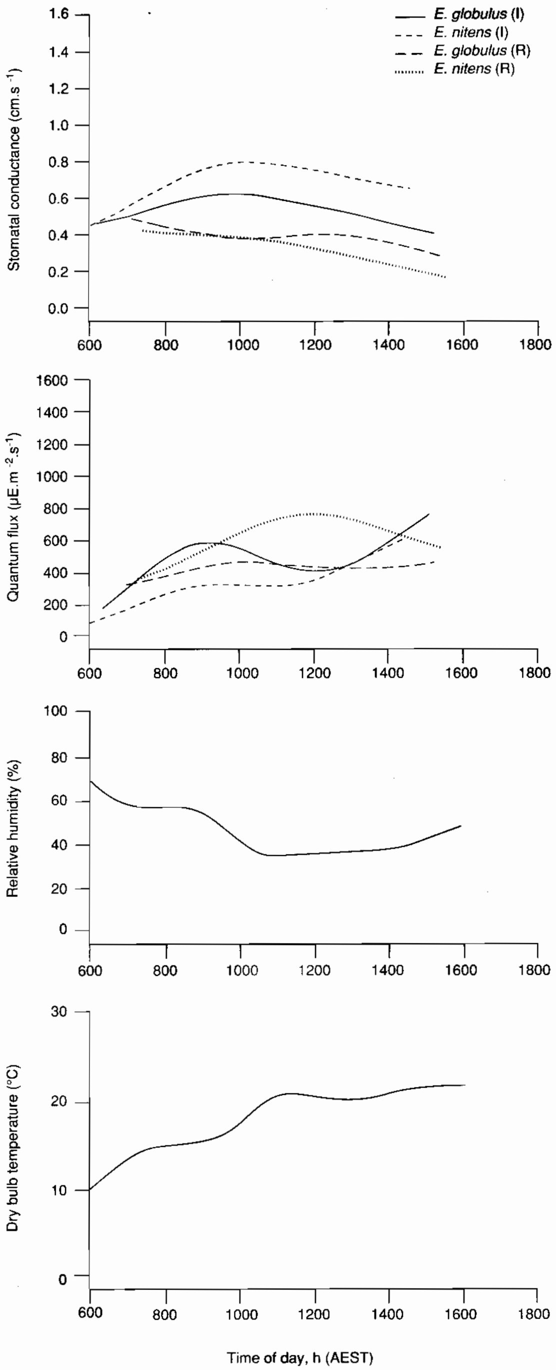

Fig. 7. Diurnal changes in stomatal conductance, quantum flux density, relative humidity and dry bulb temperature on 21 February 1992, 2 weeks after irrigation of the rainfed plots.

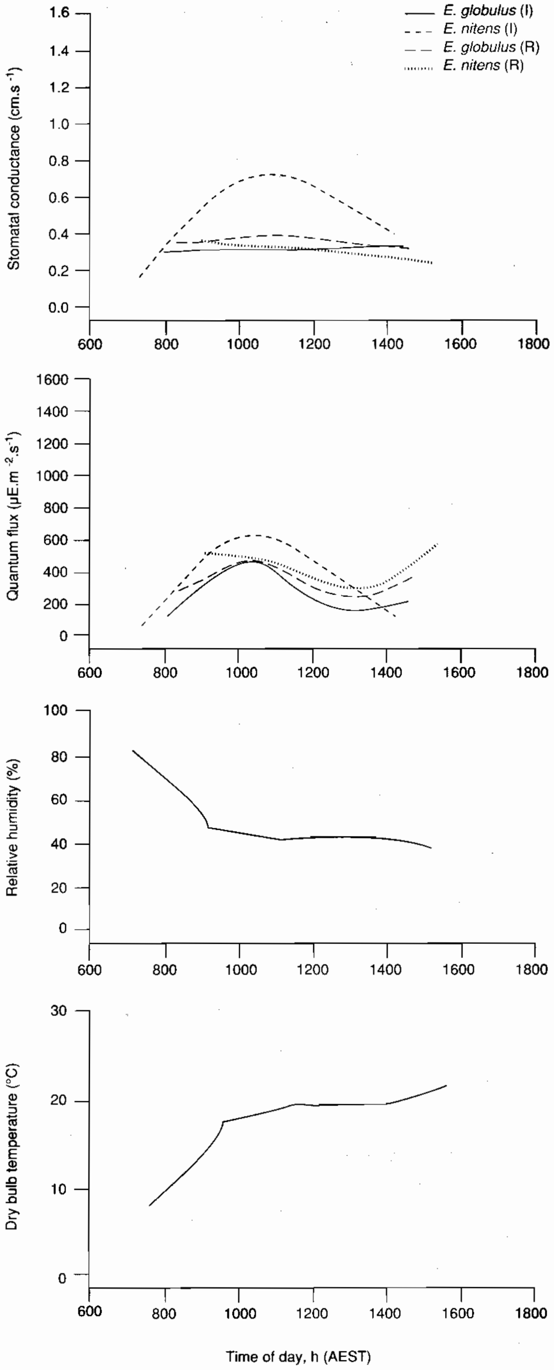

Fig. 8. Diurnal changes in stomatal conductance, quantum flux density, relative humidity and dry bulb temperature on 23 March 1992, 6 weeks after irrigation of rainfed plots.

Discussion

A series of diurnal measurements of stomatal conductance has shown that there are both similarities and differences in the behaviour of juvenile leaves of *E. globulus* and *E. nitens*. For example, in the absence of stress, g_s increased seasonally to give maximum values in early February (Fig. 6) and diurnally to give maxima well before midday in both species. In the presence of severe water stress and even following the immediate recovery of ψ_{max}, the diurnal opening response was either muted or absent (Figs 6, 7). This diurnal pattern of g_s with a single peak in the morning is typical of many woody species and has been observed previously in *E. globulus* (Pereira et al. 1986).

In the irrigated control, g_s was consistently higher in *E. nitens* than *E. globulus* throughout the summer, whereas in the rainfed treatment this was reversed. Wang et al. (1988) suggested that the lower g_s observed in *E. globulus* subspecies *bicostata* than in *E. globulus* subspecies *globulus* under conditions of water stress indicated a conservative property that might indicate the former's better adaptation to drought. The consistently lower g_s of *E. nitens* under conditions of water stress suggests a similar response. Should this be the case then growth of *E. nitens* may be significantly limited by early stomatal closure under water stress. The significance of the higher g_s of *E. nitens* in the control plots in not yet clear.

Despite the apparently higher demand for water in *E. globulus* (R) than *E. nitens* (R), ψ_{max} was 0.7 MPa more negative in the latter species. This reduced water potential may result from more osmotic adjustment to avoid desiccation at low θ or from less effective interaction with the soil matrix than by *E. globulus*. Many instances of osmotic adjustment by eucalypts have been reported (e.g. Ladiges 1974; Myers and Neales 1986). The lower g_s and the reduced growth (White et al. these proceedings) observed in *E. nitens* under these conditions indicates that this lower leaf water potential, while it may have allowed the maintenance of leaf turgor in dry soil, could not prevent closure of the stomata. Leaf water potential may act as an independent variable driving transpiration via stomatal aperture or as a dependent variable, itself a function of transpiration (Shulze et al. 1987). It is difficult to resolve how water potential is related to g_s in this experiment, although in both species g_s fell with decreasing ψ_{max}.

Throughout the summer available water did not limit growth in the irrigated treatments. The mean maximum stomatal conductances recorded were 1.22 and 1.49 cm s^{-1} in the irrigated *E. globulus* and *E. nitens* respectively (Fig. 6; mean maximum conductances of the upper canopy layer were respectively 1.33 and 1.98 cm s^{-1}). These values are substantially higher than for a range of deciduous hardwood species, conifers and other species of *Eucalyptus* under well-watered conditions. For example, in container-grown *Betula papyrifera* and *Acer negundo* the maximum conductance was 0.24 cm s^{-1} (Ranney et al. 1990), in *Pinus sylvestris* in a plantation 0.6 cm s^{-1} (Beadle et al. 1985) and for eucalypts 0.7 cm s^{-1} in the upper canopy layer of *E. grandis* (Dye 1987), 0.38 cm s^{-1} in *E. microcarpa* (Attiwill and Clayton-Greene 1984), 0.70 cm s^{-1} in *E. pauciflora* (Korner and Cochrane 1985), and 0.59 cm s^{-1} in adult *E. globulus* (Pereira et al. 1987). An exception was 1.44 cm s^{-1} in the upper canopy of *E. camaldulensis* (Roberts et al. 1992).

Irrigation and a high nutrient supply appear to have prompted a large increase in g_s in this study. Definition of the extent to which this capacity for water use is translated into wood production is essential before irrigation of *Eucalyptus* plantations is considered on a commercial scale. This will require modelling interactions between water-use efficiency and biomass partitioning under non-limiting and limiting soil water conditions.

The effect of canopy layer on g_s was inconsistent, with all layers showing the highest g_s at some time. Beadle et al. (1985) found that conductance and photosynthesis declined with depth in the canopy of mature *Pinus sylvestris* and Roberts et al. (1992) found the same occurred in juvenile *E. camaldulensis* and *E. teretecornis*. At the Tasmanian site stand density was nominally 1430 compared with 3300 trees/ha^{-1} in the stands studied by Roberts et al. The lower stocking and reduced shading of lower canopy layers may explain the weaker effect of canopy layer on g_s in this study.

In the three summer months only 25% of evaporative demand was met by rainfall. In the irrigated plots, E_t of *E. globulus* and *E. nitens* was around 350 mm during this period. In the coming year as leaf area increases demand for water will grow. This suggests that in most places where they are planted growth of these species will be limited by available water. In southern Australia this limitation will be most severe when the capacity for growth is greatest. The capacity of *Eucalyptus* species to use water may also have implications for plantation establishment programs in important catchment areas.

Acknowledgments

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Early Results from a Progeny Trial of *Eucalyptus globulus* in Yunnan Province, China

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Abstract

This report describes the establishment of a seed orchard of *Eucalyptus globulus* Labill. ssp. *globulus* at Yipinglang State Farm, Yunnan Province, China. The progeny trial has 19 complete replications of two-tree plots of 270 open-pollinated family seedlots, laid out in an incomplete block design. The seedlots were of three categories (natural populations, Yunnan land race and seed orchard selections), which were further subdivided into 11 regions and 60 provenances.This report analyses data from an assessment of growth, form and other characteristics of the trees at age 20 months. Results are only preliminary and rankings may change in later assessments, but two-tree plots (or multiple-tree plots) performed better and are strongly recommended over single-tree plot designs for large-scale progeny trials.

EUCALYPTUS *globulus* Labill. ssp. *globulus,* Tasmanian blue gum, is one of the most widely planted eucalypts in the world. It is believed that it was introduced to China in the 1890s by an English customs officer. In 1934, 30-year-old *E. globulus* were found in Kunming, the capital of Yunnan province, with diameters of 40–50 cm (Wu Zhonglun 1983). Now, the tallest eucalypt in China is an *E. globulus* in Kunming. It is 40 years old, measures 49 m in height and has a diameter of 110 cm (Qi 1983). Unfortunately, there is no record of origin or parents of these trees.

Nearly all of the Tasmanian blue gums in China are planted on the Yunnan plateau. Kunming and Chuxiong are at the centre of this area.This species is adapted to a wide range of soils and it has good survival. The growth rates are considered good. A well-adapted land race (Zobel et al. 1987) is evident.

The wood of Tasmanian blue gum is used for fuelwood, mining timber, posts, fibreboard, and even furniture and boats, although most trees have severe spiral grain. More recently, Tasmanian blue gum has been recognised as excellent for pulpwood and rayon. Cineole oil can be extracted from the leaves for medicinal and other purposes, and is an important product in Yunnan.

There are three other closely related southern blue gums. Kirkpatrick (1974) treated all four as one species with the subspecies *bicostata*, *pseudoglobulus*, *globulus* and *maidenii.* This report focuses on Tasmanian blue gum, *E. globulus* Labill. ssp. *globulus*.

New Genetic Resources Needed

By 1990 there were about 80 000 ha of eucalypt plantations in Yunnan province, with an annual planting of about 3000 ha. About 70% of the plantations are Tasmanian blue gum. In southwestern Sichuan province, the area planted with Tasmanian blue gum has increased considerably in recent years.

After many generations, the local Tasmanian blue gum is well adapted to Kunming and the local land race is an important gene resource for this area. It suffers, however, from severe spiral grain, reflected in twisting of the bark around the stem. There has already been strong selection of a small number of the best trees to provide seed for further plantations. To enhance opportunities for genetic improvement of Tasmanian blue gum in China, it is imperative to obtain a broad genetic base from natural stands, from which to build up the breeding population. A suitable breeding strategy must be implemented. A breeding plan for *E. globulus* has been prepared (Raymond 1988).

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Study Site

The progeny trial of Tasmanian blue gum is established in Yipinglang State Forest Farm (latitude 25 °, longitude 102 °, altitude 1800 m) in central Yunnan Province, 130 km west of Kunming city. Yipinglang experiences a subtropical climate, with no marked differences among the four seasons. There are, however, distinct wet and dry periods. The wet period is from June to September, while the dry period is from November to April. Average annual rainfall is 830–1000 mm, and the annual evaporation 2000–2100 mm. Mean annual temperature is 18 °C. Absolute minimum temperature is −5 °C. Frost occurs occasionally.

On the Yunnan Plateau, the natural forest is an evergreen broadleaved type in which the major species include *Quercus* and *Castanopsis*. Some mixed pine–oak forest (*Pinus yunnanensis* and *Quercus*) occurs at relatively high altitudes.

This area is mountainous and the small amount of flat land is used for agriculture. As forests can be planted only on hillsides or hilltops, the study site was set on a high-middle slope representative of the main areas that will be used for Tasmanian blue gum plantations.

The red mountain soil at the site, derived from purple shale or purple sandstone, is normally more than 1 metre in depth, with pH of 4.7–5.2. The soil is well drained, stone-free, with low to medium organic matter content and compact texture. Analyses of bulked soil samples (0–30 cm) are shown in Table 1.

In January 1990, the site was cleared. Trenches 70 cm wide and 80 cm deep were dug, along the planting lines, and the soil was filled back into the trenches along with grass collected from surrounding areas. This method is often used for intensive silviculture on the plains in northern China. It is now being gradually taken up in Yunnan. Although it uses much labour, it still is an efficient method in some parts of China.

Genetic Base

A total of 309 single-tree seedlots were used at the nursery, comprising 17 seedlots from Yunnan, one from New Zealand, 45 from Portugal and 246 from Australia. All seedlots were open-pollinated.

The seed from Yunnan was collected from plus trees, mostly on the roadside, by the Yunnan Academy of Forestry. The trees were selected for superior height, diameter, stem form, reduced bark twisting and good health.

Of the 246 seedlots from Australia, 176 were provided by the CSIRO Australian Tree Seed Centre. The others were provided by Tasmanian Regional Laboratory, CSIRO Division of Forestry. Some were from the Tasmanian seed orchard of Australian Pulp and Paper Manufacturers Ltd. King Island seedlots were supplied by Keith Orme of Forest Resources, Launceston, Tasmania, and the others were collected in natural stands in Tasmania and Victoria.

The 270 seedlots used in the trial can be grouped into three categories:

Category 1: natural stands in Australia
Category 2: seed orchards in Australia, Portugal and New Zealand.
Category 3: local land race in Yunnan Province.

Subdivision of Categories 1 and 2 allows the identification of 11 regions:

1. West coast Tasmania (WT)
2. Eastern Tasmania (ET)
3. Southern Tasmania (ST)
4. Tasmania seed orchard (TSO)
5. Bass Strait Islands (BSI)
6. Western Victoria (WV)
7. Eastern Victoria (EV)
8. Portugal seed orchard (PSO)
9. New Zealand seed orchard (NSO)
10. Yunnan Province (YP)
11. Wilsons Promontory (WP)

Sixty local provenances may be recognised, based on seed collection locations.

Table 1. Soil properties at trial site.

	pH	Organic carbon (%)	Inorganic N (ppm)	Inorganic P (ppm)	Inorganic K (ppm)	Inorganic B (ppm)
Sample 1	4.9	1.05	50	1.3	99	0.18
Sample 2	5.2	1.23	78	0.9	65	0.12
Sample 3	4.7	1.22	50	11.1	40	0.4

Design

A randomised incomplete block design generated by the computer program Alphagen (E.R. Williams, pers. comm. 1990) was used for the trial. The design used 19 complete replications with two trees in each plot, 15 plots in each incomplete block, and 18 incomplete blocks in each replicate. The incomplete blocks were trench sections containing 15 two-tree plots. Spacing was 3 m between trenches and 1.5 m between trees along the trenches, giving a plot size of 3 × 3 m and an incomplete block size of 3 × 45 m. Because the trenches were parallel to the slope, the blocks had their long axis at right angles to the main (downslope) environmental field trend.

Measurements

The trees were planted in July 1990 and the first measurement made in April 1991. Only tree height was measured: this is subsequently referred to as initial tree height (H1).

The second measurement was taken in February 1992, when nine variates were measured: tree height (H2), diameter at breast height (DBH), crown width east–west (CEW), crown width north–south (CNS), and height of lowest branch (ZXG) were measured in metres or centimetres. Stem form (STM), fungal tolerance (FGL), insect tolerance (INS) and frost tolerance (FST) were measured using simple subjective scoring systems.

Analysis

This trial data set was too large to fit all the treatments in the model on a personal computer. The analysis was therefore carried out in three stages. In the first stage, the data were checked and plot means calculated.

The second stage used Mixed Model Analysis of Variance, Restricted Maximum Likelihood (REML analysis in GENSTAT) to analyse the variance components for repl, repl.block and families and to estimate family means.

In the third stage, 11 variates were analysed. The additional variates are survival variates that were calculated within families. The other family means estimated by the second stage have no missing values. A fixed-effects ANOVA of family means could therefore be used for the third stage of the analyses. A weighted ANOVA analysis was conducted, with each family mean weighted according to the number of plots with surviving trees for that family, for each variate.

The significance tests for category, region, provenance and family means are shown in Table 2. The analysis of variance table was obtained by combining the results of the second and third stages. The weighted ANOVA of family means automatically produced the correct scaling for combining the plot-level analyses. For testing the significance of the family level in the REML analysis, an approximate F-test (E.R. Williams, pers. comm. 1992) had to be used because a mixed model was involved. The estimated category means and region means calculated by REML are shown in Table 3. Means are displayed graphically in Figures 1–6.

Table 2. Table of F values.

	Category	Region within category	Provenance within region	Family
H1	3.77*	30.75*	3.67*	4.96*
H2	16.65*	37.54*	2.71*	2.61*
DBH	2.36	7.81*	1.32	1.8 *
CEW	21.4*	16.36*	1.65	2.52*
CNS	17.93*	16.81*	1.46	2.51*
ZXG	2.91	28.55*	5.11*	4.27*
STM	3.31*	7.03*	2.39*	1.99*
FGL	7.6*	9.32*	2.81*	2.12*
INS	0.16	1.46	1.05	1.15
FST	1.42	2.55*	1.43	1.24

* significantly different
H1, Initial height; H2, height; DBH, Diameter at breast height; CEW, Crown width east–west; CNS, Crown width north–south; ZXG, Height of lowest branch; STM, Stem form; FGL, Fungal tolerance; INS, Insect tolerance; FST, Frost tolerance

Table 3. Means of categories and regions.

	H1	H2	DBH	CEW	CNS	STM	FGL	INS	FST	SVL
Natural	0.74	1.79	1.24	1.04	1.06	1.09	1.36	1.99	0.25	80.43
SO	0.75	1.90	1.29	1.12	1.13	1.13	1.42	1.99	0.25	82.22
Local	0.72	1.84	1.27	1.03	1.04	1.10	1.43	2.00	0.28	85.63
WT	0.73	1.65	1.02	0.94	0.96	1.03	1.33	2.00	0.26	78.49
ET	0.75	1.83	1.27	1.06	1.07	1.11	1.41	2.00	0.27	82.25
ST	0.75	1.80	1.23	1.03	1.06	1.10	1.41	1.98	0.25	82.72
TSO	0.80	1.93	1.30	1.11	1.13	1.14	1.36	1.99	0.26	82.56
BSI	0.73	1.77	1.24	1.06	1.08	1.11	1.26	2.00	0.26	83.19
WV	0.76	1.93	1.29	1.10	1.11	1.10	1.35	1.99	0.24	75.89
EV	0.73	1.90	1.32	1.07	1.10	1.12	1.48	1.99	0.18	81.06
PSO	0.74	1.92	1.31	1.14	1.15	1.13	1.44	1.99	0.25	82.73
NSO	0.69	1.91	1.52	1.10	1.15	1.20	1.45	2.01	0.21	73.68
YP	0.72	1.84	1.27	1.03	1.04	1.10	1.43	2.00	0.28	85.63
WP	0.51	1.08	0.63	0.80	0.82	0.83	1.53	2.00	0.18	72.65

Category: Natural, Natural stands in Australia; SO, Seed orchards; Local, Local land race in Yunnan Province
Region: WT, West coast Tasmania; ET, Eastern Tasmania; ST, Southern Tasmania; TSO, Tasmania seed orchard; BSI, Bass Strait Islands; WV, Western Victoria; EV, Eastern Victoria; PSO, Portugal seed orchard; NSO, New Zealand seed orchard; YP, Yunnan Province; WP, Wilsons Promontory
H1, Initial height; H2, height; DBH, Diameter at breast height; CEW, Crown width east-west; CNS, Crown width north-south; STM, Stem form; FGL, Fungal tolerance; INS, Insect tolerance; FST, Frost tolerance; SVL, Survival (%)

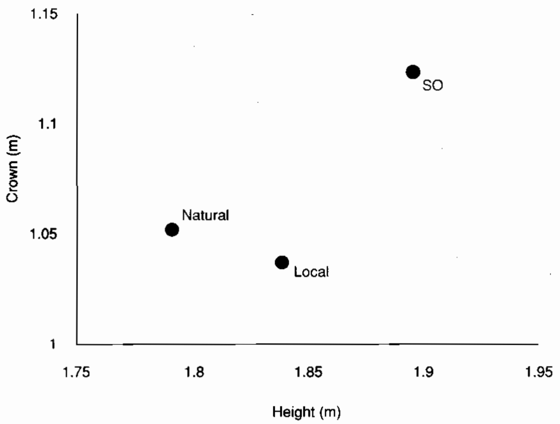

Fig. 1. Comparison of crown width and height of categories.

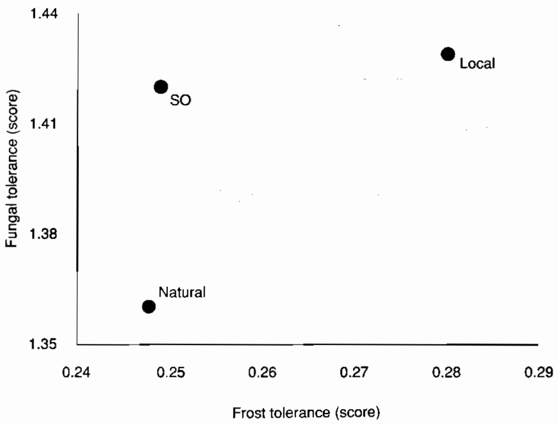

Fig. 2. Comparison of fungal tolerance and frost tolerance of categories.

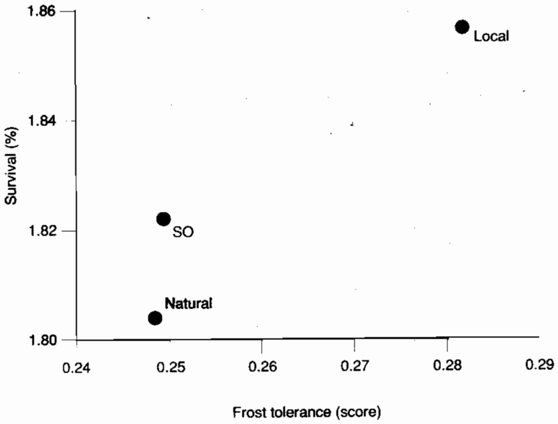

Fig. 3. Comparison of survival and frost tolerance of categories.

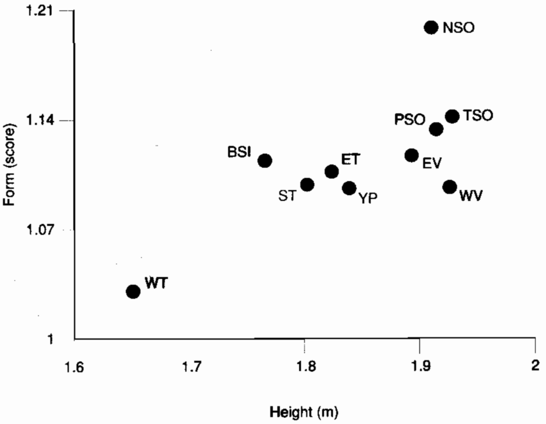

Fig. 4. Comparison of stem form and height of regions.

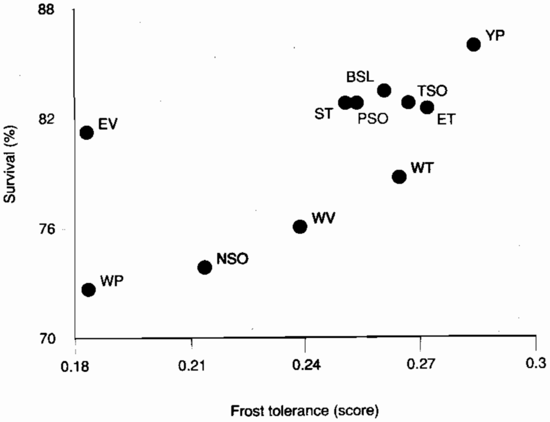

Fig. 5. Comparison of survival and frost tolerance of regions.

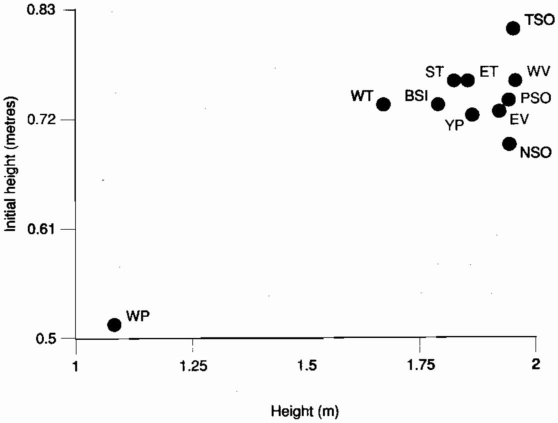

Fig. 6. Comparison of first and second heights of regions.

Results

Seedlot categories

The progenies for each category are significantly different for initial height, height, crown size, fungal tolerance and stem form (Table 2). For growth (Fig. 1) the seed orchard selections are better than natural provenances and the local landrace. For fungal tolerance (Fig. 2), the local landrace and seed orchard selections are better than natural provenances. For stem form the seed orchard selection is the best. For frost tolerance and survival (Fig. 3) the local landrace is better than natural provenances and seed orchard selections.

Regions

All the variates except insect tolerance show significant differences between regions within categories. For growth (Fig. 4) the seedlots from western Victoria, eastern Victoria and all the seed orchards are best, followed by east coast of Tasmania, southern Tasmania, Bass Strait Islands and Yunnan Province. West coast Tasmania is inferior in growth and Wilsons Promontory is the worst. This can be seen for initial height, height, dbh and crown size. For stem form (Fig. 4), all the seed orchards are best. For fungal tolerance, Wilsons Promontory is best, eastern Victoria is second and the Bass Strait Islands worst (Table 3). For frost tolerance, Yunnan Province is the best, and eastern Victoria and Wilsons Promontory worst (Fig. 5). For survival at 20 months, Yunnan Province is best, and western Victoria, New Zealand seed orchard and Wilsons Promontory worst.

Provenances

Significant differences were found between provenances within regions for initial height, height, height of lowest branch, stem form and fungal tolerance.

Families

Significant differences between families within provenances were found for the variates initial height, height, dbh, crown size, height of lowest branch, stem form and fungal tolerance.

Discussion

Genetic differences

Initial height, height, dbh and crown size are the variates for growth of the trees, and height is the most useful when the tree is young. The seedlots selected from seed orchards show the best growth, probably because these seedlots have been selected for good growth performance and improvement has already been achieved by reduction of inbreeding compared with that in natural stands. The seedlots from the local landrace in Yunnan Province are better than Tasmanian natural regions, but worse than those from western Victoria and eastern Victoria.

The spread of Tasmanian blue gum world-wide was associated with the exploration of southeast Australia in the late 1700s. It is likely that early material of the species was collected in southern Tasmania in the vicinity of Bruny Island and Recherche Bay (Orme 1978). The Yunnan-grown Tasmanian blue gum was introduced to China from Europe by Europeans (Wu Zhonglun 1983), not from Australia directly.

Tasmanian blue gum has been planted in Yunnan Province for about 100 years. It has already been exposed to selection by the local environment, and at the same time it has been selected by people for good growth, just as they select the best seeds of agricultural crops and fruit trees.

For height, dbh, crown size and stem form (Table 3), the Yunnan landrace is always very similar to or a little better than eastern and southern Tasmania, but much better than western Tasmania and quite different from Victoria. For frost tolerance and survival (Figure 5), it is much better than all others. The limited historical evidence, and the similarity of the performance of the Yunnan and eastern and southern Tasmania seedlots, suggest that the Yunnan landrace originated from southern or eastern Tasmania.

Yunnan Province has heavier frost than the natural environments of Tasmanian blue gum. After 100 years, the landrace has become adapted by natural and artificial selection to this environment, so it shows better frost resistance and survival. Although the growth and stem form are not better than seedlots from seed orchards or eastern and western Victoria, the local landrace is still an important base population for good frost tolerance and survival.

The seedlots from eastern and western Victoria are the best provenances in natural stands for growth, and better then the local landrace. The seedlots from seed orchards show the best growth of the three seedlot categories, but are similar to eastern and western Victoria regions within the natural provenance category. The seedlots from seed orchards have already been selected in Tasmania, Portugal and New Zealand and moreover should already be benefiting from reduced inbreeding. For further breeding improvement, eastern and western Victoria should be the best source of material to obtain improved growth.

Provenances and families from Wilsons Promontory showed the poorest growth, stem form, frost tolerance and percentage survival. It is the best region, however, for fungal tolerance.

Figure 6 shows that initial height (10 months old) is not well correlated with height at 20 months. This shows us that very early selection based on height is unreliable.

Field design

For this trial, there are 75 plots missing in the first year, 396 missing in the second year. There are 904 missing trees in the first year and 2095 missing in the second year (Table 4). Percentage survival of plots is much higher than that of single trees. So, the numbers of missing values are much lower for two-tree plots than they would be for a single-tree plot. This is very important for statistical analysis of progeny trials.

Table 4. Survival at tree level and plot level.

	First year	Second year
Survival of trees	9356	8165
Total trees planted	10260	10260
Survival (%)	91.2	79.6
Survival of plots	5055	4734
Total plots planted	5130	5130
Survival (%)	98.5	92.3

Future assessments

This progeny trial of Tasmanian blue gum was 2 years old when the main assessment was carried out. The results obtained, and the conclusions drawn, are only tentative at this stage. The two trees within each plot are selectively thinned shortly after the main assessment, retaining the plot as a single tree. Selective thinning to remove inferior families will be undertaken some years later, after a final assessment and analysis of retained trees. The conclusions from the final assessment may differ from the conclusions drawn from the 2-year analysis reported here.

Acknowledgments

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The Effect of Drought Stress on Height, Diameter and Leaf Area Index of *Eucalyptus globulus* and *E. nitens*

D.A. White, C.L. Beadle, J.L. Honeysett and D. Worledge*

Abstract

Growth (height and diameter) of irrigated and rainfed *Eucalyptus globulus* and *E. nitens* was measured in a plantation established on a dry site. Irrigation commenced on 6 November 1991 when the plantation was 14 months old. Relative height and diameter growth of irrigated *E. globulus* was greater than that of other treatments once irrigation began. Between January and February 1992 the rate of increase in diameter was up to five times greater in the irrigated controls compared to the rainfed trees of both species and coincided with the period of greatest water stress in the rainfed trees. Differences in height growth during this period were not as well defined.

In June 1992 the leaf area of 24 trees was determined by destructive sampling and relationships between leaf and basal areas developed for the irrigated and rainfed treatments of both species. Leaf area was strongly correlated with basal area at 0.15 m above ground. These relationships were then used to estimate leaf area index over the whole plantation for all four treatments. In May 1992 leaf area index was higher in *E. globulus* than *E. nitens*, and within-species leaf area index was significantly increased by irrigation. The highest leaf area indices were 4.2 and 3.6 respectively in the irrigated Rheban and King Island seedlots of *E. globulus*.

EXPANSION of the hardwood plantation resource in Australia is one way of relieving pressure from logging on native forests. Such an expansion will necessitate establishing plantations on sites where growth is limited by water availability. In August 1990 a 2-ha experimental plantation was established in a low rainfall area east of Hobart, Tasmania. The plantation, divided into irrigated and rainfed plots, contained two seedlots each of *Eucalyptus globulus* and *E. nitens*.

Height and diameter data are presented and leaf area index calculated from harvested trees and the distribution of basal area. Growth is considered in relation to rainfall, irrigation and pre-dawn leaf water potential.

Materials and Methods

In August 1990 a 2-ha experimental plantation was established in southeastern Tasmania on an inherently fertile site where the major limitation to growth was believed to be water availability. The site, experimental design and imposed treatments are described in detail in the other paper by White et al. in these proceedings. The planting stock of four seedlots, two of each of *E. globulus* and *E. nitens* (Table 1) was assigned randomly to the split plot of each replicate.

Environment

A weather station, comprising a thermohygrograph, manual rain gauge, class A pan evaporimeter, maximum and minimum thermometer, wet and dry bulb thermometer and wind run anemometer, was established adjacent to the plantation.

Irrigation

In December 1990, 75 mm of water was applied over the entire plantation using a travelling irrigator. In November 1991 a programmable irrigation system

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Table 1. List of seedlots.

Species	Seedlot	Description	Latitude (0 'S)	Elevation (m)	Rainfall (mm)
E. globulus	King Island	A random planting of four single-tree collections. 11 rows per replicate	39°55	50	990
E. globulus	Rheban (CSIRO S16589)	A single row per replicate	42°42	120	575
E. nitens	Forest Resources Seed Orchard	Second generation juvenile persistent *E. nitens*. 11 rows per replicate	37°50	>800	—
E. nitens	Barrington Tops (CSIRO S16304)	Three rows per replicate	32°00	1500	Not known

was commissioned. Soil water deficit and daily evapotranspiration were derived from neutron moisture meter data (Honeysett et al. 1992) and irrigation scheduled to maintain soil water deficits of <25 mm in the irrigated controls. The stress cycles imposed on the rainfed plots during the second growing season and concurrent measurements of pre-dawn water potential are described in White et al. (these proceedings).

Growth plots

Growth plots were established in all six replicates for each of the four seedlots. In the 11-row seedlots the growth plots were 5 rows x 6 trees. In the other minor seedlots a single-row plot of 15 trees was established.

Height and diameter

Height of all trees was measured using a telescopic height pole and diameter over bark was measured at 0.15 m above ground with callipers. Height was measured in December 1990 and March 1991 and both height and diameter every month from May 1991 to May 1992.

Relative height (R_h) and diameter (R_d) growth were calculated for the period between measurements as:

$$R_x = (\ln(x_2) - \ln(x_1))/t_2 - t_1$$

where x_2 and x_1 are either height (m) or diameter (cm) at time t_2 and t_1 respectively.

Leaf area index

In May 1992, trees in the irrigated and rainfed treatments of the major seedlots of each species were allocated to one of six size classes on the basis of diameter and height, using the formula d^2h. One tree from each size class was selected for leaf area determination. Two trees were chosen from the buffer zone in each replicate. The size classes taken from each replicate were assigned randomly. Diameter over bark at 0.15 m and 1.3 m and height were measured for each tree. The foliage was removed and specific leaf area measured for a subsample of leaves on the basis of oven-dry weight at 80 °C. The remaining leaves were similarly dried. The leaf area of each tree was the product of total leaf dry weight and specific leaf area. Linear regression relationships were derived between basal area at 0.15 and 1.3 m and leaf area. Leaf area index was calculated from basal area at 0.15 m in the growth plots, including those of the minor seedlots, at each measurement time.

Results

Height and diameter

There were differences in height and diameter between seedlots and treatments when irrigation commenced in November 1991. By May 1992 the ranking of seedlots within treatments was unchanged but for all seedlots the increase in both height and diameter was greater in the irrigated than rainfed treatments. The ranking of seedlots and treatments in November 1991 and May 1992 are detailed for height in Table 2 and diameter in Table 3.

Table 2. Mean height (m) at the commencement of irrigation in November 1991 and at the end of the second growing season (May 1992) for irrigated and rainfed treatments of major and minor seedlots.

Treatment	Measurement date	King Is. *E. globulus*	Forest resources *E. nitens*	Rheban *E. globulus*	Barrington Tops *E. nitens*
Irrigated	November 1991	1.4	1.2	1.6	0.8
Rainfed	November 1991	1.7	1.2	1.5	0.7
Irrigated	May 1992	4.0	2.8	4.1	1.6
Rainfed	May 1992	4.0	2.5	3.4	1.2

Table 3. Mean diameter at 0.15 m (cm) at the commencement of irrigation in November 1991 and at the end of the second growing season (May 1992) for irrigated and rainfed treatments of major and minor seedlots.

Treatment	Measurement date	King Is. *E. globulus*	Forest resources *E. nitens*	Rheban *E. globulus*	Barrington Tops *E. nitens*
Irrigated	November 1991	2.8	2.7	3.3	1.5
Rainfed	November 1991	3.2	2.7	2.9	1.3
Irrigated	May 1992	6.5	5.6	7.3	3.0
Rainfed	May 1992	6.1	5.2	5.7	2.4

Leaf area and leaf area index

Leaf area was strongly correlated with basal area at 0.15 m, and coefficients of determination (r^2) ranged from 92 to 95% (Table 4). Species rather than treatment determined the slope and y-intercept of the relationships. Irrigation increased the slope but only from 0.71 to 0.79 in *E. globulus* and from 0.52 to 0.55 in *E. nitens* (Table 4). The y-intercept was slightly more negative in the irrigated than the rainfed plots (Table 4). Values of r^2 were also high for relationships between leaf area and basal area at 1.3 m except for rainfed *E. nitens* (77%). The y-intercepts were all greater than zero while the slopes were 1.17 and 0.97 for irrigated and rainfed *E. globulus* respectively. The slope was higher for rainfed (1.29) than irrigated *E. nitens* (0.81).

By age 21 months (May 1992), the irrigated plots of all seedlots had a higher leaf area index (L) than that of the corresponding rainfed plots. L was highest (4.2) in the irrigated plot of the Rheban seedlot of *E. globulus*. Of the major seedlots both the irrigated and rainfed plots of *E. globulus* had higher L than the corresponding plots of *E. nitens* (May 1992, Fig. 1b). At the same time, leaf area indices of the irrigated and rainfed Barrington Tops seedlot of *E. nitens* were only 0.71 and 0.24 respectively.

If the development of L during the second growing season is considered in relation to the major seedlots, differences between treatments were small at the commencement of irrigation. L was less than 0.4 and apparently highest in rainfed *E. globulus* (November 1991, Fig 1b). By February 1992 L of irrigated *E. globulus* was 1.96 and had moved ahead of rainfed *E. globulus*. During the same period L of irrigated and rainfed *E. nitens* increased to 10.03 and 0.68 respectively. This order of treatments and species was then maintained for the remainder of the season.

Between 8 January and 12 February 1992 the rate of increase in L of the rainfed treatments slowed dramatically compared to the irrigated controls. In *E. globulus* L increased by 0.57 and 0.17 in the irrigated and rainfed plots respectively, and in *E. nitens* by 0.32 and 0.03 respectively. This marked slowing in the increase of L coincided with the second stress cycle. Deficits under the rainfed treatments were greater than 90 mm by the end of this period (White et al. these proceedings) and pre-dawn water potential (ψ_{max}) had fallen to -1.3 and -2.0 MPa in *E. globulus* (R) and *E. nitens* (R) respectively (Fig. 1a). The earlier stress cycle, during which ψ_{max} only dropped to -0.6 MPa had little impact on increases in L. These were 0.21 for the rainfed treatment of both species and 0.22 and 0.23 respectively for irrigated *E. nitens* and *E. globulus*.

Table 4. Slopes, intercepts and coefficients of determination (r^2) values for relationships between basal area at 0.15 m (1.3 m) above ground (cm^2) and leaf area (m^2), by species and treatment.

Treatment Species	Irrigated *E. globulus*	Rainfed *E. globulus*	Irrigated *E. nitens*	Rainfed *E. nitens*
Intercept	−5.38 (1.93)	−3.61 (5.66)	−2.2 (3.72)	−1.58 (3.48)
Slope	0.79 (1.17)	0.71 (0.97)	0.55 (0.81)	0.53 (1.29)
r^2	0.92 (0.95)	0.95 (97)	0.95 (0.77)	0.95 (0.92)

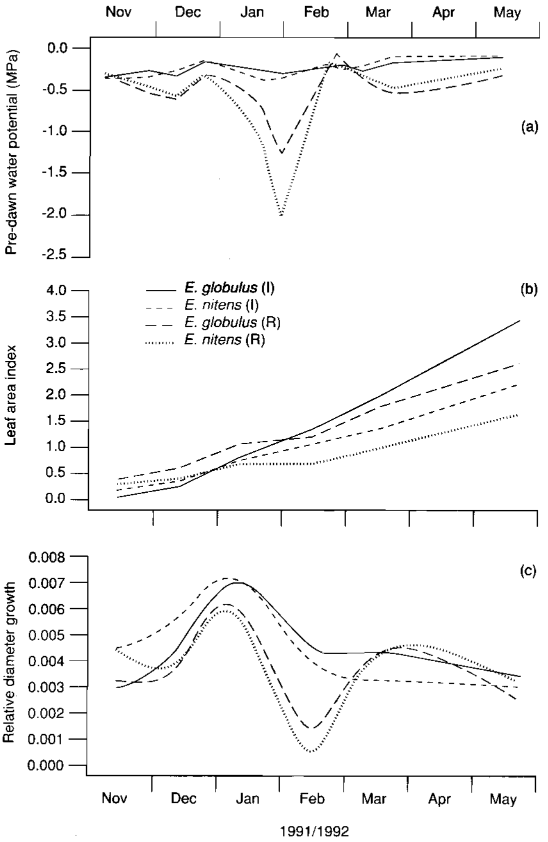

Fig. 1. a) Pre-dawn water potential (ψ_{max}), b) leaf area index (L) and c) relative diameter growth (R_d) of irrigated and rainfed *E. globulus* and *E. nitens* between November 1991 and May 1992.

Relative diameter (R_d) and height (R_h) growth

The seasonal pattern of R_d was similar to that of L (Fig. 1b, c). This was to be expected as L was well defined by diameter squared (basal area). During the first stress cycle in December 1991 R_d was 0.007 in irrigated and approximately 0.006 in the rainfed treatments of both species. No significant effect of either species or treatment was apparent in R_d ($p<0.05$). Between 8 January and 12 February 1992 severe water stress significantly reduced R_d of both species $p<0.05$). The effect of water stress overshadowed differences between species, which were not significant. Following irrigation of the rainfed plots at the end of this cycle R_d increased rapidly (Fig. 1c).

Changes in R_h were less well defined than for R_d. During the second stress cycle, severe water stress had no significant effect on R_h within species ($p<0.05$). R_h was significantly greater in irrigated *E. globulus* than rainfed *E. nitens* (Fig. 2).

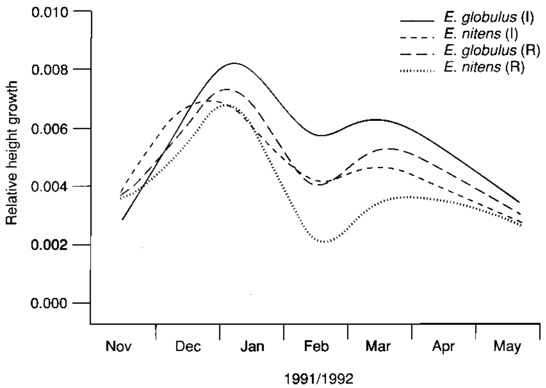

Fig. 2. Relative height growth (R_h) of irrigated and rainfed *E. globulus* and *E. nitens* between November 1991 and May 1992.

Discussion

There were marked differences between the growth of the *E. nitens* seedlots before and after irrigation (Tables 2, 3). The Barrington Tops provenance from the wet summer/dry winter environment of northern New South Wales performed poorly at this site though in relative terms there was a large response to irrigation. The Rheban provenance of *E. globulus*, which is adapted to the driest part of the range of this species, performed as well as the King Island seedlot from the wetter end of its range. No consistent pattern in R_h or R_d was observed prior to irrigation but under severe water stress the rate of increase of diameter was up to five times greater in the irrigated control compared to the rainfed treatments. Differences in height growth under severe water stress were less clearly defined.

Basal area at 0.15 m and 1.3 m above ground explained 92–95% and 77–97% respectively of the variation in leaf area for both species and treatments. Relationships between leaf area and basal area at 1.3 m (or sapwood area if heartwood is present) have been developed for other eucalypt species and sites (Brack et al. 1985; Beadle and Mummery 1990) but together these r^2 values (Table 4) are better than those obtained previously. Beadle and Mummery (1990) also showed that the slope of this relationship decreased with time during canopy development for a similar seedlot of *E. nitens* which had not been drought stressed (it was 0.87 at age 2 years compared to 0.81 for irrigated *E. nitens* in this study). In spite of the more advanced canopy development, *E. globulus* had a higher slope than *E. nitens* when the dependent variable was basal area at 0.15 m (Table 4).

Further analysis of this difference will be required to resolve whether *E. globulus* requires less sapwood than *E. nitens* per unit of water transpired. The higher stomatal conductance consistently measured in *E. nitens* (I) compared to *E. globulus* (I) (White et al. these proceedings) indicates that the latter transpires less water per unit leaf area in the absence of water stress. The slope of the relationship for basal area at 0.15 m was also slightly, but not significantly, higher for the irrigated controls. This indicates that high soil water availability slightly increased the capacity to support leaf area per unit of sapwood area. The slopes, however, were reversed in rainfed *E. nitens* for basal area at 1.3 m.

Water stress significantly reduced the development of leaf area in the rainfed treatments compared to the irrigated controls (Fig. 1b). Slower rates of leaf expansion and leaf initiation are early indicators of water stress in many herbaceous and woody species including *Eucalyptus* (Borralho et al. 1987; Metcalfe et al. 1989, 1990). Recent studies of the growth rates of individual leaves of *Populus trichocarpa* and *P. deltoides* in response to water stress have suggested that the cellular basis for this reduction in leaf growth is not reduced turgor pressure but rather decreased cell wall extensibility (Roden et al. 1990).

The development of severe water stress significantly reduced diameter growth and leaf area development between 8 January and 12 February 1992 (Fig. 1b, c). The response of both species to stress was immediate. Gazarino et al. (1990) reported that leaf area index (L) in 2-year-old irrigated and rainfed *E. globulus* growing in Portugal was 2.22 and 1.55 respectively compared to irrigated (3.40) and rainfed *E. globulus* (2.64) after two growing seasons in this study. The apparently higher L after 2 years at the Tasmanian site is probably due to the higher stocking (1430 stems/ha compared to approximately 1000 stems/ha in Portugal).

In summary, in Tasmanian environments water stress can severely limit the growth of developing canopies of *E. globulus* and *E. nitens*. This effect is mediated by the combination of reduced L and stomatal conductance (White et al. these proceedings) and is more pronounced in *E. nitens* than *E. globulus*. The relative impact has not been resolved. However Araujo et al. (1989) found that the most significant effect of irrigation on growth during the first 2 years was through increased leaf area, as biomass production of *E. globulus* was closely related to L prior to canopy closure.

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Trials of Eucalypt Species and Provenances in the Eastern Region of Hainan Island

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Abstract

The results at 5 years of species and provenance trials involving 11 species and 79 provenances at Shangyong State Forest Farm, Qionghai County in eastern Hainan Island showed that growth differences among provenances within the different species were highly significant. The growth of seedlot No. 12895 of *Eucalyptus urophylla* from Mt Mandiri in Indonesia was the best of all. Differences in growth among provenances within individual species were also highly significant. The ratios of the best to worst provenances of volume per hectare for *E. urophylla*, *E. tereticornis*, *E. camaldulensis* and *E. grandis* were respectively 8.5:1, 5.9:1, 5.3:1 and 3.0:1. The growth of height, dbh and volume per hectare of *E. tereticornis*, *E. camaldulensis* and *E. grandis* were significant and negatively correlated with the latitude of native habitat while the growth of height, dbh and volume per hectare for *E. urophylla* were highly significant and negatively correlated with the altitude of native habitat. The paper identifies some species and provenances suitable for planting in eastern Hainan Island.

EUCALYPTUS is one of the main tree species planted in southern China. Most of the many species and subspecies are endemic to the Australian continent and nearby islands. A few occur naturally to the north of Australia in Papua New Guinea and on some of the islands of the eastern part of the Indonesian archipelago (Jacobs 1979). Eucalypts were introduced to China about 100 years ago, and subsequently to Hainan Island about 70 years ago. Now these have become the main tree species planted on Hainan Island, forming half the plantation area there. *Eucalyptus exserta* accounts for 97% of eucalypt plantation area, although it has a low yield (mean annual increment for volume of 7.7 m^3/ha) and poor wind-resistance, particularly in the eastern part of Hainan. Wind breakages and windfalls of *E. exserta* reach 16% after winds of force 10–12 on the Beaufort scale.

For this reason it is most important that some species and provenances with fast growth and more wind-resistance are selected for the eastern part of Hainan. The purpose of the trial was to select species and provenances suitable for planting in eastern Hainan Island by examining 11 species and 79 provenances introduced from Australia, Indonesia and other countries.

Study Site

The trial was established at Shangyong State Forest Farm of Qionghai county in eastern Hainan Island, with latitude 19°14′N, longitude 110°28′E and altitude 15 m. The Qionghai area has a tropical ocean monsoon climate. Annual mean rainfall is 2180 mm, annual average temperature 24°C, annual mean evaporation 1830 mm and annual mean relative humidity 86%. Typhoons affect Qionghai on an average of 4.3 times each year, of which an average 0.3 directly strike Qionghai, accounting for 16% of the typhoons striking Hainan Island. The soil in the site is yellow latosol with coarse gravel derived from neritic sediment. Humus content and total nitrogen in the surface layer (0–20 cm) of the soil are 0.8–1.5% and below 0.05% respectively. Gravel (>3 mm) accounts for 62% of the soil layer at a depth of 85–120 cm, forming an extremely solid horizon (Zhou and Liang 1991).

The previous woodland vegetation was a low-yielding and incomplete stand of *E. exserta*, with stand volume of 80 m^3/ha at 10 years of age.

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Materials and Methods

Eleven species comprising 78 provenances were involved in the trial. There were 15 provenances of *E. grandis*, 14 provenances of *E. camaldulensis*, 13 provenances of *E. saligna*, 15 provenances of *E. tereticornis*, seven provenances of *E. urophylla* and six provenances of *E. citriodora*. The species and provenances tested, except for the Guangzhou provenance of *E. citriodora* and the local provenance of *E. exserta* grown as controls for comparison, were provided by the Australian Tree Seed Centre, CSIRO. Details of the species and provenance locations are given in Appendix 1.

The trial was established in June 1986. A complete randomised block design was employed with 3 × 6 tree rectangular plots, with tree spacing of 1.5 × 3 m and four replications. Planting holes of 40 × 40 × 40 cm were made after full cultivation by tractor. Fertilisation was carried out by putting 2.5 kg burnt soil and 75 g NPK compound fertiliser in each hole as base fertiliser before planting. Twelve trees from each plot were measured for height, dbh etc. each year.

Analysis of variance by GENSTAT (Lane et al. 1987), Duncan's multiple range comparison and correlation analysis were carried out mainly in relation to the 5-year results from the trial.

Results and Discussions

Adaptability of species and provenances

Initial and current survival rates There were no significant differences in initial survival among provenances within species for *E. grandis*, *E. camaldulensis*, *E. citriodora*, *E. urophylla* and *E. tereticornis* respectively, while there were significant differences among provenances for *E. saligna*. Differences in survival among 11 species were highly significant: *E. camaldulensis* and *E. tereticornis* had high survival, with 98 and 95% respectively, but these figures were not significantly different from those of *E. propinqua*, *E. torelliana*, *E. exserta* and *E. resinifera* (92%). *E. saligna* and *E. paniculata* had lower survival with 79 and 77% respectively (Table 1).

There were highly significant differences in current survival among 11 species 5 years after planting. *E. saligna*, with the lowest current survival of 10%, was significantly different from all other species. *E. paniculata* had a current survival of only 37%, but *E. camaldulensis*, *E. torelliana* and *E. tereticornis* had high survival with 90, 87 and 81% respectively, not significantly different from each other, but significantly different from the other eight species (Table 1).

There were no significant differences in current survival among provenances within the same species for *E. camaldulensis* and *E. urophylla* respectively. The current survival of a low-latitude provenance of *E. camaldulensis* from Katherine, Northern Territory (seedlot 15062) was still 100%, but that of another provenance from a higher latitude in Northern Territory (Tennant Creek, seedlot 14518) had the lowest current survival, 71% among 14 provenances of *E. camaldulensis*. In seven provenances of *E. urophylla*, seedlot 12362 had the highest survival with 71%; seedlot 12895 with 69% was the second, while seedlot 14532 was the lowest with 46%.

There were highly significant differences in the current survival among provenances within species for *E. tereticornis*, *E. grandis* and *E. citriodora* respectively. Current survival of *E. tereticornis* ranged from 40 to 92%. The Victorian provenance (seedlot 13303 from high latitude) had the lowest current survival and was significantly different from the other 14 provenances of *E. tereticornis*. In general, provenances of *E. tereticornis* from lower latitudes have best current survival. The current survival of *E. grandis* provenances ranged from 37 to 69%, the lowest being seedlot 14431, followed by seedlots 13965 and 13365 both from South Africa with 39 and 40% respectively. The highest current survival of *E. citriodora* provenances was 67%, while the 'control' provenance (Guangzhou, China) was the lowest (23%) and was significantly different from other provenances of *E. citriodora*.

Provenances with current survival of more than 80% were as follows: 12 provenances of *E. camaldulensis*, nine provenances of *E. tereticornis* and one provenance of *E. torelliana*. Thirteen provenances of *E. saligna*, and the 'control' provenances of *E. exserta* and *E. citriodora* had current survival rates less than 30%. Some species and provenances had lower current survival mainly because typhoons caused trees to fall and break — for example, *E. resinifera*, *E. urophylla* and *E. citriodora*. Some species and provenances were damaged by bacterial wilt after typhoons, for example *E. saligna* and some provenances of *E. grandis*.

Wind resistance of species and provenances Typhoon surveys Nos 23 and 24 (force 10 wind on the Beaufort scale, gust force 11) in October 1988 revealed that the control provenance of *E. citriodora* was the most seriously damaged by wind among the 79 provenances tested. Breakages and 'windfall' (more than 60° of stem lean) reached 32%

Table 1. Duncan's multiple range test of initial and current survival of 11 species (95%).

Species	Initial survival rate (%)	Species	Current survival rate (%)
E. camaldulensis	98	*E. camaldulensis*	90
E. tereticornis	95	*E. torelliana*	88
E. propinqua	94	*E. tereticornis*	81
E. torelliana	94	*E. urophylla*	60
E. exserta	93	*E. grandis*	57
E. resinifera	92	*E. exserta*	56
E. urophylla	87	*E. citriodora*	52
E. grandis	86	*E. propinqua*	48
E. citriodora	86	*E. resinifera*	45
E. saligna	79	*E. paniculata*	37
E. paniculata	77	*E. saligna*	10
	$F = 6.3 > F(0.01) = 3.0$		$F = 18.1 > F(0.01) = 3.0$

and windburn 40%. Second was *E. resinifera* (seedlot 12418) with 28% breakages and falls and 42% windburn, and third *E. paniculata* (seedlot 13657) with 12 and 32% respectively. Windburn among seven provenances of *E. urophylla* was most serious in seedlot 12898 with 13% of breakages and falls, and 21% windburn, but seedlot 12895 was not seriously burnt (3%). Windfall and windburn for 13 provenances of *E. saligna* averaged 4.5 and 22% respectively, seedlot 14526 being most seriously affected with 9 and 39% respectively. The greatest windburn among 15 provenances of *E. tereticornis* was only 7%. *E. torelliana* also had little windburn (3.3%). There were no breakages and falls in 14 provenances of *E. camaldulensis*, leaves and young branches being only slightly damaged. The three species *E. camaldulensis*, *E. tereticornis* and *E. torelliana* had good current survival as a consquence of their tolerance to typhoons.

Increment for height, dbh and volume

Since *E. saligna*, *E. resinifera* and *E. paniculata* had low current survival, the comparisons of growth were restricted to the following six species with a total of 60 provenances: *E. camaldulensis*, *E. tereticornis*, *E. urophylla*, *E. grandis*, *E. exserta* and *E. citriodora*. The control provenances of *E. exserta* and *E. citriodora* were included for comparison only, because of their low survival.

There were highly significant differences in height, dbh and volume among 60 provenances. Seedlot 12895 of *E. urophylla* was the best with height, dbh and stand volume of 13.8 m, 12.5 cm and 128 m^3/ha respectively. Stand volume was notably superior to that of other provenances. Seedlot 15089 of *E. urophylla* was second in stand volume with 92 m^3/ha, but the following provenances were not significantly different from seedlot 15089 in volume: 12362, 14532 and 12898 of *E. urophylla*, seedlots 13431, 14420, 14210 and 14849 of *E. grandis*, seedlot 14918 of *E. camaldulensis*, and seedlots 13418, 13541 and 13443 of *E. tereticornis*.

Analysis of variance showed that there were highly significant differences in height, dbh and volume among 14 provenances of *E. camaldulensis*. The best provenance on height, dbh and volume was seedlot 14918 from Laura, north Queensland. It was especially superior to the other provenances in dbh and volume (Table 2). Its height of 12.4 m, dbh of 8.7 cm and volume of 78 m^3/ha were respectively 1.5, 1.6 and 5.3 times that of the worst provenance from Northern Territory (seedlot 14518). Laura provenance had the same good performance in Zhangzhou in subtropical Fujian (Bai 1988). Another Queensland provenance from Mt Carbine (seedlot 14917) was second in height, dbh and volume. Katherine provenance from Northern Territory (seedlot 15062) was the third for dbh and volume, while Petford provenance (seedlot 14847) from Queensland, which has performanced well in other countries, was only average for height, dbh and volume.

E. camaldulensis provenances commonly showed 'spike top' of the crown when surveyed in March 1989. There were highly significant differences in the incidence of spike top among provenances, $F_0(5.7) \gtrsim F_{0.01}(2.63)$. Seedlots 14518 and 13933 were most affected with incidence of 60 and 55% respectively. Seedlots 14918 and 14917 had few affected

Table 2. Duncan's multiple range test of height, dbh and volume per hectare[1] of 14 provenances of *E. camaldulensis* at 5 years of age

Seedlot No.	Height (m)	Seedlot No.	Dbh (cm)	Seedlot No.	Volume (m^3/ha)
14918	12.4	14918	8.7	14918	78
14917	12.1	14917	7.7	14917	58
15052	11.3	15062	7.3	15062	53
13663	11.2	15052	7.3	15052	49
12187	11.2	13663	7.1	12187	47
15062	11.1	12187	7.1	13663	46
14847	10.9	15050	6.7	15050	38
15050	10.6	13941	6.5	14847	38
13941	10.3	14847	6.3	13941	35
14540	10.2	14540	6.3	14540	31
14106	10.0	13933	6.1	15049	27
13933	9.8	15049	6.0	14106	25
15049	9.1	14106	5.8	13933	25
14518	8.4	14518	5.3	14518	15
F = 10.4 > F(0.01) = 2.6		F = 10.3 > F(0.01) = 2.6		F = 12.1 > F(0.01) = 2.6	

[1] volume = $0.087266462D^2H$

trees. The spike top of *E. camaldulensis* was related to two typhoons in October 1988 which caused the leaves to drop and young branches to break off. Although damaged trees sprouted, there was some influence upon their subsequent growth. The 5-year results also clearly showed that seedlots 14918 and 14917 with few spike tops were the best for height, dbh and volume, while seedlots 14518 and 13933 with the most frequent spike tops were the worst for growth in volume.

Differences among 15 provenances of *E. tereticornis* for height, dbh and volume per hectare were highly significant. The tallest provenances were Kennedy River (13443) and Mt Garnet (13544), both from Queensland, at 12.7 and 12.6 m respectively. Although seedlot 13418 from Papua New Guinea was significantly shorter than the above two provenances, its dbh and volume were best at 9.1 cm and 74 m^3/ha respectively. Seedlot 13303 from high latitude in Victoria was the poorest in height, dbh and volume (8.5 m, 6.2 cm and 12.6 m^3/ha respectively), differing significantly in height and volume from all other provenances (see Table 3). The height, dbh and volume per hectare of the best provenance were respectively 1.5, 1.4 and 5.9 times of that of the worst provenance (seedlot No.13303).

Differences in height, dbh and volume among seven provenances of *E. urophylla* were highly significant (Table 4). Mt Mandiri provenance (12895) from a low altitude in Indonesia was the best for height, dbh and volume with 13.8 m, 12.5 cm and 128 m^3/ha respectively, being especially superior in volume to the other six provenances. Another two provenances, Mt Lewotobi (14532) and Mt Egon (15089) from lower altitude, were the second and the third respectively in height and dbh. Seedlot 10140, from the highest altitude of seven Timor provenances, was the worst performer on height, dbh and volume with only 7.1 m, 6.3 cm and 15 m^3/ha — significantly below the other six provenances. Timor provenance (13828) was the second worst performer. The height, dbh and volume of the best provenance (12895) was respectively 1.9, 2.0 and 8.5 times that of provenance 10140. The current survival rates of seven provenances of *E. urophylla* ranged from 46 to 71%. All had little wind resistance, but provenance 12895 with the most wind-resistance, high current survival and the best growth performance could be best to develop for this region.

Fifteen provenances of *E. grandis* showed highly significant differences in height and volume, and significant differences in dbh. For height, two Ravenshoe (Queensland) provenances (14420 and 14210) were better than the other provenances, with 13.2 m and 12.3 m respectively. They were respectively 1.34 and 1.26 times taller than the worst provenance, from South Africa (13365). Lewis (Queensland) provenance (13431) was the best for

Table 3. Duncan's multiple range test for height, dbh and volume per hectare of 15 provenances of *E. tereticornis* at 5 years of age.

Seedlot No.	Height (m)	Seedlot No.	Dbh (cm)	Seedlot No.	Volume (m^3/ha)
13443	12.7	13418	9.0	13418	74
13544	12.7	12965	8.9	13541	69
13319	11.9	13541	8.6	13443	69
13541	11.8	13544	8.5	13544	64
12965	11.6	13319	8.4	14424	63
13418	11.5	14424	8.3	12965	63
14424	11.2	14115	8.3	13319	61
13442	11.0	13443	8.2	13446	56
13446	10.8	13994	8.2	13994	56
13994	10.6	13446	7.9	14115	53
14115	10.3	13442	8.0	13442	53
13350	10.3	13350	7.8	13350	41
13304	9.8	13307	7.5	13304	36
13307	9.8	13304	7.3	13307	34
13303	8.5	13303	6.2	13303	13
F = 9.3 > F(0.1) = 2.55		F = 2.8 > F(0.01) = 2.55		F = 5.0 > F(0.01) = 2.55	

Table 4. Duncan's multiple range test of height, dbh and volume per hectare of seven provenances of *E. urophylla* at 5 years of age.

Seedlot No.	Height (m)	Seedlot No.	Dbh (cm)	Seedlot No.	Volume (m^3/ha)
12895	13.8	12895	12.5	12895	128
14532	13.8	14532	12.4	15089	92
15089	13.3	15089	11.8	12362	90
12362	12.0	12898	11.2	14532	84
12898	11.9	12362	11.1	12898	70
13828	10.9	13828	10.4	13828	66
10140	7.1	10140	6.3	10140	15
F = 29.5 > F(0.01) = 4.01		F = 9.5 > F(0.01) = 4.01		F = 8.6 > F(0.01) = 4.01	

dbh and volume, with 10.8 cm and 82 m^3/ha, which respectively were 1.5 times the worst provenance (14519) for dbh and 3 times the worst provenance (13365) for volume per hectare (Table 5).

The six provenances of *E. citriodora* had only modest volume per hectare at 5 years of age (mean volume 39 m^3/ha). The best one was seedlot 14703 at 60 m^3/ha, and the poorest just 27 m^3/ha. The reason the control provenance had such low volume per hectare was that its current survival was very low (survival at 2 years was 67%, but at 5 years only 23%).

The best provenance of *E. exserta* on volume at 5 years of age was seedlot 13282 with 64 m^3/ha (current survival 73%). By contrast the local control provenance was so susceptible to windfall and windbreak that its current survival was only 27% and volume only 44 m^3. Another provenance, 14864, had poor growth with volume per hectare of only 29 m^3 in spite of a current survival rate of 69%.

Table 5. Duncan's multiple range test of height, DBH and volume per hectare of 15 provenances of *E. grandis* at 5 years of age.

Seedlot No.	Height (m)	Seedlot No.	Dbh (cm)	Seedlot No.	Volume (m^3/ha)
14420	13.2	13431	10.8	13431	82
14210	12.3	14420	10.3	14420	79
13431	12.1	14431	10.2	14210	72
14849	11.9	14210	10.2	14849	68
14431	11.6	14849	10.1	13019	54
13020	11.3	14838	9.8	14838	53
14861	11.3	14393	9.8	14861	49
14838	11.2	13965	9.4	13020	49
14393	11.2	14860	9.2	14393	44
13965	11.2	13020	9.1	14509	44
13019	10.9	14861	8.9	14860	41
14860	10.4	13019	8.9	14431	40
14509	10.3	13365	8.6	13965	35
14519	9.9	14509	8.5	14519	27
13365	9.8	14519	7.5	13365	27
$F = 4.6 > F(0.01) = 2.54$		$F = 2.5 > F(0.01) = 1.93$		$F = 6.1 > F(0.01) = 2.54$	

Correlation analysis

The height, dbh, volume and current survival rate of provenances for *E. camaldulensis*, *E. tereticornis*, *E. grandis* and *E. urophylla* were subjected to correlation analysis with latitudes, longitudes and altitudes of provenances (Table 6). The results showed that the height, dbh and volume of provenances of *E. camaldulensis*, *E. tereticornis* and *E. grandis* had significant or highly significant and negative correlations with the latitudes of provenances but no significant (*E. camaldulensis* and *E. tereticornis*) or significant (*E. grandis*) correlations with the longitude and altitude of provenances. The height, dbh and volume of *E. urophylla* provenances had highly significant and negative correlations with altitude of provenances and no significant correlations with latitudes and longitudes of provenances. The current survival of other species had no significant correlations with latitude, longitude or altitude of provenances, except the current survival of *E. tereticornis* which had highly significant and negative correlations with latitude of provenances. Therefore, the low-latitude provenances of *E. camaldulensis*, *E. tereticornis* and *E. grandis*, and low-altitude provenances of *E. urophylla* should be selected for developing in the eastern part of Hainan Island.

Conclusions

- In the region of eastern Hainan Ishand with serious typhoons, the species tested showed important differences. *E. camaldulensis*, *E. tereticornis* and *E. torelliana* were more wind-resistant than the other species, and thus had higher current survival. *E. resinifera*, *E. propinqua*, some provenances of *E. urophylla* and *E. citriodora* provenances were susceptible to windfall and windbreak and thus had lower current survival. In addition to typhoon effects, young trees of *E. saligna* and some *E. grandis* provenances were easily damaged by bacterial wilt, leading to lower survival particularly in *E. saligna* (mean current survival of 10%).
- There were highly significant differences in height, dbh and volume per hectare among provenances within the various species. Seedlot 12895 of *E. urophylla* was the best of all provenances tested for height, dbh and volume. Laura provenance from Queensland (14918) was the best of 14 provenances of *E. camaldulensis*. Its dbh and volume were significantly superior to the remaining 13 provenances and its volume per hectare was 5.3 times better than the worst provenance (14518). The best dbh and volume per hectare among the 15 provenances of *E.*

Table 6. Correlations of height, dbh, volume and current survival with geographic position of provenances.

Species	Items	Latitude	Longitude	Altitude	r_a*
E. camaldulensis	Height	−0.73*	0.29	0.05	$r_{0.05}$ = 0.53
	Dbh	−0.67**	0.27	−0.04	$r_{0.01}$ = 0.66
	Volume	−0.64*	0.35	−0.01	
	Survival	−0.52	0.34	0.31	
E. tereticornis	Height	−0.589*	0.01	0.09	$r_{0.05}$ = 0.51
	Dbh	−0.73**	−0.04	0.44	$r_{0.01}$ = 0.64
	Volume	−0.77**	−0.13	0.31	
	Survival	−0.74**	−0.16	0.27	
E. urophylla	Height	−0.35	−0.65	−0.99**	$r_{0.05}$ = 0.76
	Dbh	−0.28	−0.62	−0.97**	$r_{0.01}$ = 0.87
	Volume	−0.34	−0.47	−0.88**	
	Survival	0.15	0.53	0.22	
E. grandis	Height	−0.71*	−0.59	0.569	$r_{0.05}$ = 0.60
	Dbh	−0.80**	−0.65*	0.68*	$r_{0.01}$ = 0.74
	Volume	−0.72*	−0.63*	0.58*	
	Survival	−0.12	−0.15	0.09	

*r_a = critical values for the correlation coefficients at the 5 and 1% significance levels.

tereticornis at 5 years of age was provenance 13418 from Papua New Guinea — respectively 1.4 and 5.9 times those of the worst provenance (13303). Height, dbh and volume per hectare at 5 years of age for seedlot 12895 of *E. urophylla*, were 1.9, 2.0 and 8.5 times that of the worst provenance (10140). The volume of Mt Lewis provenance (13431) of *E. grandis* was 3.0 times that of the worst provenance (13365). Seedlot 14918 of *E. camaldulensis* and seedlots 13148, 13541 and 13443 of *E. tereticornis* are suitable for planting in the eastern part of Hainan Island which experiences serious typhoons. Seedlot 12895 of *E. urophylla* also could be used in this region. In areas without serious typhoons, seedlots 12895, 15089 and 14532 of *E. urophylla*, and seedlots 13431 and 14420 of *E. grandis* could be used extensively.

- The height, dbh and volume for provenances of *E. tereticornis*, *E. camaldulensis* and *E. grandis* had significant negative correlations with latitude of provenances. The height, dbh and volume of provenances of *E. urophylla* had highly significant and negative correlations with altitude of provenances. Therefore, the low-latitude provenances of *E. camaldulensis*, *E. tereticornis* and *E. grandis*, and low-altitude provenances of *E. urophylla* should be selected for development and use in the eastern part of Hainan Island.

Acknowledgments

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Appendix 1. Details of the seed sources of 78 provenances.

Expt No.	Seedlot No.	Species	Locality	Lat. (°′S)	Long. (°′E)	Alt. (m)
1	14860	*E. grandis*	EMBRAPA, Brazil		100 00	
2	14849	″	NE Atherton, Qld	17 06	145 36	1050
3	14838	″	WNW Cardwell, Qld	18 14	143 00	620
4	14519	″	Mt George, Taree, NSW	31 50	152 01	230
5	13019	″	NW of Coffs Harbour, NSW	30 13	153 02	135
6	14509	″	Urbenville, NSW	28 31	152 30	600
7	14431	″	Belthorpe St Forest, Qld	26 52	152 42	500
8	14420	″	12 km S Ravenshoe, Qld	17 42	145 28	860
9	14393	″	25–36 km SE Mareeba, Qld	17 06	145 33	900
10	14210	″	27 km SE of Ravenshoe, Qld	17 50	145 33	720
11	13965	″	Seed Orchard, S Africa			
12	13431	″	Mt Lewis, N Qld	16 36	145 16	840
13	14861	″	EMBRAPA, Brazil		100 00	
14	13365	″	Seed Orchard, S Africa		100 00	
15	13020	″	NNW Coffs Harbour, NSW	30 10	153 01	98
16	13663	*E. camaldulensis*	Wrotham Park, Qld	16 48	144 18	230
17	15062	″	W of Katherine, NT	14 23	132 21	200
18	14518	″	Tennant Creek, NT	19 34	134 13	335
19	13941	″	Victoria River, NT	16 50	125 32	250
21	15050	″	Gibb River, WA	16 30	126 10	400
22	14540	″	Pentecost River, WA	15 48	127 53	10
23	13933	″	N Fitzroy Crossing, WA	18 06	125 42	110
24	15049	″	Bullock Creek, Qld	20 46	143 55	400
25	14918	″	Laura, W Qld	15 34	144 27	90
26	14917	″	NW of Mt Carbine, W Qld	16 22	144 43	400
27	14847	″	Emu Creek Petford, Qld	17 10	145 15	500
28	14106	″	Gilbert River, N Qld	18 00	143 00	150
29	12187	″	8 km W Irvinebank, Qld	17 24	145 09	680
30	15011	*E. saligna*	Kroombit Tops, Monto, Qld	24 51	151 01	730
31	15054	″	SE of Tamworth, NSW	31 31	151 31	1100
32	14527	″	Barrington Tops, NSW	21 00	151 50	450
33	14526	″	Glenn Innes, NSW	29 47	152 09	1030
34	14524	″	Armidale, NSW	30 39	152 09	900
35	14508	″	Urbenville, NSW	28 34	152 30	600
36	14507	″	Chaelundi SF, NSW	30 13	152 46	640
37	14435	″	Kenilworth SF, Qld	26 38	152 33	600
38	14429	″	Blackdown Tableland, Qld	23 50	149 05	780
39	13340	″	NE of Warwick, Qld	27 58	152 12	850
40	13263	″	Consuelo Tablelands, Qld	24 57	148 03	1090
41	13029	″	NE of Bulahdelah, NSW	32 22	100 28	80
42	13015	″	N of Nelligen, NSW	35 33	150 11	30
43	13282	*E. exserta*	N of Marlborough, Qld	22 40	149 54	30
44	14852	*E. citriodora*	Mt Garnet, Qld	17 41	145 07	850
45	14851	″	Herberton, Qld	17 23	145 23	1000
46	14850	″	Irvinebank, Qld	17 26	145 12	900
47	14703	″	W of Mt Carbine, Qld	16 18	145 05	940
48	13472	″	ESE of Mt Molloy, Qld	16 42	145 23	600
49	14864	*E. exserta*	Herberton area, Qld	17 25	145 23	950
50	13657	*E. paniculata*	SW of Nowra, NSW	35 00	150 30	120
52	15089	*E. urophylla*	Mt Egon, Flores, Indonesia	8 38	122 27	500
53	14532	″	Mt Lewotobi, Indonesia	8 31	122 45	398
54	13828	″	Mt Mutis, Indonesia	10 35	123 35	1200
55	12898	″	Mt Boleng, Indonesia	8 21	123 15	890
56	12362	″	S Dili, E Timor, Indonesia	8 37	125 38	1100
57	10140	″	E of Hato Bulico, Indonesia	8 53	125 32	2100
58	12895	″	Mt Mandiri, Indonesia	8 15	122 58	415

Appendix 1. (continued)

Expt No.	Seedlot No.	Species	Locality	Lat. (° 'S)	Long. (° 'E)	Alt (m)
61	12411	*E. resinifera*	14.5 km S Ravenshoe, Qld	17 42	145 28	940
62	12418	"	Mt Lewis, Qld	16 36	145 17	1100
63	13321	*E. propinqua*	W of Woolgoolga, NSW	30 04	153 06	200
64	12018	"	Kangaroo Creek SF, NSW	30 07	152 46	335
65	14130	*E. torelliana*	SSW of Kuranda, Qld	16 53	145 36	420
66	ck—ex	*E. exserta*	Qionghai, Hainan, China	19 06	110 24	30
67	ck—ci	*E. citriodora*	Guangzhou, Guangdong, China	23 08	113 19	60
68	13418	*E. tereticornis*	Sirinumu Sogeri Plat, PNG	9 30	147 26	580
69	13443	"	Kennedy River,Qld	15 26	144 11	60
70	14115	"	S of Helenvale, N Qld	15 46	145 14	14
71	13442	"	N of Mareeba, Qld	16 55	145 25	380
72	14424	"	Ravenshoe, Qld	17 39	145 21	700
73	12965	"	SW of Mt Garnet, Qld	18 30	144 45	800
74	13446	"	N of Cardwell, Qld	18 16	146 00	40
75	13994	"	Crediton SF, Qld	21 00	148 30	700
76	13544	"	40 km N of Gladstone, Qld	23 44	151 01	10
77	13541	"	9 km SW of Imbil, Qld	26 30	152 37	100
78	13350	"	S of Urbenville, NSW	28 36	152 24	400
79	13319	"	N of Woolgoolga, NSW	29 55	153 12	30
80	13307	"	Windsor, NSW	33 32	150 50	100
81	13304	"	Nerrigundah, NSW	36 13	149 48	80
82	13303	"	Sale, Vic	38 07	147 04	10

Research on Species and Provenances of *Eucalyptus* in Tropical Savanna of Southwest Hainan Island

Wu Kunming, Wu Juying and Xu Jianmin*

Abstract

A species and provenance trial of *Eucalyptus* was established in coastal tropical savanna in southwestern Hainan Island in August 1986. Results from the sixth year showed standing volumes to differ significantly between species. *E. tereticornis* and *E. camaldulensis* recorded the best performance and showed great promise for larger scale planting. Volume also differed significantly between provenances of *E. tereticornis* and *E. camaldulensis*; volume of the best provenance of each species was 153 and 138% higher than that of *E. exserta*, respectively. The trial results also provided a useful basis for selecting superior species/provenances to be planted in areas where climatic conditions are similar to those of the trial area.

THIS trial is part of ACIAR Project 8848, *Introduction and cultivation experiments of Australian broadleaved tree species*. Trial results at 16 months, 3 years and 6 years after planting are reported; the results for *Eucalyptus camaldulensis* and *E. tereticornis* have guided seed imports by Guangdong Province. Over 6 years the ranking of tree species and provenances kept changing — in particular provenances of *E. camaldulensis* changed greatly between the first 3 years and the second 3 years after planting. Differences in survival and standing volume between species and provenances were significant.

The main object of the trial was to select eucalypt species and provenances with high productivity, suitable for planting in areas with climatic conditions similar to those at the trial sites, leading to increased pulp/paper production and other economic benefits of afforestation.

Materials and Methods

The experimental site is located at Lingtou, 8 km W of Jianfengling town, Ledong County, Hainan Island Province (18°42′N, 108°52′E) at 14 m altitude about 1 km from the sea. Previous vegetation mainly consisted of *Heteropogon contortus* and thorn shrubs.

Annual mean temperature is 25°C; mean monthly temperature is 20°C/29°C in January and July respectively. The highest temperature on record is 35.4°C and the lowest is 5.6°C. Mean annual rainfall is 1083 mm; November to May is dry with monthly rainfall below 30 mm. The sandy dry red soil is derived from granite and contains 17% physical clay (<0.01 mm) and 0.58% humus over 0–40 cm depth and has a pH of 6.6. The average frequency of typhoons that may cause damage is 2.7 per year with a wind-affected standard of 26°. The site is flat and categorised as tropical savanna.

Sixteen species and 56 provenances were tested (Appendix 1). The trial was planted on 13–14 August 1986; the experimental design was RCB with four replicates. The rectangular plots contained 20 trees (5 × 4) at 2 × 2 m spacing. Height and diameter at breast height (dbh) of all trees were measured every year. The effect of a Beaufort force 11 typhoon on the trial was examined in the fourth year. Canopy width and stem height below tree branches were measured and damage from a force 12 typhoon was investigated in the fifth year. Stem form was estimated and damage from a force 11 typhoon was surveyed in the sixth year.

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Data on standing volume of provenances of *E. camaldulensis* and *E. tereticornis* at year 6 were examined by multiple comparisons with analysis of variance and the S_R test. The standing volume of the best provenances and of those species with survival exceeding 50% were used to compare tree species. Volume was calculated with the formula:

$$V = 0.33\ HD_{1.3}^2$$

Result and Discussion

Survival

Survival differed significantly between species when tested using the provenance in each species with the highest survival rate. Due to intolerance of the dry and hot climatic conditions experienced for 7–8 months each year, such species as *E. grandis*, *E. saligna*, *E. cloeziana*, *E. propinqua*, *E. paniculata* and *E. pellita* showed a progressive decrease in survival and almost all were dead three years after planting. Thirteen provenances of *E. camaldulensis* had a survival of 78–100%, which is higher than that of *E. exserta* (65%), but the differences between provenances were not significant. The survival of 10 provenances of *E. tereticornis* ranged from 25 to 94%, and six among these were better than *E. exserta*. Differences between provenances of *E. tereticornis* were significant.

The species and provenances of *Eucalyptus* from dry Australian environments had very high survival, for example *E. camaldulensis* from Gilbert River (94%), from Katherine (100%) and from Petford (94%), and provenances of *E. tereticornis* from Kennedy River (94%) and from Mareeba (80%). There were only six species and 27 provenances whose survival exceeded 50% in the 6-year-old plantation (Appendix 1).

Standing Volume per Unit Area

Because the ranking of results for different species and provenances on trial varied between survival, tree height and dbh, it is difficult to identify the best and worst species and provenances by a single attribute. The species and provenances that are mainly used for timber production will be reported using standing volume per hectare calculated from tree height and dbh.

Tree species

The differences between species in standing volume were significant. Multiple comparisons of standing volume of species showed that there was no significant difference between *E. tereticornis* (13443) and *E. camaldulensis* (14106); both were good performers with rapid growth. The difference between these two and four other species was highly significant and their growth rates were 153 and 139% respectively greater than that of *E. exserta* (Table 1).

Table 1. Multiple comparisons of standing volume at 6 years of age.

Seedlot	Species	Standing volume (m^3/ha)
13443	*E. tereticornis*	96
14106	*E. camaldulensis*	90
F_2 in Hainan	*E. ABL No.12*	39
CK	*E. exserta*	38
F_2 in Leizhou	*E. Leizhou* No. 1	32
14130	*E. torelliana*	11

$SR_{0.01}$

The ranking of species for volume production changed greatly between years 3 and 6. *E. camaldulensis* (14106) was down to second in the fourth year from first in the third year, being replaced by *E. tereticornis* (13443). *E. exserta* (CK) was down to fourth in the sixth year (formerly third), being replaced by *E.* ABL No.12. *E.* Leizhou No.1 was down to fifth in the sixth year from fourth in the third year. *E. tereticornis* (13443) and *E. camaldulensis* (14106) have characteristics of fast growth and drought endurance as well as potential for good stem form and wind resistance. Neither had branches broken except when stems were cut down twice by force 11 typhoons and once by a force 12 typhoon between the fourth and sixth years after planting, when the rate of branch break was 10 and 11% respectively, while that of *E. exserta* was 18% together with 3% of trees blown down. It is clearly necessary to choose superior provenances of *E. tereticornis* and *E. camaldulensis* to obtain the best returns from plantations in the tropical savanna of Hainan Island.

Provenances of *E. camaldulensis*

Differences in standing volume between 13 provenances of *E. camaldulensis* were significant, although all were from summer rainfall areas of northern Australia (Table 2). A provenance of Gilbert River (14106) from Queensland had the greatest standing volume. The provenances varied a lot in rank with time, such as the provenance of Laura (14918) from Queensland that was up to the second in the sixth year from eleventh in the third

Table 2. Multiple comparisons of standing volume between provenances of *E. camaldulensis*.

Seedlot	Standing volume (m^3/ha)
14106	91
14918	87
15062	85
14847	83
13933	71
13941	71
14917	71
15050	71
13663	64
15052	64
12187	61
15047	52
14518	49

$SR_{0.05}$

year, and that of Gibb River (15050) from Western Australia which fell to eighth in the sixth year from second place; the reason was that Laura had faster growth and suffered only 1.3% further mortality, while Gibb River was slower growing with 5.1% mortality after the fourth year. Standing volume per hectare of the best provenance was 1.9 times that of the worst. It is worth mentioning that the volume of all provenances tested was greater than that of *E. exserta* and that the standing volume of the worst provenance of *E. camaldulensis* was 28% greater than that of *E. exserta*. Thus *E. camaldulensis* from summer rainfall areas of northern Australia, when introduced to semi-arid parts of the coastal savanna of Hainan Island with a matching climate, had satisfactory growth.

The economic benefits will be greatest if the first four provenances of *E. camaldulensis* listed in Table 2 are used in areas where the climate conditions are similar to those of the trial sites, although differences in standing volume between the top eight provenances of *E. camaldulensis* were not significant.

Provenances of *E. tereticornis*

Ten provenances of *E. tereticornis* were tested; all were from coastal areas of eastern Australia containing the following rainfall types: summer rainfall in the north, year-round rainfall in the mid-south and winter rainfall in the south. Differences between provenances in standing volume per hectare were significant (Appendix 2). The S_R test showed that ranking on standing volume per hectare in the sixth and in the third year was similar in all provenances.

Table 3 shows that provenance 13443 from Kennedy River of Queensland had the greatest standing volume per hectare which was 33 times that of the worst provenance (Sale 13303). When measured 3 years after planting, Kennedy River was fourth behind three provenances of *E. camaldulensis* in rank, but in the fourth year it rose to first position and subsequently kept its superiority.

E. tereticornis provenances from Queensland were superior to those from NSW and Victoria in growth, drought tolerance and typhoon resistance.

Table 3. Multiple comparisons of standing volume between provenances of *E. tereticornis*.

Seedlot	Standing volume (m^3/ha)
13443	96
13544	72
14424	54
13442	50
13446	45
14115	38
13350	27
13319	25
13307	19
13303	3

$SR_{0.05}$

Conclusion

The trial showed that, of the 16 species and 56 provenances of *Eucalyptus* tested, provenances of *E. camaldulensis* from Gilbert River and Katherine and a provenance of *E. tereticornis* from Kennedy River were best. Their standing volume per hectare was consistently superior during the six years after planting. The growth rate of the provenance of *E. camaldulensis* from Laura increased after the fourth year, reaching third place in the sixth year. The standing volume per hectare of these local provenances was 139, 123, 153 and 128% greater than that of *E. exserta* respectively. Thus the provenances are suitable for growing in the dry red soil of southwest Hainan Island, and should be cultivated widely.

Appendix 1. List of species and provenances on trial.

Seedlot	Species	Location	H (m)	Dbh (cm)	Survival (%)
14106	*E. camaldulensis*	Gilbert River N Qld	11.4	10.0	94
14198	"	Laura N Qld	11.5	9.7	91
15062	"	Katherine NT	11.2	9.3	100
14847	"	Petford Qld	11.3	9.5	94
13933	"	Fitzroy Crossing WA	11.2	9.4	88
13941	"	Victoria River NT	11.0	9.3	89
14917	"	Carbine N Qld	11.3	9.5	84
15050	"	Gibb River WA	11.2	9.2	89
13663	"	Wrotham Park Qld	10.9	8.9	91
15052	"	Isdell River WA	11.2	9.3	78
12187	"	Irvinebank Qld	10.9	8.7	89
15049	"	Bullock Creek Qld	9.8	8.6	85
14518	"	Tennant Creek NT	9.7	8.4	85
13443	*E. tereticornis*	Kennedy River Qld	11.8	10.2	94
13544	"	Gladstone Qld	11.3	9.7	74
14424	"	Ravenshoe Qld	10.3	9.7	67
13442	"	Mareeba Qld	9.3	8.9	80
13446	"	Cardwell Qld	9.6	9.3	69
14115	"	Helenvale N Qld	8.7	8.3	67
13350	"	Urbenville NSW	8.4	7.9	63
13319	"	N of Woolgoolga NSW	8.8	7.7	55
13307	"	Windsor NSW	7.8	7.4	53
13303	"	Sale Vic	5.5	4.8	25
14519	*E. grandis*	Mt George, Taree NSW	—	—	0
14210	"	27km SE of Ravenshoe Qld	—	—	0
14509	"	Urbenville NSW	—	—	0
14861	"	EMBRAPA Brazil	—	—	0
13019	"	NW of Coffs Harbour NSW	—	—	0
13965	"	Seed Orchard S. Africa	—	—	2
13020	"	NNW Coffs Harbour NSW	—	—	3
14429	*E. saligna*	Blackdown Tableland Qld	—	—	3
15011	"	Kroombit Tops, Monto Qld	—	—	4
14527	"	Barrington Tops NSW	—	—	1
14508	"	Urbenville NSW	—	—	0
12895	*E. urophylla*	Mt Mandiri Indonesia	—	—	31
14532	"	Mt Lewotobi Indonesia	11.0	10.4	38
13828	"	Mt Mutis W. Timor Indonesia	—	—	25
14703	*E. citriodora*	W of Mt Carbine Qld	11.0	9.3	48
14852	"	Mt Garnet Qld	—	—	0
13742	"	ESE of Mt Molloy Qld	—	—	46
14851	"	Herberton Qld	—	—	33
13999	*E. pellita*	71.2km NE Wenlock Qld	—	—	3
11956	"	5km S Helenvale Qld	—	—	11
11947	"	Near Kuranda Qld	—	—	5
12018	*E. propinqua*	Kangaroo Ck SF NSW	—	—	3
12203	*E. cloeziana*	Cardwell Qld	—	—	10
14127	"	S of Ravenshoe Qld	—	—	0
13450	"	SE of Gympie Qld	—	—	3
10863	*E. punctata* var. *longirostrata*	Barakula SF Chinchilla Qld	—	—	41
13265	*E. punctata*	Consuelo T'Land Qld	—	—	23
14130	*E. torelliana*	SSW of Kuranda Qld	5.9	5.9	60
13657	*E. paniculata*	SW of Nowra NSW	—	—	5
14864	*E. exserta*	Herberton area Qld	—	—	40
	"	Jianfeng Hainan China	9.0	8.8	65
	E. ABL No. 12	Jianfeng Hainan China	9.1	9.1	59
	E. Leizhou No. 1	Leizhou Guangdong China	9.8	9.4	54

Appendix 2. Results of analysis of variance for volume per hectare.

Source of variance		DF	MS	F-ratio
Eucalyptus sp.	Species	5	477	9.60**
	Block	3	151	0.29
	Error	15	527	
Eucalyptus camaldulensis	Provenance	12	672	3.03**
	Block	3	3130	14.11**
	Error	36	222	
Eucalyptus tereticornis	Provenance	9	2960	6.36**
	Block	3	675	1.45
	Error	27	465	

**Significant at $P_{0.01}$

Relationships between Site Characteristics and Survival Strategies of *Eucalyptus camaldulensis* Seedlings

A. Gibson and E.P. Bachelard*

Abstract

Seedlings of *Eucalyptus camaldulensis* Dehnh. from Katherine, Northern Territory, in the dry tropics, Petford, Queensland, in the humid tropics and Tennant Creek, Northern Territory, in semi-arid Central Australia were grown in competition in a range of conditions to assess their performance under stresses similar to those experienced in nature. Katherine seedlings grew best with unlimited resources and responded to stress by shedding most leaves. This is appropriate for their environment where the dry winter is followed reliably by a heavy monsoon. Petford seedlings grew well and responded by stomatal closure without shedding leaves. This is appropriate where dewy mornings, which permit gas exchange, alternate with dry afternoons throughout the dry season. Tennant Creek seedlings grew least when unstressed and responded to stress by producing more sclerophyllous, persistent leaves and making significant growth in drying soil. This response is appropriate for arid conditions with unreliable rainfall. While the innate differences in form and stress response between the provenances appear to be adaptations for survival in particular environments they also influence growth parameters and performance in plantations. Small-scale seedling growth response trials may be useful in predicting the success of species and provenances.

IT is well accepted that climatic factors determine, in part, the distribution of species and ecotypes of eucalypts within Australia, and that the success of an Australian species in overseas plantations is most likely when the natural and alien climates are well matched. An understanding of the physiological bases for site adaptation, particularly adaptation for establishment and growth in increasingly dry climates, may complement climatic matching.

Eucalyptus camaldulensis Dehnh. occurs along the permanent and intermittent water courses in a wide range of climates in inland Australia, and comparisons of the morphological and physiological characteristics of seedlings from three climatic zones have shown them to be innately different and different in their responses to water stresses applied in glasshouse experiments (Gibson and Bachelard 1989, 1990; Gibson et al. 1991). Seedlings from Katherine, Northern Territory, in the dry tropics were not responsive to the stresses applied.

Seedlings from Petford, Queensland, in the humid tropics responded by the physiological process of stomatal closure, and seedlings from Tennant Creek, Northern Territory, in the semi-arid zone by changes in morphology which made the seedlings more xeric in form. The significance of these differences for growth and for survival through the dry season was assessed by establishing the seedlings in competition in large volumes of soil, subjecting them to root restriction and also to water stress after establishment.

Materials and Methods

Seed sources

The CSIRO Australian Tree Seed Centre seedlots chosen to represent the dry tropics, humid tropics and semi-arid climates were 14517, 14338 and 14518 respectively. The sites from which these seeds were collected are on an annual rainfall gradient between 1000 and <400 mm and they differ significantly in other parameters that influence moisture conditions (Table 1). Winter dry-season temperatures are

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greater than 10 °C and morning atmospheric saturation deficits are >12 mb at Katherine and the wind speeds are low. The dry season is followed by a reliable and heavy monsoon with saturation deficits below 8 mb. At Petford the saturation deficits are <8 mb with fogs and dews occurring in the cool mornings (less than 10 °C) throughout the winter dry season. At Tennant Creek low and unreliable summer rainfall with high saturation deficits creates a very difficult environment. While cooler temperatures and occasional rainstorms from southern weather systems reduce saturation deficits to 12 mb the consistently high wind speeds make conditions harsher than at Katherine.

Table 1. Approximate geographical and meteorological parameters for three provenances of *Eucalyptus camaldensis.*

	Katherine	Petford	Tennant Creek
Latitude	14°26′	17°17′	19°34′
Longitude	132°18′	145°03′	134°13′
Altitude (m)	95	500	335
Ann. rainfall (mm)	866	673	342
Air temp. max. °C	38	33	38
Air temp. min. °C	12	9	6
9 am saturation deficit driest month (mb)	11	7	12
9 am saturation deficit wettest month (mb)	8	9	22
9 am wind speed driest month ($m.s^{-1}$)	0–0.3	1.6–3.3	5.5–7.9

Experimental procedure

One seedling (seven leaf pairs expanded) from each provenance was transplanted into each of 24 large plastic nursery bags each containing 60 litres of unsieved clay loam soil. The three seedlings in each bag were arranged in a triangle with 25 cm sides. Three fine cloth bags of 1 L or 0.25 L capacity were set into each plastic bag outside the sides of the triangle formed by the transplanted seedlings (Fig. 1). A seedling from one of the provenances was transplanted into each cloth bag. The 24 large plastic bags, each with either three 1 L or three 0.25 L cloth bags were arranged at random in two blocks on the floor of a glasshouse with a diurnal temperature range of 12–25 °C and natural light. Roots did not penetrate the cloth bags but soil water moved freely between the bulk soil and soil inside the cloth bags. The seedlings were watered well for 60 days when the largest were approaching 1 m in height, then watering ceased and the time to wilting and subsequent leaf shed of the seedlings were observed.

The soil moisture content was determined 7 days after watering ceased and stomatal conductances 7 and 14 days after watering ceased. After 35 days the seedlings were removed from the soil, separated into roots, stems and leaves, oven dried at 60 °C for two days and weighed. An analysis of variance was performed on the dry weights.

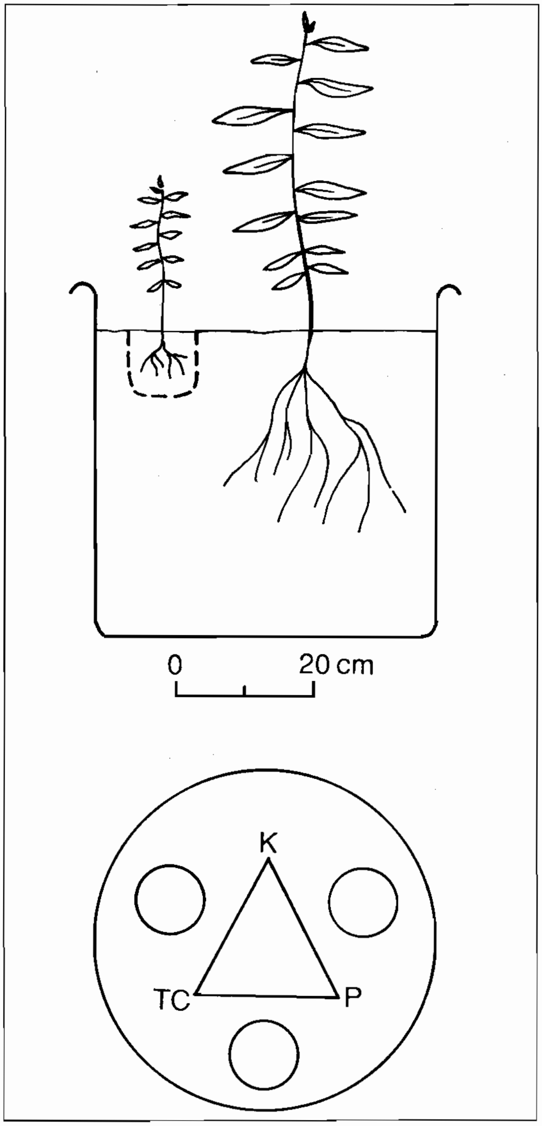

Fig. 1. Section (left hand side) and plan views of the arrangement of Katherine (K), Petford (P) and Tennant Creek (TC) seedlings in 60 L bags containing small cloth bags.

Results

Overall growth

Katherine and Petford seedlings grown without restricted roots in the large bags (which also contained 1 L or 0.25 L cloth bags) had the same total dry weight, approx. 13 g at harvest; Tennant Creek seedlings were significantly lighter than these (Table 2). Petford root systems had significantly lower dry weights than Katherine systems. Petford leaves that had expanded before watering ceased had broader bases and blunter tips than leaves from the other provenances (Fig. 2). Restriction of the roots in 1 L cloth bags reduced seedling dry weights by 66% in all provenances (Table 2) and reduced leaf area without changing leaf shape (Fig. 2). Restriction within 0.25 L cloth bags further reduced Katherine and Petford dry weights and leaf areas and Petford leaves became more linear in shape. Tennant Creek seedlings growing in 0.25 L cloth bags had the same dry weight as those in 1 L bags and leaf area and shape were little changed.

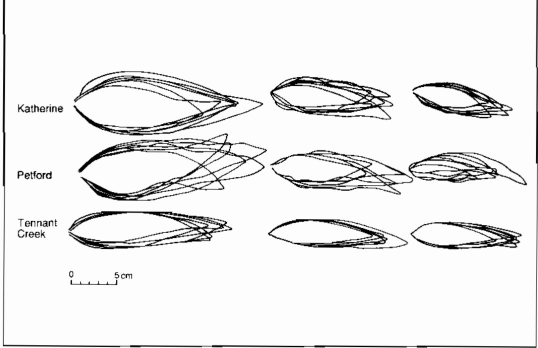

Fig 2. Superimposed tracings of the newest fully expanded leaf on six well watered Katherine, Petford and Tennant Creek seedlings. Left, unrestricted roots, centre, restricted roots in 1 L bags and right, in 0.25 L bags.

Stress response

One week after watering ceased Katherine seedlings were wilting and the wilted leaves subsequenty dried and were shed (Fig. 3). Wilting occurred later in Petford seedlings and the leaves were not shed. Tennant Creek seedlings did not wilt. The soil moisture content was approx. 7.5% when wilting began and Katherine seedlings, whether wilted or not, had stomatal conductances between 0.6 and 0.5 mol.m^{-2}s^{-1}. At this time Petford seedling conductances were between 0.4 and 0.1 mol.m^{-2}s^{-1} and Tennant Creek between 0.5 and 0.4 mol.m^{-2}s^{-1}. Stomatal conductances of all seedlings fell to low levels 14 days after watering ceased. Seedlings with restricted roots generally wilted later than unrestricted seedlings (Fig. 3). Wilting again occurred first in Katherine seedlings, and Tennant Creek seedlings did not wilt.

Leaves on the lower two-thirds of Katherine seedlings senesced and abscised as the soil dried (Fig. 4). At harvest some wilted leaves remained and the apex was wilted. While some leaves were shed from Petford seedlings the majority were wilted but alive and the upper leaves were still turgid at harvest. The lowest leaves were shed from Tennant Creek seedlings and the remainder were turgid and growth had continued in the dry period, as shown by the expanded leaves towards the apex of the seedling in Figure 4.

Table 2. Final dry weight of seedlings of *E. camaldulensis* well watered for 60 days and then not watered for 35 days. Seedlings with roots confined in 1 L and 0.25 L bags, and unconfined.

Provenance		Roots not confined (1 l)	(0.25 l)	Roots confined 1 l bags	0.25 l bags
Katherine	Root	3.41	3.56	1.35	0.88
	Stem	3.73	3.91	1.18	0.80
	Leaves	5.97	6.49	2.02	1.30
	Total dry wt	13.10	13.96	4.55	2.98
Petford	Root	2.59	2.60	1.30	0.91
	Stem	3.65	3.90	1.37	0.86
	Leaves	5.91	6.47	2.53	1.54
	Total dry wt	12.16	12.94	5.10	3.31
Tennant Ck	Root	1.83	1.80	0.91	0.76
	Stem	2.02	2.34	0.63	0.68
	Leaves	4.58	5.54	1.33	1.42
	Total dry wt	8.43	8.68	2.87	2.85

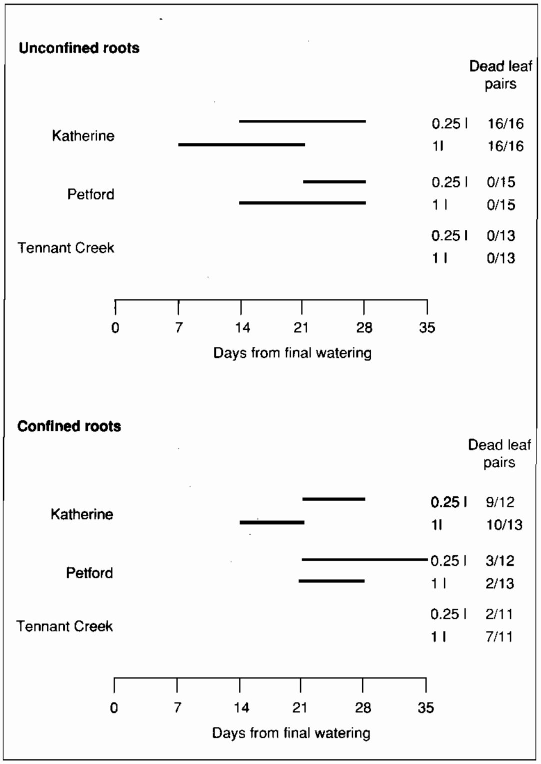

Fig. 3. Time to wilting and subsequent loss of leaves from Katherine, Petford and Tennant Creek seedlings with unrestricted roots and roots confined in 1 l and 0.25 l bags.

Discussion

The large volume of clay loam soil which dried more slowly than the potting mix in standard 10 cm pots used in earlier experiments (Gibson and Bachelard 1989; 1990; Gibson et al. 1991) enabled the seedlings to adjust more naturally than hitherto to water stress.

Katherine seedlings, from the wettest environment (Table 1) grew rapidly when unrestricted and well watered, producing large root systems, tall stems and large leaves which wilted readily, dried out and fell off (Table 2, Figs 2, 3, 4) . Seedlings with restricted roots shed leaf pairs from the base upwards by senescence and abscision after watering ceased. They responded to drying soil in the same way as the unrestricted seedlings but more slowly, without changes in leaf shape. Clearly the response is to rapidly produce a tall seedling by means of large, poorly lignified leaves with high gas-exchange rates (Gibson et al. 1991). When water-limited in the dry season the seedlings shed the leaves, greatly reducing transpirational area. On arrival of the next monsoon they continue growth from the apical bud, producing a tall seedling capable of competing for light with tall grasses and tending to produce tall, clean poles in plantations. The seedlings' insensitivity to the onset of stress prevents them from assuming the more sclerophyllous, xeric form and maintains their capacity for rapid apical growth. This is appropriate where the summer monsoon is heavy and reliable and the winter dry season saturation deficits are high.

Petford seedlings made as much growth overall as Katherine seedlings when roots were unrestricted, but the leaves differed, being broader and less regular in shape. This appears to be related to the mobile stomata which open to allow rapid growth when water relations are favourable and close readily in response to drying (Gibson et al. 1991) so that expanding leaves experience irregular growth. When the roots were restricted the leaves produced were more linear and reduced in area, and since the leaf dry weight and total number of leaves was the same as on Katherine seedlings there was increased dry weight per unit area. The Petford leaves were thus more sclerophyllous, more likely to resist physical damage at wilting and more persistent than Katherine leaves. This strategy is appropriate for the humid tropics where reliable summer rains are followed by a dry winter with relatively mild mornings. Regrowth will occur in the axils of the top leaves surviving the dry season as well as the apex, producing a well-formed seedling in the second year. The capacity for utilising all moist periods for rapid growth and conserving the leaves may explain the success of Petford in plantations.

Tennant Creek seedlings from the most difficult environment grew less than the monsoon seedlings when unconfined, producing seedlings with leaves that withstood wilting and persisted as the soil dried. Seedlings in the most severe conditions (0.25 L cloth bags) maintained growth in the drying soil. Clearly the intrinsically slow-growing Tennant Creek seedlings hardened more readily than the monsoon seedlings, consistent with their greater sensitivity to stress described previously. They produced persistent leaves able to utilise any periods when rainfall reduces saturation deficits and calm conditions reduce boundary layer conductance so that leaf-to-air vapour pressure deficits are relatively low. At these times axillary buds will develop in all leaf axils, giving rise to the woodland form typical of the provenance.

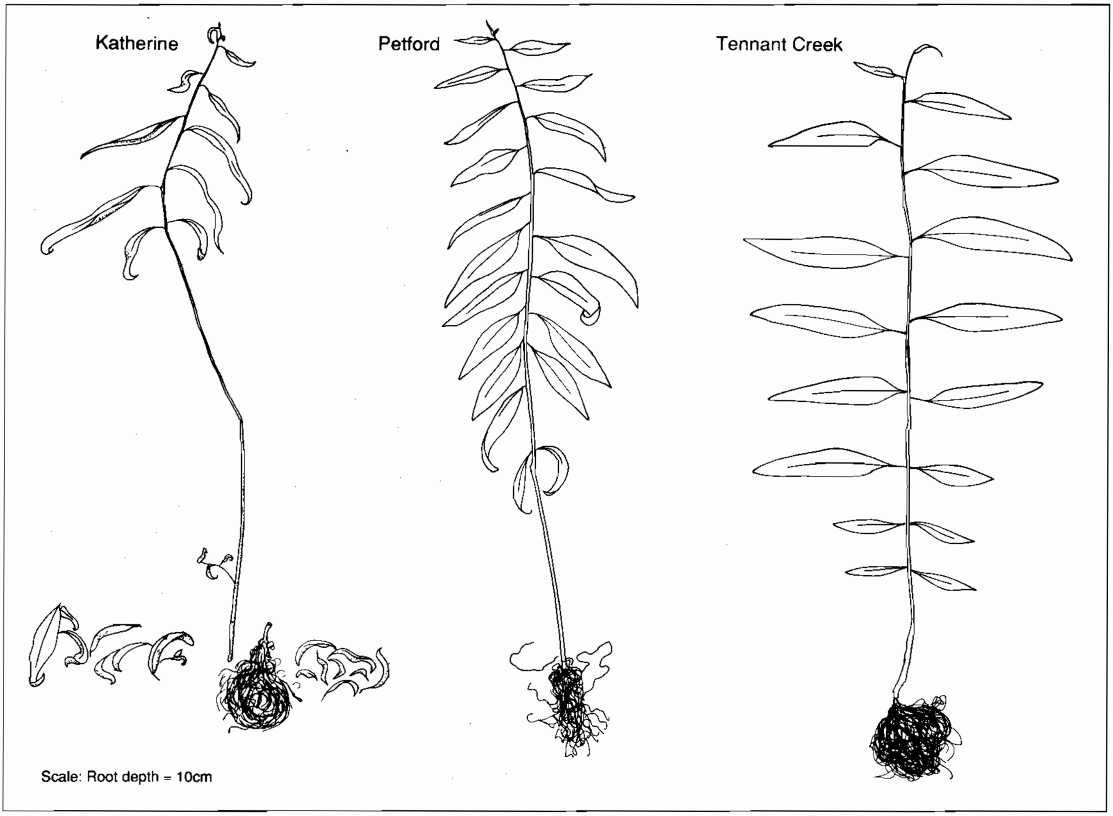

Fig. 4. A comparison of Katherine, Petford and Tennant Creek seedlings with roots restricted in 0.25 l bags 35 days after watering ceased.

The differences in form and strategy between seedlings from the three sites are consistent with the moisture conditions that prevail at each site. While the strategies are well developed in the seedlings, which must withstand difficult conditions before reaching the water table, they are also evident in trees in the field (Gibson and Bachelard, unpubl.), including those on the banks of permanent water courses. Identification of seedling growth strategies in glasshouse trials may thus define the conditions under which particular provenances will be successful in plantations outside Australia.

Acknowledgments

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Determining Soil Nutrient Limitations to Tree Growth: Nutrient Omission Experiments with *Eucalyptus grandis* on Six Forest Soils

Zhong Chonglu* and Paul Reddell**

Abstract

A nutrient omission experiment was conducted under glasshouse conditions to identify the most critical nutritional limitations to growth of *Eucalyptus grandis* seedlings in six forest soils from Queensland, Australia. Soils used in this experiment were representative of the major forest soil types occurring in the humid coastal lowlands of north Queensland and they derive from a range of soil parent materials.

More than one nutrient limited growth of *E. grandis* seedlings in each of the six forest soils that were examined. Phosphorus was the most widespread nutrient deficiency and limited plant growth in all soils. Nitrogen and sulfur deficiencies were also common, occurring in four of the six soils. Deficiencies of other nutrients (K, Ca, B, Zn, and Mo) were also detected in some of the soils. From the results a simple guide to diagnosis of foliar symptoms of deficiencies of five major elements (N, P, K, S and Ca) has been prepared for *E. grandis* seedlings.

The experiment provides an example of one approach to determining soil nutrient limitations to tree growth. This is a necessary first step in developing a nutritional strategy to optimise productivity of forest plantations on infertile soils.

MOST soils available for forestry activities in the tropics are inherently infertile. Consequently, the potential to increase plantation productivity in the tropics by enhancing the supply of nutrients available for tree growth is high (Bowen and Nambiar 1984). Management of forest nutrition involves an integrated approach in which soil fertility, fertilizer application, nutrient interactions, symbiotic associations (mycorrhizas, rhizobia), nutrient losses and plant genotypic differences in nutrient use efficiency are all considered in developing the most economically and ecologically effective strategy to optimise tree growth and wood quality (Evans 1992).

The first stage in developing a nutrition management strategy for forest plantings is to define the nutritional characteristics of soils at planting sites. The three phases in this process involve:

1. identifying which particular soil nutrients are limiting tree growth
2. examining possible interactions between limiting nutrients (the level of one particular nutrient in soil can affect the plants requirements for others)
3. determining how much fertilizer needs to be applied to alleviate the deficiency and maximise tree productivity.

The nutrient requirements of individual tree species and the possibilities for mycorrhizal inoculation and for using nitrogen-fixing trees in the silvicultural system as well as nutrient losses then need to be considered before implementing an operational plan.

There are two experimental approaches for identifying the nutrients most limiting tree growth on particular soils. These are nutrient omission and nutrient addition experiments. Both can be conducted either in the field or under glasshouse or nursery conditions and each has advantages and disadvantages. In nutrient omission experiments, a range of treatments is applied to soil in which individual (or groups of) nutrients are omitted from a complete nutrient formulation. There is also a 'control' treatment in which no nutrients are

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** Davies Laboratory, CSIRO, Townsville, Queensland applied. This approach is useful for detecting multi-element deficiencies, but does not reveal strong interactions which often occur between nutrients (e.g. P and Zn) in tropical soils. For nutrient addition experiments, individual or groups of elements are added to the unamended soil. Simple factorial designs are commonly used in addition experiments. However, such experiments can generate a large number of treatment combinations and there is often need to either (i) restrict the nutrient combinations by using a fractional factorial treatment structure or (ii) carry out two smaller experiments instead of one large experiment. To run this second alternative efficiently some prior knowledge of possible site responsiveness.

Here we provide an example of one of these approaches — omission experiment, conducted under glasshouse conditions, that was designed to detect possible soil nutrient limitations to growth of *Eucalyptus grandis* in six forest soils from north Queensland.

Materials and Methods

Experimental design

Twelve nutrient treatments were imposed on each of six forest soils in a randomised block design using split plots. In each block, soil types were allocated to the main plots and nutrient addition treatments were designated as subplots. The nutrient treatments used were:

1. no nutrient addition (nil)
2. a complete nutrient formulation adequate for optimal seedling growth
3. complete nutrient formulation minus N
4. complete nutrient formulation minus P
5. complete nutrient formulation minus K
6. complete nutrient formulation minus S
7. complete nutrient formulation minus Ca
8. complete nutrient formulation minus Zn
9. complete nutrient formulation minus Cu
10. complete nutrient formulation minus B
11. complete nutrient formulation minus Mo
12. complete nutrient formulation minus Mn and Mg

There were two plants in each pot and three replicate pots of each treatment combination.

Soil collection and nutrient application

Surface soil (0–30 cm) was collected at each of six forest sites in the humid tropics of north Queensland, Australia. These soils were representative of each of the major groups of lowland forest soils from this area. Site details, soil types and their chemical characteristics are outlined in Tables 1 and 2.

Prior to use in the glasshouse experiment, all soils were sieved through a 5 mm mesh and dried in an oven at 60 °C for 3 days. Soils (800 g of dry soil per pot) were then weighed into rigid black plastic pots, each of which was lined with a polythene bag. Depending on the treatment, the appropriate combination of nutrients were pipetted onto the surface of soil in each pot and allowed to air dry. After drying, nutrients were incorporated into soil by thorough mixing.

The composition of the complete nutrient formulation used in this experiment is presented in Table 3. Omission treatments involved deleting salts containing individual nutrients from this standard, complete formulation. Where necessary, additional salts were added to replace any counterpart ion lost due to the omission treatment. For example, in the $-P$ treatments, K_2SO_4 was added to compensate for the reduced level of K in the nutrient formulation that resulted from deleting the P source (KH_2PO_4) from the nutrient recipe.

Table 1. Details of soil type, parent material and vegetation at the collection site for the six forest soils used in this study.

Soil series*	Parent material	Soil classification*	Vegetation association
Galmara	Metamorphic	Tropeptic haplorthox	lowland rainforest
Tyson	Granite	Orthoxic tropudult	lowland rainforest
Pingin	Basalt	Tropeptic haplorthox	lowland rainforest
Kirrima	Granite	Kandiusult	sclerophyll forest
Bulgun	Mixed alluvium	Oxic humitropept	sclerophyll forest
Hull	Beach ridges	Typic haplorthod?	sclerophyll forest

* After Murtha (1986) and Cannon et al (1992)

Table 2. Chemical characteristics of soils used in the experiment (0–10 cm depth).

Characteristic	Galmara	Tyson	Pingin	Kirrima	Bulgun	Hull
pH	4.96	4.73	5.43	5.1	5	5.7
Org. C (%)	0.16	1.69	4.04	4.07	2.74	0.65
N (%)	0.04	0.13	0.27	0.2	0.12	0.06
HCO_3 extractable P (ppm)	2	8.3	6	4.6	8.7	5.3
Tot. P (%)	0.019	0.017	0.15	0.016	0.043	—
Tot. K (%)	0.31	0.245	0.023	0.105	0.9	—
Tot. S (%)	0.034	0.029	0.075	0.031	0.13	—
Free Fe (%)	2.21	1.16	15.8	1.35	—	0.38
Exchange properties m.e./100 g soil						
Ca	0.067	0.36	1.2	0.09	0.1	0.87
Mg	0.15	0.31	1.07	0.15	0.145	0.25
K	0.047	0.105	0.31	<0.02	<0.03	<0.01
Na	0.02	0.035	0.23	<0.02	0.065	0.025
H + Al	1.19	1.8	0.46	2.4	2.67	0.34
CEC	1.48	2.61	4.27	2.65	3.05	1.5

Table 3. Composition of complete nutrient formulation used in this experiment.

Nutrient salt	mg salt/kg soil	mg nutrient/kg soil
KH_2PO_4	200	57.4 K; 45.4 P
NH_4NO_3	280*	100 N
K_2SO_4	140	62.9 K; 25.8 S
$CaCl_2.2H_2O$	100	27.3 Ca; 48.3 Cl
$MgSO_4.7H_2O$	80	8.0 Mg; 10.4 S
$CuSO_4.5H_2O$	5	1.3 Cu; 0.7 S
$ZnSO_4.7H_2O$	10	2.3 Zn; 1.1 S
$MnSO_4.H_2O$	15	3.7 Mn; 2.1 S
H_3BO_3	0.7	0.12 B
$CoSO_4.7H_2O$	0.5	0.11 Co; 0.06 S
$Na_2MoO_4.2H_2O$	0.4	0.16 Mo
FeNaEDTA	20	3.0 Fe; 1.2 Na

* 0 week (280 mg salt/kg soil); 4 weeks (70 mg salt /kg soil); 6 weeks (70 mg salt/kg soil); 8 weeks (112 mg salt /kg soil)

Plant culture

The experiment was conducted in an airconditioned glasshouse (temperature range 19–36 °C) at CSIRO Davies Laboratory in Townsville, Queensland.

Seeds of *Eucalyptus grandis* (collected 12 km south of Ravenshoe, Queensland by the CSIRO Australian Tree Seed Centre) were surface sterilised in sodium hypochlorite for 5 min and thoroughly rinsed in distilled water. These seeds were then sown into trays of a sterilised sand and left to germinate.

Four weeks after sowing, two seedlings were transplanted into each pot of soil to which the nutrient treatments had been applied. Pots were then placed on benches in a randomised block arrangement and watered regularly to 80% of field moisture capacity. Pots were re-randomised within each block every 2 weeks.

Seedlings were harvested 107 days after transplanting. Plants were photographed and notes made on any foliar symptoms of nutrient deficiency that were observed in the different treatments. The soil was carefully washed from the root system of each plant and the roots then separated from aboveground parts of the seedlings. Leaves were also separated from stems and all plant material was dried at 80 °C for 48 hr prior to weighing. Plant biomass in the different soil × nutrient application treatments was later analysed using ANOVA of untransformed dry weight data.

Results

There were very significant differences ($P<0.01$) in seedling biomass amongst the six soil types used and between the nutrient treatments imposed (Figure 1).

Dependent on soil type, application of complete nutrients increased total dry matter production of *E. grandis* seedlings by between 1.4 and 23 times compared to the same soil which had not been fertilised (Figure 1). However, even with application of complete nutrients, there were still up to threefold differences in biomass production between the soil types (Figure 1). Seedlings grew best in the Tyson (granitic) and Pingin (basaltic) soils and worst in the Hull (beach ridge) and Galmara (metamorphic) soils. Similar rankings were found when no nutrients where applied to these soils.

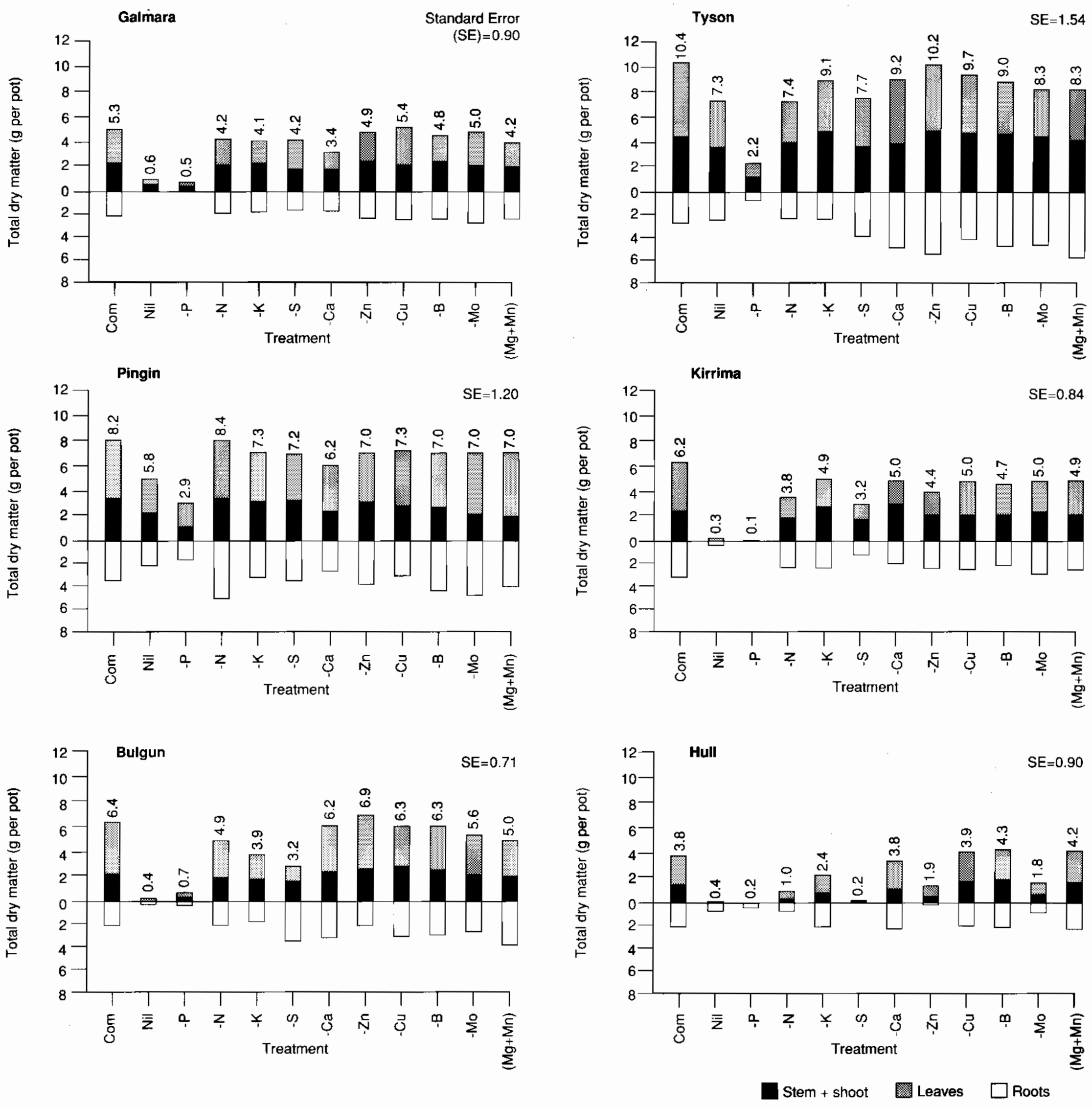

Fig. 1. Effect of nutrient omission treatments on total dry matter production (g per pot) of *Eucalyptus grandis* seedlings grown on six forest soils.

Deficiencies of more than one nutrient were found on each of the six soils. Nutrients that significantly reduced seedling biomass in comparison to the complete treatment ($p \leq 0.05$) on each soil type were:

Galmara	P, Ca
Tyson	P, N, S
Pingin	P, Ca
Kirrima	P, N, S, Zn, B
Bulgun	P, N, K, S
Hull	P, N, K, S, Zn, Mo

P was the most widespread deficiency occurring in all soils. It was also the most severe, being the primary limitation on seedling growth in five of the six soils (all except Hull). In three soils (Tyson, Kirrima and Pingin), seedling dry matter production in the complete-nutrients-minus-P treatment was actually lower than when no nutrients were applied.

N and S were also common deficiencies, occurring on four of the six soils. Omission of N from the complete nutrient formulation on these four soils reduced seedling biomass by between 23 and 71%, with the greatest decline being found in the beach ridge soil (Hull). Omission of S from the complete nutrient formulation reduced seedling biomass by between 25 and 98%, again with the greatest growth reduction occurring in the Hull series soil.

Other nutrient deficiencies were less common, occurring on only one or two of the soil types. K deficiency was found in two soils and reduced growth in both situations by approximately 40% compared to the biomass obtained when complete nutrients were applied. Ca deficiency was also found in two soils, the Galmara metamorphic and the Pingin basalt. Omission of Ca from the complete nutrient formulation reducing seedling growth by 25–30% in both of these soils. Three trace element deficiencies limited seedling growth in this experiment: B deficiency in the Kirrima series soil reduced growth by 25%, while Zn and Mo deficiency in the Hull beach ridge soil both reduced growth by about 50%.

Distinctive foliar symptoms of deficiencies of some of these nutrients were also observed. The occurrence of such symptoms reflects the severity of the deficiency in the soils (the first consequence of nutrient deficiency is reduced growth rate; foliar symptoms indicate an extreme deficiency). These observations have been used as the basis for preparing a diagnostic guide to visual symptoms of deficiencies of five major nutrients on seedlings of *E. grandis* (Table 4).

Conclusion

Deficiencies of at least two different nutrients significantly reduced the productivity of *E. grandis* seedlings on all six forest soils used in this experiment. As a result, an appropriate nutritional strategy involving mycorrhizal inoculation and judicious use of specific fertilizers during plantation establishment would be expected to substantially increase the productivity of any plantations on these soils.

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Table 4. A diagnostic guide to nutrient deficiency symptoms observed in *Eucalytpus grandis* seedlings.

Symptoms appear first in the oldest leaves	
Nitrogen	General yellowing (chlorosis) of older leaves followed by some reddening (anthocyanin?) of central vein in advanced cases; chlorosis eventually spreads to younger leaves
Phosphorus	Oldest leaves with dark purple colour developing initially at the leaf tip and extending down the mid-vein, purple colour more pronounced on the leaf underside; younger leaves stunted, dark blue-green in colour
Potassium	Older leaves leaves twisted or wrinkled, sometimes with necrotic spots
Symptoms appear first in the youngest leaves	
Sulfur	Youngest leaves with interveinal chlorosis; symptoms less severe on older leaves
Calcium	Younger leaves become wrinkled with leaf margins turned under, irregular yellow-green patches appear along the margins; some die-back of the terminal shoot

Eucalyptus Experiments in Guangdong Province

Wu Juying, Wu Kunming and Xu Jianmin*

Abstract

Six species of *Eucalyptus* planted at three sites of Guangdong Province were assessed at 4 years of age. There were significant differences in volume per hectare between species at the one site and between sites for a given species. *Eucalyptus urophylla* and *E. tereticornis* grew faster (33–248% in volume per unit area) than the extensively planted *E. exserta*. The two new species deserve wider use in Guangdong province.

GUANGDONG Province began expanding *Eucalyptus* plantings in the mid 1950s. In 1987 there were 300 000 ha of *Eucalyptus* plantations. The major cultivated tree species is *E. exserta*, followed by *E. citriodora*. A long-standing problem is that growth of these stands is not high, averaging 4.5–7.5 m^3/ha per annum. An analysis of data from other domestic trials and other countries' trials suggests that the main reasons for the slow growth are inefficient management and inappropriate choice of species. In order to select good, high-yielding species for more extensive plantings, experiments on several candidate species were established in Yangxi, Huiyang and Boluo Counties in 1988.

Collaborators are the Forestry Department of Guangdong Province and the Forestry Bureaus of Yangxi, Huiyang and Boluo Counties. The species in the trials are *E. urophylla*, *E. tereticornis*, *E. camaldulensis*, *E.* ABL No. 12, *E. exserta*, the hybrids of *E. crawfordii* x *E. botryoides* and *E. grandis* x *E. urophylla*, *E. pellita*, *E. citriodora* and *E. leizhou* No. 1. (Note that *E. crawfordii* is a 'species' well known in China, but reputed to be a hybrid of *E. acaciiformis* and *E. saligna*.)

This paper presents results from the first six species when 4 years old at three sites.

Materials and Methods

The seed of *E. urophylla* used for the trials was a mixture of Indonesian seedlots 10140 (Heto Bulico), 12895 (Mt Mandiri), 12897 (Mt Wuko), 14531 (Mt Egon) and 14532 (Mt Lewotobi). The seed of *E. tereticornis* was a mixture of seedlots from Queensland, Australia: 14115 (Helenvale), 13443 (Kennedy River), 12965 (Mt Garnet), 15198 (Cooktown) and 14856 (Mareeba). The seed of *E. camaldulensis* was a mixture of 21 provenances from northern Queensland and Western Australia. The seed of *E. pellita* (seedlot 11956) was taken from Helenvale, Queensland. This seed was provided by CSIRO's Australian Tree Seed Centre. *E.* ABL No. 12 was from Dianbei County, Guangdong Province. *E. exserta*, a control species, was from Qionghai County, Hainan Province. The hybrid of *E. grandis* x *E. urophylla* was originally from Brazil (Aracruz Company provided the seed). The hybrid of *E. crawfordii* x *E. botryoides* was from Meixian County, Guangdong Province. *E. citriodora* was from a clonal seed orchard in Longdong, Guangzhou city. *E. leizhou* No. 1 was provided by the Research Institute of Forestry, Leizhou Forestry Bureau of Guangdong Province.

The sites (Table 1) were situated in the southwest and southeast of Guangdong Province. Trials were planted during April and May 1988. A complete randomised block design with four replications was used. There are three kinds of rectangular plot: 45 trees (9 trees/row x 5 rows), 60 trees (15 trees/row x 4 rows) and 120 trees (15 trees/row x 8 rows). The spacing between rows and within rows is 2.7 and 1.7 m respectively. A buffer with 2–6 rows of trees was set up between plots, and trial sites were also surrounded by a protective belt of trees.

Height (H) and diameter at breast height (dbh) were measured once a year. The formula $V = \frac{1}{3} \times H \times dbh^2$ was used for calculating stem

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volume. Volume production per unit area, at age 4 years, was analysed over species and sites. The significance of differences among species at each site was assessed by the SR-test.

Results

Growth difference of the same species at different sites

There were differences in both the volume per unit area and relative volume compared with the control species (*E. exserta*). For example, the volume of *E. urophylla* at Huiyang, Yangxi and Boluo Counties was 70, 36 and 28 m³/ha respectively. The greatest volume, 2.5 times as much as that at Boluo, was at Huiyang. As to relative volume, *E. urophylla* occupied first place among the tested species at Huiyang and Yangxi sites, and second at Boluo site; relative volumes at Huiyang, Yangxi and Boluo sites were 348, 140 and 151% respectively.

There were no significant differences in the volume of *E. tereticornis* among the sites; the greatest was 34 m³/ha at Huiyang site and the smallest was 30 m³/ha at Boluo site. It occupied first place among the tested species at Boluo and was second at the two other sites. Relative volumes at Huiyang, Boluo and Yangxi were 168, 163 and 133% respectively.

There were no significant differences in the volume of *E. camaldulensis* at the three sites. Relative volumes at Huiyang, Yangxi and Boluo were 160, 115 and 139% respectively. The hybrid of *E. crawfordii* x *E. botryoides* took the last place in volume among the tested species at each site, and there were great differences in both volume and relative volume among the sites. Its greatest volume was 14 m³/ha at Huiyang — 1.5 times the smallest (9.1 m³/ha at Boluo). Relative volume at Huiyang, Yangxi and Boluo sites were 69, 37 and 49% respectively. There were similar differences in volume of the other two species (Table 2).

Table 1. Details of experimental sites.

Item	Huiyang	Yangxi	Boluo
Latitude (N)	22°52′	21°48′	23°11′
Longitude (E)	114°20′	111°43′	114°17′
Altitude (m)	50	30	40
Annual mean temperature (°C)	21.7	22.2	22.0
Annual mean precipitation (mm)	1800	2250	1890
pH	5.17	5.15	5.20
Organic matter of soil (%) (0–40 cm)	2.61	1.04	1.25
Hydrolytic nitrogen (mg/100g)	3.87	4.81	3.31
Rapidly available phosphorus (mg/100g)	0.21	0.24	0.47
Rapidly available potassium (mg/100g)	2.04	0.94	1.30
Main undergrowth species	*Ischaemum barbatum*, *Dicranopteris linearis*	*Eriahne pallescense*, *Baeckea frutescens*	*D. linearis*, *Rhodomyrtus tomentosa*

Table 2. Growth of six species of *Eucalyptus* at three sites in Guangdong Province.

Site	Huiyang			Yangxi			Boluo		
Species	Volume (m³/ha)	R. V%	Rank	Volume (m³/ha)	R. V%	Rank	Volume (m³/ha)	R. V%	Rank
E. urophylla	70	348	1	36	140	1	28	151	2
E. tereticornis	34	168	2	34	133	2	30	163	1
E. ABL No. 12	33	165	3	29	112	4	15	82	5
E. camaldulensis	32	160	4	29	115	3	26	139	3
E. exserta	20	100	5	25	100	5	19	100	4
E. crawfordii x *botryoides*	14	69	6	9	37	6	9	49	6

R. V% = relative volume (%) compared with that of *E. exserta*

The analysis of variance of volume of the six species at age 4 years in the three trials showed that there were most significant differences between sites, between species and between site x species (Table 3).

Table 3. The analysis of variance of volume.

Source of variation	df	ms	F
Block (R)	3		
Site (B)	2	968	8.7**
Species (P)	5	1535	13.7**
P × B	10	305	2.7**
Error	55	112	
Total	72		

E. urophylla is very sensitive to the quality of habitat. It grew faster than other tested species at the good site (Huiyang, for example, with 2.6% of soil organic matter). *E. tereticornis*, *E. camaldulensis* and *E. exserta* are adaptable and are not highly sensitive to site quality, but consequently did not take full advantage of conditions at the best site.

Growth differences between species at the same site

Huiyang site There were great differences in the volume per hectare of the six species at 4 years at Huiyang (Table 2); the best was *E. urophylla* with 70 m³/ha and the smallest was *E. crawfordii* x *E. botryoides* with 14 m³/ha. The former was five times greater than the latter, and also 3.5 times greater than *E. exserta* (the control species) with 20 m³/ha. Differences among the species were most significant. The range test showed that there were most significant differences between *E. urophylla* and the other five species, but there were no significant differences between *E. tereticornis*, *E.* ABL No. 12 and *E. camaldulensis*, or between *E. exserta* and *E. crawfordii* x *E. botryoides*. There were obvious differences between the latter two species and each of the former three species (Table 4).

Table 4. Ranking of species at Huiyang.

Tree species	Volume (m³/ha)	SR$_{0.05}$
E. urophylla	70.1	
E. tereticornis	33.7	
E. ABL No. 12	33.1	
E. camaldulensis	32.3	
E. exserta	20.1	
E. crawfordii x *E. botryoides*	13.9	

Yangxi site Although volume per hectare of 4-year-old *E. urophylla* at Yangxi was not as great as that at Huiyang, it still occupied first place (36 m³/ha) among all tested species. It was 3.5 times as much as that of *E. crawfordii* x *E. botryoides* which was the smallest with 9.4 m³/ha, and 1.4 times as much as that of *E. exserta* (the control species) with 25 m³/ha. Analysis of variance showed that there were significant differences among the species. The range test showed that there were no significant differences among *E. urophylla*, *E. tereticornis*, *E. camaldulensis*, *E.* ABL No. 12 and *E. exserta*, but there were significant differences between them and *E. crawfordii* x *E. botryoides* (Table 5).

Table 5. Ranking of species at Yangxi.

Tree species	Volume (m³/ha)	SR$_{0.05}$
E. urophylla	35.6	
E. tereticornis	33.7	
E. camaldulensis	29.2	
E. ABL No. 12	28.6	
E. exserta	25.3	
E. crawfordii x *E. botryoides*	9.4	

Boluo site The volume production of *E. tereticornis* took second position among the species at Huiyang and Yangxi, but occupied first place at Boluo site with volume of 30 m³/ha (1.6 times greater than that of *E. exserta* (control species) with 19 m³/ha, and 3.3 times that of *E. crawfordii* x *E. botryoides* with 9 m³/ha). There were significant differences among the tested species. The range test showed that there were no significant differences among *E. urophylla*, *E. tereticornis* and *E. camaldulensis*, that there existed significant or most-significant differences between them and *E.* ABL No. 12, *E. exserta*, *E. crawfordii* x *E. botryoides*, and that there were no significant differences among the latter three species (Table 6).

Table 6. Ranking of species at Boluo.

Tree species	Volume (m³/ha)	SR$_{0.05}$
E. tereticornis	30.4	
E. urophylla	28.0	
E. camaldulensis	25.8	
E. exserta	18.6	
E. ABL No. 12	15.2	
E. crawfordii x *E. botryoides*	9.1	

Discussion and Conclusion

The results of the trials for the six 4-year-old *Eucalyptus* species at three sites in Guangdong province showed that there were differences in volume production per unit area of the same species at different sites and of different species at the same site.

E. urophylla and *E. tereticornis* grew faster (33–248%) in volume than the species now widely planted, *E. exserta*. All the seed of *E. urophylla* and *E. tereticornis* used for the trials was a mixture of many provenances. Also, the results of provenance trials (Liang et al., Wu et al., these proceedings) indicated that provenance 10140 (Hato Bulico) of *E. urophylla* is the worst provenance and provenances 14115 (Helenvale), 12965 (Mt Garnet), 15198 (Cooktown) and 14856 (Mareeba) of *E. tereticornis* are medium performers. *E. exserta*, the control, is a good provenance from Qionghai County, Hainan. If the best provenance of *E. urophylla* (14532 Mt Lewotobi) and the best provenance of *E. tereticornis* (13443 Kennedy River) had been used for the trials, the advantages in volume production of these species would have been even greater. These provenances of *E. urophylla* and *E. tereticornis* deserve much wider use in Guangdong province.

There were no significant differences in volume of *E. tereticornis*, *E. camaldulensis* and *E. exserta* at the three sites, indicating that they have good adaptability. Conversely, *E. urophylla* is very sensitive to habitat conditions. If the principle of the right tree on the right site is observed during afforestation, and *E. urophylla* is chosen for planting in good forest soil, its capacity for rapid growth will result in high yields. *E. crawfordii* x *E. botryoides* is not recommended because its volume production was very small and its taxonomic status and genetic history are quite uncertain.

Provenance Variation in Growth and Wood Properties of *Eucalyptus grandis* in China

Wang Huoran*, Zheng Yongqi*, Zang Daoqun* and Cai Xiuwu**

Abstract

Fifteen provenances of *Eucalyptus grandis* were included in species and provenance trials of eucalypts established in southeastern China in 1986. There were very significant differences in volume growth among these provenances: those from north Queensland performed better than others; one seedlot from Coffs Harbour and seed from a seed orchard in South Africa were relatively inferior. Although wood density did not vary significantly between provenances, tree-to-tree variation was great, ranging from 350 to 670 kg/m^3, with a mean of 432 kg/m^3.

FIFTEEN provenances of *Eucalyptus grandis* Hill ex Maid. were included in the species and provenance trials of eucalypts established in southeastern China in 1986. This was the first time that this species had been examined in range-wide tests in China. In 1990 *E. grandis* was selected as a major species for growing in southern China by the National Afforestation Programme, using a forestry sector loan from the World Bank. *E. grandis* is grown in China to produce wood for the paper industry using intensively managed short rotations.

Materials and Methods

Trial establishment

The establishment of the species and provenance trials 25 km northeast of Zhangzhou, Fujian Province and 10 km east of Qionghai, Hainan Island was described by Wang (1989) and Wang et al. (1989). Seedlot details are given in Table 1.

Wood sampling

At 4.5 years of age discs 5 cm thick were taken at breast height from stems in the trials mentioned above. One tree from each plot was sampled; in total 75 discs representing 15 provenances were collected from five replications. Samples were taken from both the central and outer segments of each disc to measure the basic density of wood.

Length and width of fibre were determined from 100 fibres randomly chosen from the central, intermediate and outer segments of each disc (i.e. 300 fibre measurements for each sampled tree).

Data analyses

The attributes examined were —

$$\text{Standing volume} = \pi d^2 h/12$$

$$\text{Basic density} = \frac{\text{dry weight}}{\text{green volume}}$$

(Hillis 1984; Zobel & van Buijtenen 1989)

$$\text{Relative bark thickness} = \frac{\text{overbark dbh} - \text{underbark dbh}}{\text{overbark dbh}} \times 100$$

All data were analysed using GENSTAT 5.

Results

Growth rate

The calculated stem volume at 4.5 years of age is listed in Table 2: there was significant variation between the provenances (SED = 0.0068, p = 0.01). Of the 15 provenances, those from higher elevation in northern Queensland were best. In contrast, provenances from NSW, almost the same as those from South Africa, were relatively inferior.

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Table 1. Details of the seedlots provided by Australian Tree Seed Centre, CSIRO.

CSIRO Seedlot	No. of parent trees	Location	Lat.	Long.	Alt (m)
13431	7	Mt Lewis Qld	16°36′	145°16′	840
14393	11	SE of Mareeba Qld	17°06′	145°33′	900
14849	22	NE of Atherton Qld	17°06′	145°36′	1050
14420	20	S of Ravenshoe Qld	17°42′	145°28′	860
14210	5	SE of Ravenshoe Qld	17°50′	145°33′	720
14838	7	Cardwell Qld	18°14′	143°00′	620
14431	25	Belthorpe Qld	26°52′	152°42′	500
14509	25	Urbenville NSW	28°31′	152°30′	600
13020	10	Coffs Harbour NSW	30°10′	153°01′	98
13019	10	Coffs Harbour NSW	30°13′	153°02′	135
14519	25	Taree NSW	31°50′	152°01′	230
14860	—	EMBRAPA Brazil	—	—	—
14861	—	EMBRAPA Brazil	—	—	—
13965	—	SO South Africa	—	—	—
13365	—	SO South Africa	—	—	—

Table 2. Provenance means of stem volume (SV), vessel length (VL), fibre length (FL), fibre width (FW) basic density (BD), and relative bark thickness (BT) at age 4.5 yr of *E. grandis* planted in July 1986.

Seedlot	SV (m^3)	VL (mm)	FL (mm)	FW (mm)	BD (kg/m^3)	BT (%)
13431	0.040	0.49	0.86	0.019	460	8.5
14393	0.054	0.44	0.80	0.019	442	7.3
14849	0.052	0.45	0.83	0.019	440	6.5
14420	0.040	0.45	0.81	0.020	427	7.9
14210	0.051	0.46	0.84	0.019	407	6.8
14838	0.045	0.44	0.80	0.019	415	8.0
14431	0.049	0.42	0.82	0.019	462	9.4
14509	0.034	0.45	0.84	0.020	440	7.8
13020	0.035	0.50	0.89	0.021	432	7.8
13019	0.051	0.49	0.87	0.020	421	8.2
14519	0.041	0.48	0.86	0.019	437	7.8
14860	0.051	0.51	0.90	0.019	450	5.5
14861	0.041	0.52	0.89	0.019	422	6.2
13965	0.039	0.47	0.89	0.019	416	8.6
13365	0.045	0.50	0.90	0.019	410	7.3
Grand mean	0.043	0.47	0.85	0.019	432	7.6
S.E.D	0.007	0.02	0.04	0.0007	23	0.6

Wood density

The mean value of the basic density of wood was 432 kg/m^3. There was no statistically significant difference in density between provenances. There was great tree-to-tree variation within the species, however, with values for trees ranging between 350 and 617 kg/m^3. Radial trends were also evident — the average values of the central and outer segments were 417 and 449 kg/m^3 respectively.

Vessel length

There were significant differences in the vessel length between provenances (SED = 0.02, p = 0.001), varying from 0.42 mm to 0.52 mm. The vessel length of individual trees ranged between 0.34 and 0.57 mm.

Fibre size

On average, wood fibre length was 0.85 mm (SED = 0.04, P = 0.05) and width 0.02 mm. Values for individual trees ranged between 0.72 and 1.03 mm.

Bark thickness

The thickness of bark of young *E. grandis* varied from 2.9 to 4.7 mm between provenances, with a mean of 3.7 mm for the species. Bark accounted for 7.6% of the overbark diameter.

Discussion and Conclusion

E. grandis will certainly become more important in plantation forestry in southern China as the techniques and application of vegetative propagation develop quickly in the next few years. Seed from north Queensland is preferable for planting in China because of higher growth rates.

Wood density is a critical characteristic for pulping and paper making of eucalypts (Higgins

1984; Hillis 1984). Wood density can be used as a criterion (Ikemori et al. 1986; Zobel and Buijtenen 1989) in tree breeding of *E. grandis*, particularly in progeny testing (rather than provenance selection). A new breeding project has been launched in China with progeny trials which include 150 families of *E. grandis*, and wood density will be an essential criterion for family selection.

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Results of *Eucalyptus pellita* trials at Dongmen, China

R.E. Pegg and Wang Guoxiang*

Abstract

A trial established in 1987 at Dongmen indicates some potential for *Eucalyptus pellita* in China, but performance falls short of that from *E. urophylla*. A second trial established at Dongmen in 1989, involving 79 families from nine provenances of *E. pellita* from Papua New Guinea and Queensland, shows variations at both family and provenance levels at 3 years. This trial suggests some superiority of the PNG and northern Queensland occurrence over that of the other Queensland occurrences if the Coen provenance is excluded from the northern group. A provenance from the southern occurrence (Kuranda) along with one of the PNG provenances (Ggoe) produced significantly more volume at 3 years than the other provenances.

For further improvement in the species, seedlots from the PNG and northern Queensland occurrence may produce better results in general than those from the southern group. The trial suggests, however, that there would still be merit in including seedlots from the southern group in future trials. There is little likelihood of plus tree selection for any tree improvement program from the poorer-performing provenances of the 1989 trial . But suggestions are made for conversion of the 1989 trial to a seed production area and for the selection of plus trees from the better performing provenances for use in the hybrid program.

THE species historically recognised as *Eucalyptus pellita* is recorded by Boland et al. (1984) as occurring from Batemans Bay in New South Wales (lat. 36°45′) to Iron Range in far north Queensland (lat. 12°45′). However, in 1986 during a seed collecting expedition by the Australian Tree Seed Centre (ATSC) and the Papua New Guinea (PNG) Department of Forestry, *E. pellita* was recorded in New Guinea (Thompson and Cole 1986 cited by Gunn et al. 1992). Later collections were made from extensive stands in Irian Jaya (Vercoe and McDonald 1991), but this seed was not available when the progeny trial was established at Dongmen.

The species occurs in Australia mainly in open-forest formation. In the northern part it is often associated with species such as *E. tereticornis*, *E. tessellaris*, *E. intermedia* and *E. torelliana* and in the southern areas with *E. gummifera*, *E. paniculata*, *E. botryoides* and *E. saligna*. In Papua New Guinea it is associated with species such as *Acacia aulacocarpa*, *A. mangium*, *Xanthostemon* sp., *Stenocarpus* sp. and *Grevillea baileyana*. On fertile sites trees of 40 m height and 1 m dbh are common.

Recent examinations of *E. pellita* by Johnson and Hill (1990) and Pinyopusarerk et al. (1992) have resulted in: 1) the recognition of the previously designated *E. pellita* in New South Wales as *E. scias* L. Johnson & K. Hill; 2) a tendency for a separation of *E. pellita* between the northern occurrences (New Guinea and northern Cape York Peninsula, Queensland) and more southern occurrences in Queensland (Helenvale to Rockhampton).

The separation of the historically recognised *E. pellita* is illustrated in Figure 1 (from Pinyopusarerk et al. 1992). The smaller leaves and more distinctly square stems of the northern provenances gives them noticeably different seedling morphology from the southern *E. pellita*.

Species Choice for Trial

E. pellita is closely related to *E. urophylla* (Pryor and Johnson 1971; Turnbull and Brooker 1978) which shows great potential as a plantation species in southern China. *E. pellita* shows some potential for planting in countries with tropical and subtropical climates where the annual rainfall exceeds

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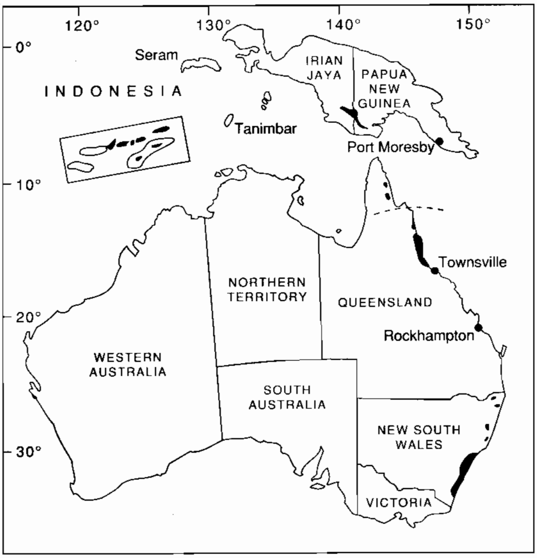

Fig. 1. Distribution of *E. urophylla* in Indonesia, *E. scias* in New South Wales and the northern and southern separation of *E. pellita* in PNG and Queensland (after Pinyopusarerk et al. 1992).

1000 mm. North Queensland provenances have shown promise in subtropical areas of Brazil with a rainfall of 1100–1500 mm.

At Dongmen (latitude 22°23′N and longitude 107°30′E) in the Guangxi Zhuang Autonomous Region, an unreplicated plot of a provenance of *E. pellita* from Helenvale in north Queensland (seedlot 11956) grew well for several years on a poor site, but growth later slowed markedly (Mo Qiping, Dongmen State Forest Farm, pers. comm.). Two other provenances from Kuranda (Batch 81) and Daintree (13826) in north Queensland showed good initial growth in the arboretum established at Dongmen in 1987 (Mo and McGuire 1989). At 21 months, these two provenances had mean heights of 6.28 and 5.81 m and volumes of 12.42 and 10.88 m^3/ha respectively, compared with a mean height of 6.36 m and a volume of 15.03 m^3/ha attained by the most productive taxa, *E. urophylla* (seedlot 14534 from Mt. Egon). Interest in *E. pellita* at Dongmen has been mainly as a possible species for hybridising with *E. grandis* and *E. urophylla*.

Reports from Hainan indicate some interest in using *E. pellita* as a plantation species. Seedlots 11956 (Helenvale), 13999 (Wenlock), and 15946 (Byfield) are reported to have performed well (Wen Wuyuan, Hainan Forestry Bureau, pers. comm.). One of these seedlots is identical to the one that reportedly slowed in growth at Dongmen after a fast start. In 1986, three seedlots of *E. pellita* (11947 (Kuranda), 11956 (Helenvale) and 13999 (Wenlock)) were included in a species/provenance trial in the semi-arid (about 1000 mm annual rainfall) red earth region of Hainan. At 16 months however, survival was low (less than 30% for each provenance (Wu and Wu 1988)). This result may indicate the unsuitability of the species to low rainfall areas.

Wang (1989), reporting on 18-month growth of a species/provenance trial at Zhangzhou in Fujian, ranked *E. pellita* (represented by seedlots 11947 (Kuranda) and 11956 (Helenvale)) among the top group of performers with 4.0–5.2 m average height.

In 1988, individual tree seedlots from the 1987 collection in PNG were available for trial in China, so these were obtained from the ATSC and combined with Australian seedlots for sowing and establishment in two trials at Dongmen.

Materials and Methods

Details of the seedlots of 80 individual mother trees from nine provenances of *E. pellita* used in the experiment established at Lei Ka Branch Farm in April 1989 are given in Table 1. All seedlots with the exception of Batch 81 were obtained from the ATSC. Batch 81 consists of 10 mother trees collected by the Queensland Forest Service. Rainfall data for individual PNG sites are not available, so figures from the Morehead meteorological station have been used in Table 1.

Four of the seedlots in this Dongmen trial — 14339, 15946, 16120 and 16121 — were used by Pinyopusarerk et al. (1992) in studies of seedling morphology. In the trial at Dongmen, the northern Queensland and PNG occurrence of *E. pellita* is represented by five seedlots (14339, 15652, 16120 and 16121) and the southern occurrence in Queensland by four seedlots (11947, 14211, 15652 and 81).

E. pellita from seedlot 16120 (from Mata, PNG) was also used in 1989 in a eucalypt species × fertiliser trial that tested all the promising Dongmen species. Details of the species and fertiliser regimes tested are in Table 2.

Establishment — family trial

From the area selected for the establishment of the family trial, the previous crop of *E. citriodora* was harvested (final crop yield at 21 years was 147 m^3/ha) and the stumps removed. Site cultivation was effected by ripping on the contour.

Table 1. Family trial: details of seedlots of *E. pellita* tested at Dongmen in 1989.

Seedlot	Provenance	Lat. S (° ′)	Long E (° ′)	Elev. (m)	Rain (mm)	No. parents
11947	Near Kuranda, Qld	16 14	145 33	450	2000	8
14211	5–12 km S of Helenvale, Qld	15 45	145 15	500	1733	10
14339	14.6 km NE of Coen, Qld	13 53	143 17	580	1200	18
15652	Keru, PNG	8 36	141 45	30	1913	3
15946	Byfield State Forest, Qld	22 55	150 38	30	1670	1
16120	6 km South Keru to Mata, PNG	8 36	141 45	30	1913	9
16121	North Tokwa to Kiriwa, PNG	8 30	141 25	45	1913	11
16122	Between Ggoe & Kiriwa, PNG	8 20	141 32	50	1913	10
81	SF 591 Abergowrie, Qld	18 25	145 57	50	2030	10

Table 2. Species x fertiliser trial details of seedlots used at Dongmen in 1989.

Species	Seedlot	Provenance	Lat. S or N (° ′)	Long. E or W (° ′)	Elevation (m)	Rainfall (mm)
E. exserta	Local	Dongmen	22 23	107 30	200	1213
E. citriodora	Local	Dongmen	22 23	107 30	200	1213
E. propinqua	9	Monto	24 52	150 58	480	730
E. saligna	46	Blackdown	23 50	149 05	760	1270
E. urophylla	14534	Mt Egon	8 38	122 27	500	1400
E. camaldulensis	21	Petford	17 20	144 50	770	800
E. tereticornis	14802	Kennedy R.	15 34	144 02	140	1600
E. pellita	16120	Mata	8 36	141 45	30	1913
E. grandis x *urophylla*	G-44	Aracruz, Brazil	19 48	48 17	30	1364
E. cloeziana	D47	Dongmen	22 23	107 30	200	1213
E. urophylla	D14534	Dongmen	22 23	107 30	200	1213
E. grandis	D68	Dongmen	22 23	107 30	200	1213

The soil is a lateritic clay loam typical of the Dongmen area. The slope of the area is slightly to the south at generally less than 2 degrees.

The design used was a non-contiguous single-tree plot; one plant from each of the 80 families used in the trial was planted in each unit of 8 rows × 10 trees at a spacing of 3 m × 2 m (only 79 families were finally established as one family from seedlot 16120 failed to produce sufficient plants for testing). Plants were randomly located within each unit to ensure each family and provenance covered the full range in site variation. Thirty units were established in April 1989. The location and family identity of each plant was recorded. Excess stock was planted in 50-tree family rows in the same sub-compartment.

The trial was fertilised in early June 1989 at the rate of N_{100} P_{50} K_{50} (where the subscript indicates the elemental kg/ha applied). Further details on trial establishment are given by McGuire (1989a).

Establishment — species x fertiliser trial

The experimental site in Qu Duo Branch Farm had supported a plantation of bamboo which was harvested in 1988. The bamboo rhizomes were removed by tractor and the site cultivated by ripping on the contour.

The soil is similar to that in the family trial site. The slope is slightly to the south at less than 1°.

The design used was a randomised block with split plots. Three fertiliser regimes were tested viz: Nil, N_{50} P_{25} K_{25} and N_{100} P_{50} K_{50}. Further details are given by McGuire (1989b).

Results

Arboretum

In July 1992 the two *E. pellita* and one *E. urophylla* plots in the arboretum were remeasured. Details of average predominant height and volume production are given in Table 3.

Table 3. Arboretum details of growth at 5 years 3 months in three plots established at Dongmen in 1987.

Species	Seedlot	Provenance	Average predom. ht (m)	Volume (m^3/ha)
E. pellita	81	Kuranda	17.0	106
E. pellita	13826	Daintree	18.6	118
E. urophylla	14534	Mt Egon	20.0	132

Family trial

The trial was measured annually. In this paper we report results as at May 1992. Parameters measured were dbh and height of all trees. Form was assessed using a scale of 1 (worst) to 6 (best). This assessment was done with the aim of achieving a normal distribution for this parameter. Figure 2 indicates that the assessment attained this aim.

Provenance variation Table 4 gives details of performance of the nine provenances as at May 1992.

Family variation As is usually observed in family trials of this nature there is a continuum of performance. Table 5 illustrates the range among the top 40 families in mean height and their ranking for volume and straightness.

Mean height in the trial ranges from 9.52 to 6.10 m. Volume production ranges from 58.0 m^3/ha for family 65 from Ggoe in PNG to 7.7 m^3/ha for family 30 from Coen. Volume production for family 65 was significantly higher (applying Duncan's multiple range test) than that of all the other families.

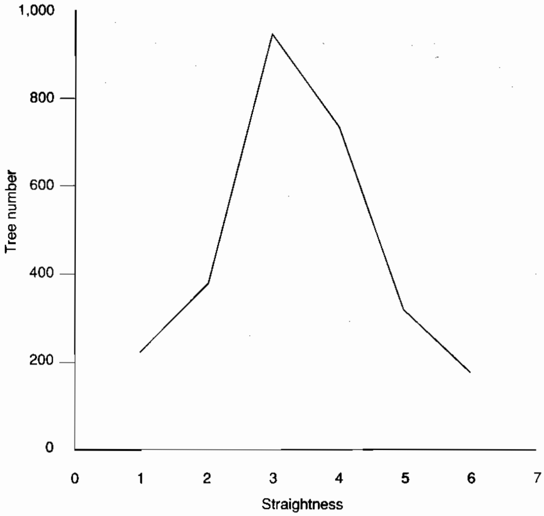

Fig. 2. Distribution of trees by straightness score in a 1989 *E. pellita* provenance/family trial at 3 years.

Flowering of E. pellita At Dongmen *E. pellita* has been observed to flower in the period September–December (Xiang Dongyun, Dongmen SFF, pers.comm.), that is at much the same time as *E. urophylla*. In this trial it appears that some trees set capsules during the first 18 months after planting.

Species x fertiliser trial

The results of volume production to May 1992 are given in Table 6. There has been little change in the ranking in growth from that at the previous measurement at 18 months, apart from the general pattern of a slowing of the well-known 'fast starters' *E. camaldulensis* and *E. tereticornis*.

Table 4. Family trial: details of *E. pellita* performance when families are aggregated into provenances, at approximately 3 years for volume per hectare, survival, mean height and mean straightness with outcome of Duncan's multiple range test (DMRT) for each.

Provenance	Volume (m^3/ha)	DMRT	Survival (%)	DMRT	Mean height (m)	DMRT	Mean straightness	DMRT
11947 Kuranda	38.6	I	98	I	8.6	I	3.3	I
16122 Ggoe	37.2	I	90	III	8.6	I	3.2	I
14211 Helenvale	32.4	I	95	II	8.2	I	3.1	I
15652 Keru	32.3	I	87	II	8.6	I	3.2	I
16120 Mata	31.7	I	90	III	8.6	I	3.1	I
16121 Tokwa	31.1	I	82	II	8.6	I	2.9	I
81 Abergowrie	24.0	I	90	II	7.9	II	3.36	I
14339 Coen	21.0	II	83	II	7.4	I	2.4	I
15946 Byfield	17.9	I	75	I	7.8	I	3.1	I

Table 5. Family trial: details at 3 years of the 40 top-ranking families of *E. pellita* for mean height with Duncan's multiple range test (DMRT) along with family ranking (top 25% = 1; lowest 25% = 4) for volume and straightness. Data for 39 poorer families are not presented.

Family	Provenance	Height (m)	DMRT for height	Volume rank	Straightness rank
55	16121 Tokwa	9.52	I	1	2
65	16122 Ggoe	9.49	II	1	1
60	16121 Tokwa	9.45	III	2	4
4	11947 Kuranda	9.19	IIII	1	1
45	16120 Mata	9.17	IIIII	1	1
39	15652 Keru	9.15	IIIIII	2	3
35	14339 Coen	9.14	IIIIIII	1	4
46	16120 Mata	9.07	IIIIIIII	2	3
52	16121 Tokwa	8.95	IIIIIIII	3	4
61	16122 Ggoe	8.93	IIIIIIII	1	3
41	16120 Mata	8.93	IIIIIIII	1	2
54	16121 Tokwa	8.92	IIIIIIII	2	1
69	16122 Ggoe	8.91	IIIIIIII	1	3
51	16121 Tokwa	8.89	IIIIIIII	3	2
9	14211 Helenvale	8.87	IIIIIIII	1	1
5	11947 Kuranda	8.81	IIIIIIII	1	1
2	11947 Kuranda	8.79	IIIIIIII	1	1
43	16120 Mata	8.78	IIIIIIII	2	2
70	16122 Ggoe	8.71	IIIIIIII	2	1
22	14339 Coen	8.70	IIIIIIII	2	4
63	16122 Ggoe	8.66	IIIIIIII	2	3
67	16122 Ggoe	8.66	IIIIIIII	1	1
53	16121 Tokwa	8.65	IIIIIIII	2	4
1	11947 Kuranda	8.64	IIIIIII	1	4
38	15652 Keru	8.63	IIIIIII	1	4
57	16121 Tokwa	8.61	IIIIII	2	4
12	14211 Helenvale	8.60	IIIIII	1	2
64	16122 Ggoe	8.55	IIIII	1	2
8	11947 Kuranda	8.50	IIIII	1	3
50	16121 Tokwa	8.41	IIIII	2	1
3	11947 Kuranda	8.38	IIIII	1	2
44	16120 Mata	8.35	IIIII	3	1
80	10 Abergowrie	8.34	IIIII	3	2
48	16120 Mata	8.33	IIIII	3	4
78	10 Abergowrie	8.32	IIIII	3	1
16	14211 Helenvale	8.31	IIII	2	3
77	10 Abergowrie	8.29	III	2	1
10	14211 Helenvale	8.28	II	1	2
76	10 Abergowrie	8.26	I	2	2
71	10 Abergowrie	8.34	I	3	3

Table 6. Species x fertiliser trial: volume production (m^3/ha) of various eucalypt species under three fertiliser regimes at 3 years at Dongmen.

Species	Seedlot	Fertiliser treatment			Mean
		Nil	N_{50} P_{25} K_{25}	N_{100} P_{50} K_{50}	
E. exserta	Local	6.3	22.4	17.1	15.3
E. citriodora	Local	4.7	15.6	23.1	14.5
E. propinqua	9	16.0	41.3	41.0	32.8
E. saligna	46	4.8	25.5	22.1	17.5
E. urophylla	14534	17.8	48.4	51.2	39.2
E. camaldulensis	21	10.3	30.6	38.8	26.6
E. tereticornis	14802	17.4	28.9	47.4	31.2
E. pellita	16120	9.9	23.6	28.2	20.6
E. grandis x *urophylla*	G-44	24.5	56.4	65.4	48.7
E. cloeziana	D47	20.4	32.5	39.1	30.7
E. urophylla	D14534	19.6	46.1	40.6	35.4
E. grandis	D68	8.6	24.9	36.1	23.2

Discussion

Arboretum

The growth of *E. urophylla* in the arboretum is about average for the species when fertilised at N_{100} P_{50} K_{50} at Dongmen with a MAI of approximately 25 $m^3/ha/a$. The performance of the two *E. pellita* provenances is somewhat inferior, although the two plots are perhaps on a slightly better site than the *E. urophylla*. However, there are some promising trees for selection in the *E. pellita*, e.g. in the plot of the Daintree provenance (seedlot 13826) there is a very straight tree of good form and height of 19.5 m and dbh of 18.7 cm.

Family trial

A striking feature of the results of the family trial (Table 4) is the very poor performance of the Coen provenance (seedlot 14339) in both growth and form: in the analysis of straightness this provenance was significantly poorer than all the other provenances. This is rather surprising as the Coen source of *E. pellita* is highly regarded in Brazil (J. Doran, pers. comm.). In fact, the collection of seedlot 14339 was undertaken in 1983 as a collaborative effort by the ATSC and EMBRAPA (the Brazilian forestry authority). The trees in the collection area are not particularly large — maximum height is about 25 m and bole height is of the order of 4–10 m, with 4–6 m being most common.

No firm conclusion can be drawn about the most southerly provenance (seedlot 15946), as it is represented by only one family which is not among the top 40 performers and does not rank very highly for any parameter. It is probable this provenance is of little interest for plantation work in China.

The two provenances that have volume production significantly superior to the others are Kuranda (seedlot 11947) and Ggoe (seedlot 16122) (Table 4).

Aggregation of the provenances into the northern occurrence and the southern occurrence of *E. pellita* (as defined by Pinyopusarerk et al. 1992) produces average volumes per hectare (without weighting for the number of families per provenance) of 30.7 m^3/ha for the northern five and 28.2 m^3/ha for the southern four. However if weighting is applied these figures become 28.9 m^3/ha and 30.7 m^3/ha respectively. If the Coen provenance is excluded from the northern occurrence (to leave only the PNG provenances), the weighted mean for volume becomes 33.3 m^3/ha. Thus there may be some trend for PNG provenances on the average to offer some promise in south China.

The data in Table 5 for the top half (40) of the families in the trial on the basis of mean height show a high representation of PNG families in the top ranks. Table 7 examines the distribution of the first-ranked 10 families (i.e. the top 12.6%) for various parameters.

The most promising provenances (from the data in Tables 4, 5 and 7) are from PNG and Kuranda, but there could still be some plus tree candidates in provenances such as Helenvale. There are unlikely to be many potential breeding candidates from within the Coen, Abergowrie or Byfield provenances.

Table 7. Family trial: provenances of the top 10-ranked families of *E. pellita* at 3 years for mean height, mean dbh, volume production and stem form.

Provenance	Total no. of families	Frequency of occurrence of best 10 families			
		Mean height	Mean dbh	Vol/ha	Stem form
11947 Kuranda	8	1	2	3	2
14211 Helenvale	10	—	1	1	—
14339 Coen	18	1	1	1	—
15652 Keru	3	1	—	—	1
15946 Byfield	1	—	—	—	—
16120 Mata	9	2	2	2	2
16121 Tokwa	11	3	1	1	1
16122 Ggoe	10	2	3	2	2
81 Abergowrie	10	—	—	—	2

The family line plots of excess stock could be exploited should there be a desire to vegetatively reproduce outstanding trees for clonal testing. Plus tree candidates for testing via seedling progeny and for use in the hybrid program could be selected now.

There is a need to record the time of flowering of each family to see if there are differences between provenances which could affect the general pattern of pollination within the trial area.

Species x fertiliser trial

The data from the species x fertiliser trial (Table 6) indicate the general superiority in growth of *E. urophylla* and the hybrid *E. grandis* x *E. urophylla* over that of *E. pellita* at Dongmen. There is no evidence of any difference in response to fertiliser application between these three taxa. The growth in the species x fertiliser trial is somewhat lower than that in the family trial and below what might be expected generally at Dongmen. For the Mata seedlot of *E. pellita* volume production at the N_{100} P_{50} K_{50} fertiliser regime was 28.3 m^3/ha in the species x fertiliser trial compared with 31.7 m^3/ha in the family trial.

Conclusions and Recommendations

In accordance with the plan for managing family trials at Dongmen (Nikles 1989), the trial should now be thinned to half stocking on a silvicultural basis. Thinning prior to flowering will upgrade the next seed crop.

Systematic crossing of about six plus trees from this trial with *E. urophylla*, *E. grandis and E. grandis* x *E. urophylla* may produce productive hybrids. There is currently interest in some other countries in the use of *E. pellita* in hybrid combinations e.g. with *E. urophylla* in Sumatra (Werren 1991) and in the Congo (Verignon 1991). Wang (1989) demonstrated that *E. pellita* has smaller crowns than species such as *E. urophylla* and *E. grandis*, which may result in better resistance to strong winds. This characteristic could be beneficial in hybrid combinations for use in areas subject to frequent typhoons.

From an exchange of Dongmen seed with a colleague in South Africa, we have, among a range of 39 hybrid seedlots, for sowing late in 1992 six lots of hybrid seed involving *E. pellita*. The species combinations are *E. grandis* x *E. pellita* (four lots) and (*E. grandis* x *E. urophylla*) x *E. pellita* (two lots). These hybrids will be tested in 1993 in trials involving Chinese hybrids and other select material.

With the promise shown to date by the PNG provenances in the family trial, seedlots of *E. pellita* from the 1990 collections from Irian Jaya (Vercoe and McDonald 1991) should be obtained from the ATSC for testing in China. These collections are from areas with humid conditions and an annual rainfall of over 2000 mm. One possible test site would be in Hainan, where there is some interest in *E. pellita* as a plantation species.

Acknowledgments

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Trials of *Eucalyptus smithii* and other Eucalypt Species in Yunnan Province, China

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Abstract

A trial established in July 1987 at Haikou Forest Farm, 50 km southwest from Kunming City, comprised 30 species and provenances of temperate eucalypts from Australia. The experimental design was randomised complete blocks, with nine replicates and nine-tree single row plots. Local landraces of *Eucalyptus maidenii* and *E. globulus* were used as controls. At age 4.5 years, significant differences were found between species and provenances in growth rates, pest resistance and adaptability. *E. smithii* (15092, 15059), *E. benthamii*, *E. badjensis*, *E. nitens* and *E. camphora* had faster growth than local *E. maidenii*, and provenance 15092 of *E. smithii* exceeded local *E. maidenii* in volume by 101%. In addition to above species and provenances, *E. grandis*, *E. chapmaniana*, *E. smithii* (15091, 15090), *E. nova-anglica*, *E. amplifolia*, *E. cypellocarpa* (12655, 9440) and *E. deanei* (14521) had faster growth than local *E. globulus*. *E. camphora* and local *E. globulus* had the highest survival while *E. cypellocarpa* and *E. smithii* (15090) had the lowest. Newly-introduced species are more resistant to pests and diseases than the two controls. Several species suffered slightly from drought, *E. benthamii* and *E. triflora* being affected more than others. Frost damaged all species, most severely *E. cypellocarpa*. Of those that exceeded local *E. maidenii* in growth, all but *E. benthamii* have higher essential oil content than the controls.

EUCALYPTUS species have been widely planted throughout the world. First introduced to China 100 years ago, they are now some of the most productive trees planted in southern China.

The first introductions to China were on a small scale and limited by the less developed science, technology and management methods of that time. Many eucalypt species and provenances, especially those suitable for the cool subtropical areas in China, remained unexplored.

Most species in this trial naturally occur in temperate or high mountain areas in Australia. For instance, *E. pauciflora*, *E. dalrympleana* and *E. delegatensis* occur where there is snow in winter (Brooker et al. 1971–78; Boland et al. 1984). Such species resist low temperatures but were ignored in early introductions of eucalypts to China. This test is the first time most of them have been systematically studied in China.

The trial is part of the ACIAR/CAF cooperative Project 8457, and is intended to select species and provenances for cool areas in the subtropics of China for wood production, essential oil production and landscaping.

Materials and Methods

Species and provenances

Seed provided by the Australian Tree Seed Centre was bulked and collected from natural stands (Table 1).

Experiment site

The experimental site is on a northwesterly slope of 15–20 degrees in Haikou Forest Farm, 50 km southwest of Kunming City, at longitude 102°34 'E,

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Table 1. Details of species and provenances.

Species	Seedlot	Location	Lat.	Long.	Alt. (m)
E. amplifolia	13349	NSW	36°32′	149°15′	900
E. badjensis	13286	NSW	31°27′	151°15′	150
E. benthamii	14214	NSW	35°17′	148°49′	1070
E. camphora	12448	ACT	36°16′	147°01′	140
E. chapmaniana	9775	Vic	34°51′	148°54′	490
E. cinerea	11711	NSW	34°39′	150°29′	0
E. cypellocarpa	12910	Vic	37°12′	148°42′	860
E. cypellocarpa	9440	NSW	38°25′	146°29′	520
E. cypellocarpa	12655	Vic	31°27′	151°15′	1250
E. dalrympleana	12563	NSW	34°13′	150°31′	240
E. deanei	14521	NSW			
E. deanei	10340	NSW	33°02′	151°25′	370
E. deanei	11688	NSW	29°48′	152°07′	950
E. grandis	8602	—			
E. johnstonii	11825	Tas	42°30′	147°35′	670
E. laevopinea	14840	NSW	31°30′	151°06′	186
E. macarthurii	15057	NSW	34°39′	150°10′	600
E. mannifera	12159	Vic	34°51′	148°54′	0
E. neglecta	9751	Vic	36°42′	146°53′	760
E. nitens	12401	Vic	37°27′	147°57′	1100
E. nova-anglica	13606	NSW	31°09′	151°31′	1045
E. parvifolia	12284	NSW	34°04′	149°30′	1300
E. propinqua			—		
E. scoparia	12576	ACT	35°17′	149°06′	620
E. smithii	15091	NSW	36°00′	150°00′	450
E. smithii	15059	NSW	36°18′	150°01′	305
E. smithii	15092	NSW	34°42′	150°10′	650
E. smithii	15090	NSW	37°05′	149°47′	220
E. globulus		Yunnan			
E. maidenii		Yunnan			

latitude 24°50′N and altitude 1970–2030 m. The soil is mountain red soil derived from limestone, 80–100 cm in depth and containing 0.43% organic matter, 0.036% N, 2.3 ppm P and 53 ppm K. The site experiences a cool subtropical climate with mean annual temperature of 15°C, absolute maximum temperature of 30°C, absolute minimum temperature of −6.8°C, frost on 85 days and annual rainfall of 940 mm. Most rainfall occurs in summer and the dry season in winter is relatively long. There is evidence that boron may be deficient.

Experimental design

The design used was randomised complete blocks with nine replicates and nine-tree single-row plots. Initial spacing was 2 × 2 m. Local seedlots of *E. globulus* ssp. *maidenii* and ssp. *globulus* were used as controls.

Data analysis

Data were processed with Datachain (Roger and Muraya 1991) and analysed with Genstat 5 (Lane et al. 1987). *E. pauciflora*, *E. johnstonii* and *E. triflora* were excluded from analysis because they had insufficient seedlings or low survival.

Establishment

The site was fully prepared before planting holes 60 × 60 × 60 cm were dug. NPK fertiliser (100 g) was put in each hole before planting. Seedlings were transplanted at a spacing of 2 × 2 m at age 3.5 months.

Seed was directly sown in the seedbed. Seedlings were transferred to plastic containers after 3–4 pairs of leaves appeared. Soil in the container consisted of 87% subsoil, 10% ash and 3% compound NPK fertiliser.

Results

Growth

Species comparison Table 2 compares the growth of the 32 species. At age 1.5 years, significant differences existed in height, diameter and crown width between species and provenances. Eighteen species and provenances exceeded local *E. globulus* and 10 species and provenances exceeded local *E. maidenii* in height.

At age 4.5 years, significant differences between species were found in height, diameter, volume and survival. *E. smithii* (15092), *E. benthamii*, *E. badjensis*, *E. nitens*, *E. smithii* (15059), and *E. camphora* ranked highly on volume, and had greater volume than local *E. maidenii*. The volume of local *E. globulus* was less than the grand mean and also less than that of local *E. maidenii*. In addition to those exceeding local *E. maidenii*, *E. grandis*, *E. macarthurii*, *E. chapmaniana*, *E. smithii* (15091, 15090), *E. nova-anglica*, *E. amplifolia*, *E. cypellocarpa* (9440, 12655) and *E. deanei* (14521) had greater volume than local *E. globulus*.

Provenance comparisons Significant differences were found between four provenances of *E. smithii*. Provenances 15092 and 15059 exceeded local *E. maidenii* and 15091, 15090 exceeded local *E. globulus* in volume. The largest 15092 exceeded the smallest 15090 by 162% in volume (Table 2).

Table 2. Growth, survival and other factors observed at 1.5 and 4.5 years of age.

At 1.5 years

Species	Seedlot	Ht (m)	Dbh (cm)	Cw (m)	Sv (%)	Ds (%)	Ps (%)	Dr (%)	Fr (%)
E. smithii	15092	2.29	2.4	1.65	99	0	1.4	0	35
E. benthamii	14214	2.01	2.5	1.54	93	0	0	18	29
E. badjensis	13286	1.94	2.2	1.35	92	0	2.8	1.4	30
E. nitens	12401	1.68	2.5	1.50	95	0	2.8	0	29
E. smithii	15059	1.97	2.0	1.48	94	0	1.4	0	35
E. camphora	12448	2.36	2.0	1.38	97	0	0	0	11
E. maidenii	Yunnan	1.85	2.0	1.51	99	18	9.7	1.4	16
E. grandis	8602	2.00	2.2	1.52	99	0	0	1.4	44
E. macarthurii	15057	1.39	2.2	1.29	91	0	0	0	36
E. chapmaniana	9755	2.24	2.3	1.63	99	0	4.2	0	24
E. smithii	15091	2.08	2.2	1.54	95	0	0	0	40
E. nova-anglica	13606	1.82	2.3	1.49	97	0	0	0	1
E. smithii	15090	1.78	2.0	1.34	93	0	1.4	0	42
E. amplifolia	13349	1.71	1.9	1.29	100	0	5.6	0	31
E. cypellocarpa	12655	1.89	2.0	1.47	91	0	0	0	39
E. deanei	14521	1.89	2.2	1.45	100	0	0	0	15
E. cypellocarpa	9440	1.75	2.2	1.40	99	0	0	0	39
E. globulus	Yunnan	1.60	2.0	1.46	99	32	2.8	0	27
E. parvifolia	12284	1.42	1.7	1.09	87	0	0	5.6	11
E. scoparia	12576	1.70	2.1	1.33	91	1	4.2	0	1
E. laevopinea	14840	1.47	1.8	1.14	88	0	8.3	4.2	17
E. mannifera	12159	1.61	1.6	1.28	92	0	2.8	0	15
E. cypellocarpa	12914	1.89	2.3	1.48	95	0	2.8	1.4	49
E. deanei	11688	1.46	2.1	1.24	96	0	0	0	36
E. dalrympleana	12563	1.28	2.0	1.24	91	0	2.8	1.4	3
E. deanei	10340	1.44	1.5	1.26	95	0	2.8	0	22
E. propinqua	unknown	1.65	2.0	1.18	85	0	0	0	62
E. cinerea	11711	1.44	1.9	1.35	96	0	1.4	0	12
E. neglecta	9751	1.29	1.7	1.28	100	0	5.6	2.8	17
E. johnstonii	11825	1.45	1.7	0.74	80	0	6.9	2.8	25
E. pauciflora	13831	1.23	1.7	0.83	82	10	4.2	0	3
E. triflora	14207	1.43	1.5	0.85	61	0	0	28	31
	Mean	1.72	2.02	1.33	93	1.92	2.31	2.13	26

Table 2. (continued)

At 4.5 years

Species	Seedlot	Ht (m)	Dbh (cm)	Vl (m^3)	Sv (%)
E. smithii	15092	6.1	6.7	0.0139	79
E. benthamii	14214	6.7	7.3	0.0119	82
E. badjensis	13286	6.2	5.9	0.0111	76
E. nitens	12401	5.7	5.8	0.0089	68
E. smithii	15059	5.7	5.6	0.0087	65
E. camphora	12448	6.5	6.3	0.0080	95
E. maidenii	Yunnan	5.7	5.8	0.0069	93
E. grandis	8602	5.2	5.0	0.0066	79
E. macarthurii	15057	4.9	5.3	0.0064	65
E. chapmaniana	9755	5.7	5.2	0.0063	85
E. smithii	15091	5.8	5.1	0.0061	78
E. nova-anglica	13606	4.9	4.7	0.0057	70
E. smithii	15090	4.8	4.9	0.0053	56
E. amplifolia	13349	4.7	4.5	0.0052	81
E. cypellocarpa	12655	4.8	4.4	0.0051	70
E. deanei	14521	4.8	4.9	0.0047	96
E. cypellocarpa	9440	4.6	4.3	0.0042	81
E. globulus	Yunnan	4.5	4.4	0.0037	74
E. parvifolia	12284	4.8	4.4	0.0034	67
E. scoparia	12576	4.2	4.1	0.0029	68
E. laevopinea	14840	3.7	3.9	0.0028	68
E. mannifera	12159	3.7	3.8	0.0027	62
E. cypellocarpa	12914	4.5	4.2	0.0027	81
E. deanei	11688	3.8	4.1	0.0026	65
E. dalrympleana	12563	3.6	3.3	0.0018	64
E. deanei	10340	3.3	2.9	0.0014	69
E. propinqua	unknown	3.1	3.0	0.0011	54
E. cinerea	11711	3.2	2.8	0.0011	56
E. neglecta	9751	2.4	1.8	0.0003	89
	Mean	4.7	4.6	0.0052	74

Ht: height; Dbh: diameter at breast height; Cw: Crown width; Sv: survival; Ps: pests; Ds: disease; Dr: drought; Fr: frost; Vl: volume.

Three provenances of *E. cypellocarpa* were significantly different in growth. They all have smaller volume growth than local *E. maidenii*, but provenance 12655 and 9440 exceeded local *E. globulus* by 38 and 13% in volume respectively, and also exceeded 12914 by 89 and 56% respectively (Table 2).

There were significant differences between three provenances of *E. deanei*. All of them are significantly inferior to local *E. maidenii*; provenance 14521 is superior to local *E. globulus* in volume. The largest provenance 14521 exceeded local *E. globulus* and the smallest 10340 by 27 and 236% in volume respectively (Table 2).

Growth patterns

Table 3 gives the ranking of species and provenances at different ages. It showed three types of ranking pattern: (1) ranks remain stable — *E. benthamii*, *E. smithii* (15091, 15092), *E. badjensis* and *E. camphora* ranked highly, while *E. neglecta*, *E. deanei* and *E. triflora* ranked low; (2) the ranks change steadily — *E. nitens* and *E. maidenii* ranked increasingly with age, while *E. grandis*, *E. cypellocarpa* and *E. deanei* ranked decreasingly with age; (3) the ranks change randomly — this was the case with *E. scoparia*, *E. smithii* (15090) and *E. amplifolia*.

Table 3. Height ranking at different ages.

Species	Seedlot	0.5	1.5	2.5	3.5	4.5
E. benthamii	14214	2	5	4	1	1
E. camphora	12448	9	1	1	3	2
E. badjensis	13286	4	4	3	4	5
E. smithii	15092	1	3	2	2	4
E. smithii	15091	3	4	3	4	5
E. maidenii	Yunnan	18	10	16	6	6
E. nitens	12401	18	16	14	5	7
E. chapmaniana	9755	12	2	7	7	8
E. smithii	15059	8	8	9	8	9
E. grandis	8602	5	6	6	10	10
E. nova-anglica	13606	16	11	21	11	11
E. macarthurii	15057	20	25	11	13	12
E. parvifolia	12284	24	23	19	20	13
E. cypellocarpa	12655	12	9	5	15	14
E. deanei	14521	10	7	12	14	15
E. smithii	15090	9	12	10	9	16
E. amplifolia	13349	13	15	17	15	17
E. cypellocarpa	9440	11	14	16	18	18
E. globulus	Yunnan	21	19	20	17	19
E. cypellocarpa	12914	7	9	15	17	20
E. scoparia	12576	17	15	18	19	21
E. deanei	11688	14	24	27	16	22
E. laevopinea	14840	24	20	24	21	23
E. mannifera	12159	20	18	23	23	24
E. dalrympleana	12563	26	27	29	25	25
E. deanei	10340	15	22	26	24	26
E. propinqua	unknown	6	17	25	22	27
E. cinerea	11711	19	22	32	26	28
E. neglecta	9751	22	26	28	29	29
E. triflora	14207	27	21	22	10	
E. pauciflora	13831	25	28	30	28	
E. johnstonii	11825	23	21	31	27	

Survival

At age 4.5 years, survival of *E. deanei*, *E. camphora* and *E. maidenii* was over 90%, *E. propinqua* was 54% and *E. smithii* (15090) was 56%. Survival of the others ranged from 60 to 90%. There was no correlation between survival rate and growth (Table 2).

Pests and diseases

At age 1.5 years, diseases were found only on *E. scoparia*, *E. pauciflora* and two controls. The incidence of disease on *E. scoparia* and *E. pauciflora* was significantly lower than on the two controls. Light pest damage was found on a few species, the highest incidence of 9.7% being on local *E. maidenii* (Table 2).

Drought and frost

Several species suffered slightly from drought. The incidence of drought damage on *E. benthamii* and *E. triflora* was 18 and 28% respectively, whereas on the others it was lower than 6%. The rainfall from January to April in the year was 38 mm (Table 2).

Frost damage was found on all species at age 1.5 years following an absolute minimum temperature of −1.3 °C. Big differences existed between species and provenances. *E. propinqua* had the highest incidence of 62.%, and the incidence on local *E. maidenii* and *E. globulus* was 16 and 27% respectively. *E. scoparia*, *E. nova-anglica*, *E. parvifolia* and *E. camphora* had the lowest incidence (Table 2).

Leaf essential oils

Essential oils of eucalypts are important medicinal and chemical materials, and cineole content is the main commercial characteristic. Table 4 presents the oil and cineole contents for faster-growing species in the trial. *E. smithii* exceeded local *E. maidenii* in both oil and cineole content (by 36 and 21% respectively). The oil content of *E. benthamii* is only 27% of local *E. maidenii* and its cineole content is minimal. The oil contents of *E. camphora* and *E. badjensis* are close to that of the control, but their cineole contents are higher (Table 4).

Species selection

For wood production, it was concluded that the species/provenances outperforming local *E. maidenii* should be planted on a large scale. Species exceeding local *E. globulus* are promising and need further testing, while those growing slower than local *E. globulus* should not be used for wood production. Table 4 compares several fast-growing species and local *E. maidenii*. Note that the volume of provenance 15092 of *E. smithii* exceeded that of the control by 101%.

For oil production, the oil content is the main criterion for species and provenance selection. Species and provenances listed in Table 4, excluding *E. benthamii* and *E. nitens*, could be used for commercial oil production.

Discussion

The typical summer rainfall and the relatively long dry season in Kunming are the main factors affecting growth of the eucalypts. Most species and provenances naturally occur in areas of Australia with high altitude or high latitude, and the climate in their natural range is cool. They are more resistant to low temperatures. During winter and spring, shoots of a few species died (possibly from drought) and leaves of some species, especially of *E. grandis* and *E. deanei*, became reddish purple — clearly a reaction to low temperatures. Additionally, boron deficiency probably limits growth. The effects of drought, low temperature and boron deficiency on the growth of eucalypts need further study. Moreover, the seasonal incidence of rainfall may affect growth — for instance *E. johnstonii* and *E. pauciflora*, with lower growth rates, are from a winter rainfall area.

The results indicate that most recently introduced eucalypt species are superior to local *E. maidenii* and *E. globulus* in growth and disease resistance. Those species selected for wood and oil production have limited distribution in Australia. Multi-site experiments should be carried out to select species and provenances for different environments, and to assess biomass production. Management models are needed for oil production.

The trial species *E. pauciflora*, *E. triflora* and *E. laevopinea* belong to the subgenus *Monocalyptus*. There are few reports of successful introductions of *Monocalyptus* elsewhere in the world, but they grew normally in the environment of the trial, although at low rates of survival. More tests should be done in carefully selected local environments.

Most species in the trial were introduced to China for the first time. The trial is an important resource for the further development of breeding populations in China.

Because of early strong competition between species and provenances, the experimental design with single-row plots and relatively close spacing (2 × 2 m) is not suitable for long-term evaluation of fast-growing trees.

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Table 4. Oil content, cineole content and volume increment of several fast-growing species compared to the control.

Species	Oil content (% fresh weight)	Cineole content (% fresh weight)	Volume (m^3)	Volume increment (%) above the control
E. smithii 15092	1.50	80	0.014	101
E. smithii 15059	1.20	82	0.009	26
E. camphora	1.00	74	0.008	16
E. benthamii	0.30	trace	0.012	72
E. badjensis	1.00	70	0.011	61
E. nitens	—	—	0.009	29
local *E. maidenii*	1.10	66	0.007	

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Genetic Variation in a Provenance Trial of *Eucalyptus tereticornis*

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Abstract

Ten provenances of *Eucalyptus tereticornis* from Australia were evaluated 5 years after planting in a semi-arid area in southwestern Hainan Island. Variances were estimated for six traits, and correlations were found among some traits. There were highly significant differences in all traits. Provenances from Queensland were better than those from New South Wales and Victoria. Provenances with superior performance were identified as 13443 from Kennedy River Queensland and 13544 from north of Gladstone Queensland. Suggestions are offered for further improvement.

*E*UCALYPTUS *tereticornis* is one of the most widely introduced and cultivated eucalypts in the world due to its multipurpose wood products, rapid early growth, ability to endure both wind and drought, and an apparently low fertiliser requirement. This species occurs naturally in Australia and Papua New Guinea with the most extensive latitudinal distribution in the genus *Eucalyptus*, extending from southern Papua New Guinea (5°20′S) to southeastern Victoria of Australia (38°08′S). In the southern part of its range it generally occurs in coastal areas; but in higher rainfall areas it extends into the Great Dividing Range and tablelands of north Queensland. The altitudinal range is from near sea level to about 1150 m in north Queensland, and up to 2000 m in Papua New Guinea (Jacobs 1981). It generally prefers fairly alluvial soils, sandy or gravelly loams which are moist but not waterlogged (Boland et al. 1984).

In recent years some tropical and subtropical developing countries have been paying great attention to the genetic improvement of *E. tereticornis*, making a wide selection of superior individual trees for developing breeding populations, using vegetative propagation techniques to speed genetic improvement and mass produce improved planting stock (Hong Jusheng et al. 1991). In China, systemic studies on the introduction and silviculture of the species have been conducted with the support of ACIAR Projects 8457 and 8848, 'Introduction and Cultivation Experiments of Australian Broadleaved Tree Species' and an AIDAB project, 'Eucalypts Afforestation Project at Dongmen'. The ACIAR projects had the main aims of selecting species and provenances to increase productivity of eucalypt plantation in southern China and of improving wood quality for industrial purposes (Bai Jiayu 1988). An improvement program including progeny testing, establishing a breeding population, refining vegetative propagation techniques and selection has been undertaken. An understanding of variation in basic natural populations is of great importance in choosing strategies of breeding and utilisation.

This paper reports results from one of the oldest tropical *Eucalyptus* species/provenance trials of the ACIAR projects in China. This trial was established on the semi-arid land in southwestern Hainan Island in August 1986.

Materials and Methods

Plant material

Seed for all plantings was supplied by the CSIRO Australia Tree Seed Centre in Canberra. Details of the seed sources used are in Table 1. The species/provenance trial comprised 56 provenances from 16 species including *E. tereticornis.*

Trial site

The trial is located at Lingtou, 8 km W of Jianfengling Town, Ledong county of Hainan Island (18°42′N, 108°52′E, 20 m asl), and 1 km from the sea.

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Table 1. Seed sources of *Eucalyptus tereticornis* used in the trial.

Seedlot No.	No. of parent trees	Location	Lat. (° 'S)	Long. (° 'E)	Alt. (m)	Climate type*
13303	5	Sale Vic	38 07	147 04	10	Cfb
13307	8	Windsor NSW	33 32	150 50	100	Cfb
13319	6	N of Woolgoolga NSW	29 55	153 12	30	Cfb
13350	10	S of Urbenville NSW	28 35	152 24	400	Cfa
13544	10	40 km N of Gladstone Qld	23 44	151 01	10	Cfa
13446	4	N of Cardwell Qld	18 16	146 00	40	Cwa
14424	30	Ravenshoe Qld	17 39	145 21	700	Aw
13442	7	N of Mareeba Qld	16 55	145 25	380	Aw
14115	30	S of Helenvale N Qld	15 46	145 14	120	Aw
13443	10	Kennedy River Qld	15 26	144 11	60	Aw

*Note: Cfb — Uniform rainfall, long warm summer, cool winter
Cfa — Uniform rainfall, long hot summer, mild winter
Cwa —long hot moist summer, mild dry winter
Aw — marked dry season in winter (Plumb 1973).

The climate is tropical monsoon with typhoons occurring in August and September. Average annual rainfall is 1080 mm, falling mostly in August and September each year; November to May is a dry season with monthly rainfall less than 30 mm. Mean annual temperature is 25.2 °C. The lowest temperature recorded is 5.8 °C.

Soil on the site is a red sandy latosol derived from granite. The 0–40 cm soil layer is 0.58% organic matter, hydrolytic nitrogen 2.89%, available P 1.82%, available K 7.14% and with pH of 6.6. The soil was highly disturbed during site preparation for the trial. This involved the complete removal of *Casuarina cunninghamiana* and *Eucalyptus exserta* from the site.

Establishment and design

After the original trees were cut and the stumps removed, the land was ploughed twice. Planting holes (40 × 40 × 40 cm) were dug and 1000 g barnyard manure and 150 g superphosphate as basal fertiliser added to each hole and covered with soil. A randomised blocks design with four replications was used. There were 20 trees in each plot, spaced at 2 × 2 m. *Eucalyptus exserta* was planted as a control treatment. All experimental trees were planted in August 1986.

Statistical analysis

An index of resistance to wind (irw) was calculated in October 1987 and August 1991 following two typhoons that affected Qionghai and Ledong counties. These typhoons had wind speeds of force 7 and gusts of force 8. For each provenance irw was calculated using the formula:

$$\text{irw} = 1 - (X_1/X_2) \times 100\%$$

where X_1 is the number of damaged trees (with an angle between the tree and ground from 0 to 75° and broken stems) and X_2 represents the total number of observed trees in each plot. Plot means were calculated for tree height (h), diameter at breast height (dbh), the under-branch height (ubh), rate of current survival (rcs), value of h/dbh (vhd) and irw. Data contributing to each plot mean were examined using Bartlett's test for homogeneity of variances (Schefler 1979). Rcs and irw were transformed using arcsin X^{-2} prior to variance and covariance analyses. All the statistical analyses were carried out using the package GENSTAT 4.03 (Alvey et al. 1982).

Results

Variance analysis of traits (see Tables 2 and 3) indicated that there were highly significant differences between provenances. The fraction which the provenance variance component represented in the total variance was quite different between traits, being 0.86, 0.75, 0.69, 0.57, 0.46, 0.45 for ubh, irw, rcs, h, vhd and dbh respectively.

The correlations (see Table 4) among **h, dbh, ubh,** rcs and irw were strong and positive relationship but those with vhd were generally small and negative.

Table 2. Trait means for 10 provenances of *E. tereticornis* and the *E. exserta* control at 5 years of age.

	H (m)	Dbh (cm)	Ubh (m)	Vhd	Rcs (%)	Irw (%)
E. tereticornis						
13303	5.45	4.36	1.74	126.1	35.1	50.0
13307	7.42	6.69	2.61	111.1	52.4	57.2
13319	7.94	6.95	3.31	115.1	54.0	72.9
13350	7.73	7.10	2.91	110.0	56.2	64.6
13544	10.52	8.99	5.16	118.2	68.5	88.1
13446	8.42	7.91	3.06	107.7	58.1	90.1
14424	9.21	8.45	3.91	109.3	72.4	85.2
13442	8.49	7.85	3.15	108.7	78.5	87.3
14115	7.98	7.66	2.81	104.7	63.6	89.0
13443	10.63	8.76	5.00	122.2	91.3	89.0
E. exserta	7.40	6.68	3.55	110.8	71.2	65.4

Ubh = under-branch height; Vhd = h/dbh; Rcs = Rate of current survival; Irw = Index of resistance to wind.

Table 3. Analyses of variance for six traits for 10 provenances at 5 years.

Source of variance	df	Mean squares					
		H	Dbh	Ubh	Vhd	Rcs	Irw
Replication	3	5.437	7.219	0.4827	172.03	265.1	167.4
Provenance	9	9.160	7.104	4.4709	190.60	977.3	910.1
Error	27	1.373	1.622	0.2161	50.41	169.7	129.1
F value		6.672**	4.379*	20.685**	3.781*	5.759**	7.051**

Note: * and ** indicate significance at the 5% and 1% levels respectively

Table 4. Correlations between provenance means for traits.

	H	Dbh	Ubh	Vhd	Rcs
Dbh	0.95				
Ubh	0.85	0.70			
Vhd	−0.23	−0.51	0.10		
Rcs	0.41	0.32	0.54	−0.02	
Irw	0.35	0.33	0.45	−0.12	0.60

Discussion and Conclusion

In data sets such as these derived from a large species/provenance trial, a selection index may be used to identify the best individual trees or families. Such an index would take into account both economic and biological data (e.g. Cotterill and Dean 1990). In this case, the matrix of provenances x traits is small, and it is possible to identify the best provenances by inspection.

Queensland provenances were better than provenances from New South Wales and Victoria. The best provenance 13443 from Kennedy River Queensland compared very favourably with local *E. exserta*, the control treatment in the trial, the percentage gains on the traits measured being 44, 31, 41, 28, 36, 10 for h, dbh, ubh, rcs, irw and vhd respectively. Corresponding values for the second best provenance 13544 from 40 km north of Gladstone, Queensland were 42, 35, 45, −3.8, 35 and 7. The climate from which provenance 13443 originates in Australia is similar to that of the experimental site, namely hot, with rain in summer and very dry in winter.

We recommend that provenances such as 13443 and 13544 be used to establish seed production areas for large-scale plantations of *E. tereticornis* in China. Further provenance/progeny test trials of the species should be established over a wider area embracing representative ecological environments to identify genotype x environment interactions. Assessments should be extended to include traits which will be important in future utilisation, e.g. wood density.

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Provenance Trials of *Eucalyptus tereticornis*

Zhou Wenlong and Liang Kunnan*

Abstract

Variation in tree height, diameter at breast height (dbh), timber volume, survival, stem form and wind resistance of the 5-year-old trees of 15 *E. tereticornis* provenances which were introduced from Australia and established in eastern Hainan Island in 1986 are reported. Significant differences occurred among the provenances. For height, Queensland provenances from Kennedy River (13443) and Mt Garnet (13544) were the best with 12.68 and 12.66 m respectively. As to dbh, the provenance from Papua New Guinea (13418) was the best with 9.05 cm. The poorest performer was from Victoria (13303), a high-latitude provenance, which was only 8.48 m high, with dbh of 6.23 cm and volume of 10.10 m^3/ha. Tree height, dbh and timber volume of the best provenances was 149, 145 and 607% respectively greater than the worst provenance. In addition, obvious differences occurred in other characters such as survival, stem form and wind resistance.

EUCALYPTUS tereticornis has a natural distribution from 6 to 38 °S, ranging from southern Victoria through New South Wales and Queensland, Australia, to tropical savanna in coastal Papua New Guinea. It also has a wide altitudinal distribution from sea level to 1000 m in Australia and to 800 m in Papua New Guinea (Jacobs 1979).

Early in 1890, China introduced *E. tereticornis* from France to Longzhou county, Guangxi province (Qi Shuxiong 1989), but it was in the 1980s that large-scale introduction and provenance trials were started.

The wood of *E. tereticornis* is widely used by the building and mining industries in Australia. In other countries introducing the species, the wood is used for pulp, fuelwood, posts, pillars, plywood, particle board, etc. The purpose of the trial reported in this paper was to assess growth (including tree height, dbh, timber volume) and adaptability (including survival, stem form and wind resistance) of the different *E. tereticornis* provenances in China, and to provide a scientific basis for selection of good provenances for tropical and subtropical areas of the country.

The trial is located at Shang Yong State Forest Farm, Qionghai County, eastern Hainan Island, latitude 19°06'N, longitude 110°24'E at an altitude 30 m. The soil is yellow-red latosol with coarse chad developed from sediment of a shallow seabed. The fertility of the soil is very low, and the fraction of gravel in it is high. In the surface soil (0–30 cm), the content of gravel (>3 mm) is 6.0 kg/m^2, and increases with depth. At the depth of 85–120 cm, gravel occupies 62% of the soil volume, and together with cement forms a hard pan. In the surface the humus content is 1.36%, total nitrogen (N) 0.031%, rapidly available P (determined by the 0.03N NH_4F–0.025N HCl method) 0.82 mg/100 g and K 0.83 mg/100 g, and pH value 6.0 (H_2O) or 4.8 (KCl).

The site is in the monsoon tropics with annual mean temperature of 24 °C, annual rainfall 2180 mm, annual evaporation 1830 mm and annual average relative humidity 86%. Typhoons frequently hit or affect the area.

The trial site was originally occupied by a poor stand of *E. exserta* with little understorey. The 10-year-old trees had an average height of 11.8 m, average dbh 9.9 cm, and annual volume growth of 4.0–8.7 m^3/ha (average 7.0 m^3/ha) (Zhou Wenlong and Liang Kunnan 1991).

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Materials and Methods

Materials

The seed of 79 provenances from 11 species used for trial was provided by the CSIRO Australian Tree Seed Centre. *E. teretocornis* was represented by 15 provenances. The localities of the provenances and the viability of the seed are given in Table 1.

Methods

The land was ploughed completely with tractors, and holes of 40 × 40 × 40 cm were dug. Base fertiliser of 2.5 kg burned earth and 75 g compound fertiliser (N 10%, P_2O_5 10%, K_2O 10%) was applied to each hole. A complete randomised blocks design with four replications was used. There were 18 trees in each plot, and spacing in rows and between rows was 1.5 and 3.0 m respectively. The trial was planted in June 1986. Survival, tree height, dbh, crown diameter and under branch height were measured, and typhoon damage and stem form were assessed.

Data were analysed by variance analysis, correlation analysis and cluster analysis.

The formula for stem volume was:

$V = 0.00003333HD^2$ (m^3/tree), or

$V = 0.00003333HD^2 \times 10000 \times L/(1.5 \times 3.0)$ (m^3/ha)

V: timber volume (m^3)

H: tree height (m)

D: dbh

L: current survival rate

Results

Variation in tree height, dbh and wood volume

E. tereticornis had rated early growth, straight stems and good wind resistance, but there was very significant variation among provenances in the growth of tree height, dbh and volume (Table 2).

The provenances from Kennedy River (13443) and Mt Garnet (13544) were best with average tree height 12.68 and 12.66 m respectively at 5 years of age. Provenance 13303 from Victoria was worst, with an average tree height only 8.49 m at the same age. Analysis of height revealed significant variation between provenances (Tables 2 and 3).

The provenance from Papua New Guinea (13418) had the best dbh (9.05 cm at 5 years of age), which was 145% of that of provenance 13303 from Victoria. Analysis revealed significant or highly significant variation between provenances (Tables 2 and 3).

As to the stem volume growth of the 5-year-old trees, the provenance from Papua New Guinea (13418) was best with a volume of 0.032 m^3 per single tree, and provenance 13303 was worst with only 0.011 m^3 per single tree. There was very significant variation among the different provenances for volume growth (Tables 2 and 3).

The average height, dbh and volume of the 5-year-old trees of the 15 provenances were 10.95 m, 8.09 cm and 44.6 m^3/ha respectively. There were seven provenances (including 13418, 13544, 13541, 13319, 12965, 14424 and 13443) which had growth

Table 1. Details of the seed sources of *E. tereticornis*.

Expt. No.	Seedlot No.	Locality	Lat. (S)	Long. (E)	Alt. (m)	Viable seed*
1	13418	Sirinumu Sogeri Plat PNG	9°30′	147°26′	580	11 896
2	13443	Kennedy River Qld	15°26′	144°11′	60	4 000
3	14115	S of Helenvale N Qld	15°46′	145°14′	120	7 900
4	13442	N of Mareeba Qld	16°55′	145°25′	380	10 500
5	14424	Ravenshoe Qld	17°39′	145°45′	700	5 800
6	12965	SW of Mt Garnet Qld	18°30′	146°00′	800	4 970
7	13446	N of Cardwell Qld	18°16′	148°30′	40	5 700
8	13994	Crediton SF Qld	21°00′	151°01′	700	4 530
9	13544	40 km N of Gladstone Qld	23°44′	152°37′	10	8 250
10	13541	9 km SW of Imbil Qld	26°30′	152°24′	100	4 700
11	13350	S of Urbenville NSW	28°36′	152°12′	400	2 100
12	13319	N of Woolgoolga NSW	29°55′	153°52′	30	5 700
13	13307	Windsor NSW	33°32′	150°50′	100	3 000
14	13304	Nerrigundah NSW	36°13′	149°48′	80	7 700
15	13303	Sale Vic	38°07′	147°04′	10	2 500

* Viable seed/10 g

Table 2. Analysis of variance each year for height, dbh and volume.

Age (yr)	Height			Dbh			Volume		
	MS	E	F	MS	E	F	MS	E	F
1	0.82	0.15	5.47**	0.59	0.16	3.69**	1.3	0.5	2.71**
2	4.00	0.52	7.69**	1.50	0.28	5.35**	54.4	9.8	5.34**
3	4.67	0.34	13.74**	2.44	0.42	5.81**	158.6	25.8	6.15**
4	4.39	0.66	6.65**	1.25	0.52	2.40**	211.8	65.5	3.23**
5	5.13	0.48	10.57**	1.97	0.60	3.30**	437.4	87.8	5.99**
		$F_{0.05}$ = 1.91				$F_{0.01}$ = 2.51			

Table 3. Mean values of height, dbh and volume with Duncan's multiple range test.

Seedlot No.	Height (m)	Seedlot No.	Dbh (cm)	Seedlot No.	Volume (m^3/ha)
13443	12.7	13418	9.05	13418	61
13544	12.7	12965	8.95	13541	57
13541	11.8	13541	8.64	13443	57
13391	11.8	13544	8.51	13544	54
12965	11.5	13319	8.45	12965	53
13418	11.5	14424	8.34	14424	53
14424	11.2	14415	8.26	13319	50
13442	11.0	13994	8.24	13446	48
13446	10.8	13443	8.12	13994	47
13994	10.6	13446	7.98	14115	44
14115	10.3	13442	7.93	13442	43
13350	10.2	13350	7.83	13350	33
13304	9.8	13307	7.53	13304	30
13307	9.7	13304	7.31	13307	28
13303	8.5	13303	6.22	13303	10

above the average of 15 provenances in height, dbh and volume. There was no significant difference among these seven provenances at the level of 0.05, but very significant variation occurred between these and the poor provenances (13304, 13307 and 13303). The provenance from Papua New Guinea (13418) was the best, the provenances from Mt Garnet (12965) and from 40 km N of Gladstone, Queensland (13544) were second-best, while those from New South Wales (13350, 13319, 13307 and 13304) and Victoria (13303) were all poor.

Survival

The trees of *E. tereticornis* had high survival if they were planted in suitable weather (overcast and rainy). Even in the hot season, high survival could be obtained as long as rain fell around the planting days. Survival 6 months after planting of provenances 13443, 14424 and 13446 was up to 98.5%, while 89% of provenance 13303 seedlings survived. There was no significant variation among the provenances.

Current survival The three provenances with the highest initial survival also had the highest current survival (96, 96 and 94% respectively). The provenance with the lowest initial survival (13303) had the lowest current survival (42%). The average current survival of the 15 provenances was 81%. The seven provenances with above-average current survival were 13418, 13443, 14115, 13442, 13446, 13994 and 13541; differences between provenances were very significant.

There was a high correlation (r = 0.81) between current survival and the initial survival.

Wind resistance In 1988 two typhoons, Nos 23 and 24, hit eastern Hainan Island with greater than force 10 wind, causing damage to eight of the 15 provenances. The total average damage rate to the eight provenances was 1.8%. The damage rate for four provenances (seedlots 13418, 13541, 13350 and 13304) was 6.6, 3.0, 6.6 and 4.8% respectively. In the other seven provenances leaves and young branches were damaged slightly but there was no wind throw, windbreak or tilting.

Stem form Although *E. tereticornis* is characteristically straight-stemmed the variation of stem form in different provenances is large and very significant (Tables 4 and 5). Provenances 13443, 13544 and 13418 with fast height growth had a high percentage of straight type I stems (see footnote to Table 4 for explanation of code) and a low percentage crooked type III stems. Conversely, the slow-growing provenance 13303 had a low percentage of type I stems.

Correlation analysis

The 15 provenances tested were from widely-differing localities. The latitude range of the provenances was from 9°30 'S (Papua New Guinea) to 38°7 'S (Victoria, Australia) and the altitude from 10 to 800 m above sea level. The tree height, dbh, wood volume, survival rate, current survival rate and stem form had highly significant or significant negative correlations with the latitudes of the localities, and had no significant correlations with the longitudes and altitudes (Table 6).

Thus provenances from low latitudes were most suitable for planting in tropical China. These provenances grew fast and had high survival with good stem form. Provenances from higher latitudes (13303, 13307 and 13304) were slow growing, had low survival and poor stem form.

Table 5. Analysis of variance of 'adaptability' of provenances.

	Initial survival	Current survival	Form: Type I incidence	Windburn rate
MS	6754	361	2589	95
Error	73	109	550	9
F value	91.98**	3.31**	4.70**	2.97**

Table 6. Correlation between each item observed and geographical source of provenance.

Item	Lat.	Long.	Alt.
Height	−0.58*	0.01	0.08
Dbh	−0.71**	0.01	0.46
Volume	−0.78**	−0.11	0.32
Initial survival	−0.74**	−0.21	0.26
Current survival	−0.83**	−0.43	0.27
Stem form	−0.60**	−0.22	0.05

Comprehensive analysis

Tree height, dbh, volume, initial survival, current survival and percentage of type I stems of the 5-year-old trees were used as factors for a cluster analysis. The result suggests that the 15 provenances could be classified into 6 types (Table 7 and Fig. 1). The main growing characters and phenotypes of the different types are:

Type 1: the fastest growing, highest survival and highest percentage of type I stems
Type 2: fast growing, high survival, high percentage of type I stems
Type 3: moderately fast growing, high survival, lower percentage of type I stems

Table 4. Stem form of 15 provenances of *E. tereticornis*.

Form class*	Provenance														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
I	94	100	52	73	69	75	75	25	94	52	46	56	48	71	0
II	6	0	17	15	19	19	6	52	6	42	46	44	12	21	28
III	0	0	31	12	12	6	19	23	0	6	8	0	40	8	72

* Types of stem form
I: straight, small branches, no forking;
II: somewhat crooked, small branches and no forking;
III: crooked larger branches, forking, low crown.

Table 7. Classification of each item observed after cluster analysis.

Category		Height (m)	Dbh (cm)	Volume (m^3/ha)	Initital survival (%)	Current survival (%)	Stem form (%)
I	Range	11.5-12.7	8.1-9.0	54.0-61.3	79.2-91.7	94.4-98.6	93.7-100
	Mean	12.3	8.6	57.4	86.1	96.8	95.8
II	Range	11.6-11.8	8.4-8.9	49.9-57.5	77.1-87.5	94.4-97.2	52.1-75.0
	Mean	11.7	8.6	53.6	81.9	95.8	61.1
III	Range	10.3-11.2	7.9-8.3	43.5-52.9	81.2-91.7	95.3-98.6	52.1-75.0
	Mean	10.85	8.1	48.0	87.0	97.5	67.1
IV	Range	10.6	8.2	47.4	87.5	95.8	25.0
	Mean	10.6	8.2	47.4	87.5	95.8	25.0
V	Range	8.5	6.2	10.1	40.6	88.6	0
	Mean	8.5	6.2	10.1	40.6	88.6	0
VI	Range	9.8-10.3	7.3-7.8	29.5-33.2	75.0-68.7	88.6-93.1	45.8
	Mean	9.9	7.6	10.4	70.8	91.1	54.9

Type 4: moderately fast growing, medium volume, high survival, low percentage of type I stems

Type 5: slow growing, medium survival, low percentage of type I stems

Type 6: slowest growing, lowest survival, poorest stem form.

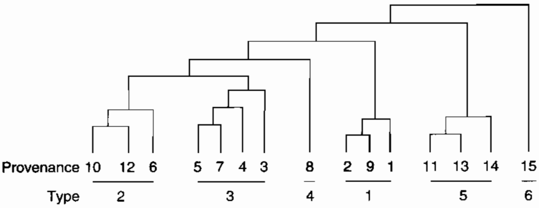

Fig. 1. Dendrogram of hierarchical cluster analysis for 15 provenances of *E. tereticornis*.

Conclusions

Significant or very significant variation occurred among the 15 tested provenances in the growth and other characters of the young trees. The two provenances from lower latitudes (13418 and 13443) were the best on the site, with rapid growth, high survival and straight stems. The timber volume of the 5-year-old trees of the two provenances was 61 and 57 m^3/ha, with mean annual growth of 12.2 and 11.4 m^3/ha, respectively. The provenances from higher latitudes (13303, 13307 and 13304) grew poorly. Provenance 13303 has especially slow growth, the volume of the 5-year-old trees being 10 m^3/ha, and mean annual growth only 2.0 m^3/ha, and stem form very poor — crooked, no obvious trunk and much branched.

Tree height, dbh, survival and the percentage of straight stems had significant or most significant negative correlations with the latitude of the seedlot localities, and no significant correlations with the longitude and altitude. Provenances from low latitudes grew best.

The cluster analysis grouped the tested 15 provenances into six types: type 1, comprising 13418, 13443 and 13544, was the best with the characteristics of rapid growth, high survival, high yield and straight stem form.

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Ectomycorrhizas and Nutrients: their Importance to Eucalypts in China

N. Malajczuk*, T.S. Grove*, N.L. Bougher*, B. Dell** and Gong Mingqin***

Abstract

Ectomycorrhizas are symbiotic associations between tree roots and certain groups of fungi which increase the efficiency of soil nutrient uptake by trees in infertile soils. A large diversity of indigenous ectomycorrhizal fungi (mushrooms, toadstools and truffles) occur in association with eucalypts in Australian forests, but very few occur in eucalypt plantations in China. This paucity of fungi associated with eucalypts in China may affect productivity of the plantations. The strains of ectomycorrhizal fungi differ in their ability to increase seedling growth. Results from a number of recent field trials worldwide demonstrate that inoculation of eucalypts can enhance tree growth. Forms of ectomycorrhizal fungal inocula that can be applied to seedlings in forest nurseries are presented. Development of practices for fertiliser application suited to maximise benefits from inoculation are required. These include the use of minor elements which are essential to overcome secondary nutrient disorders in eucalypts. The relevance of ectomycorrhizal research to China's reforestation program is discussed.

THE roots of most tree species are colonised by a specialised group of soil-borne fungi which form a symbiotic relationship termed ectomycorrhiza. The extent to which this association occurs with the host tree varies but, for trees in both undisturbed and disturbed environments, this relationship is essential for growth and development.

Ectomycorrhizas are the predominant mycorrhizal form found with fine roots of eucalypts in the Australian environment (Fig. 1a). They are characterised by an intricate mesh of fungal hyphae on the root surface comprising a loosely or tightly woven layer of mycelium known as the fungal sheath or mantle. The sheath is 1–30 cells thick (Fig. 1b). A number of fungal structures such as hairs, cystidia and rhizomorphs may form in and on the outer surface of the sheath. The fungus penetrates the root intercellularly, and in most eucalypts rarely extends past the epidermal cells. In root sections, the epidermal cells are separated by a mesh of hyphae, known as the Hartig net. These fungal structures between the epidermal cells provide an increase in surface area for the exchange of nutrients between the fungus and the host partners. Ectomycorrhizas make direct contact with the soil at the mantle or by means of hyphae, hyphal strands or rhizomorphs that penetrate the soil substrate. This increased surface contact with soil greatly assists the uptake of nutrients and water by the mycorrhiza.

In the tropical and subtropical regions of southern China, eucalypts are favoured for revegetation of vast areas because of their capacity to tolerate degraded surfaces (Turnbull 1991). The upland soils are typically yellow or red earths, low in organic matter, usually acidic in reaction and highly leached (Zhao Qiguo 1989). Because of their very low phosphorus status and the absence of symbiotic fungi that are normally associated with eucalypts in their native habitat (Bougher and Malajczuk, unpubl.), there is the potential for improving tree growth on these impoverished sites through inoculation with selected isolates of Australian ectomycorrhizal fungi.

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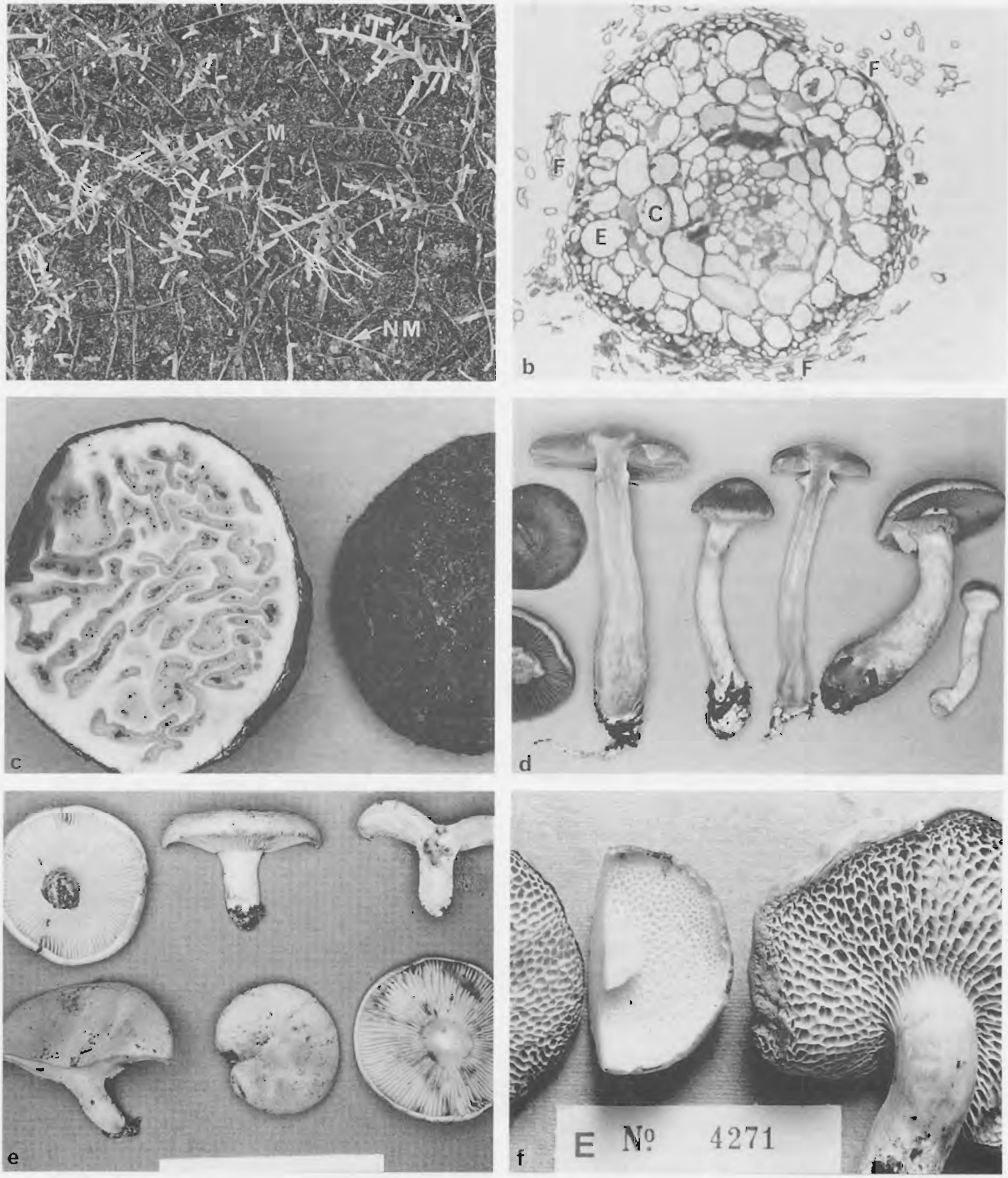

Fig. 1. (a) Eucalypt mycorrhizal (M) and non-mycorrhizal (NM) roots, (b) Transverse section of a mycorrhizal root showing fungal hyphae (F) on the surface and between epidermal (E) cells, (c) Section through a belowground, truffle fungus, (d, e and f) a range of larger mushroom fungi found under eucalypts in Australia.

The advantages of inoculation of tree seedlings with ectomycorrhizal fungi in nurseries has long been realised for pine species (Marx and Cordell 1988), but research leading towards practical application of fungi associated with eucalypts has been initiated relatively recently (Grove and Malajczuk 1993).

This paper summarises current information on the application of mycorrhizas in eucalypt plantations and evaluates the need to introduce suitable ectomycorrhizal fungi onto eucalypts, with the view to enhancing productivity of plantations in the extensive reforestation program currently underway in China.

The Fungal Genetic Resource

In Australia, many thousands of fungal species are associated with eucalypts and initiate ectomycorrhizas. Current information indicates that most of these fungi are unique to eucalypts. The majority of these are in the Basidiomycotina, Ascomycotina and sporocarpic Endogonaceae fungal groups (Miller 1982). They produce sexual fruiting structures commonly termed the larger fungi — including mushrooms, toadstools and truffles (Fig. 1c–f). Most ectomycorrhizal ascomycetes produce hypogeous (below-ground) ascocarps e.g. *Tuber*. The ectomycorrhizal basidiomycetes include the gasteromycetes (e.g. *Pisolithus*) and the hymenomycetes. This latter group contains the most common of all the ectomycorrhizal fungi producing epigeous agaricoid (above-ground, mushroom-like) basidiocarps and includes taxa which are almost exclusively ectomycorrhizal e.g. *Amanita*, *Laccaria*, *Hebeloma* and *Boletus*.

Many of the basidiomycetes which were formerly regarded as gasteromycetes, because they produce puffball or truffle-like basidiocarps, are now known to have close taxonomic relationships with the agaricoid genera. For example, *Zelleromyces* forms truffle-like basidiocarps that produce latex, and its microscopic characteristics resemble those found in the epigeous agaricoid genus *Lactarius*. There are also forms which have an intermediate taxonomic link between truffle-like and agaricoid Agaricales. These are the sequestrate fungi which produce subagaricoid basidiocarps that have a stipe, but the hymenium is convoluted or sublamellate and remains enclosed during all stages of development. For example, in the family Cortinariaceae, *Thaxterogaster* (subagaricoid basidiocarp) is an intermediate genus linking *Cortinomyces* (truffle-like basidiocarp) and *Cortinarius* (agaricoid basidiocarp) from an evolutionary point of view.

The truffle-like Agaricales occur worldwide, but are particularly abundant in native Australian eucalypt forests, where the diversity has been previously under-estimated and little is known of their taxonomic affinities (Castellano and Bougher 1993). Recent expeditions to a range of native forest types in Queensland and Tasmania have yielded over 1000 collections of these fungi. Preliminary assessment of these collections indicate that 95% of the truffle-like fungi from Australia are unique, with at least 22 genera and three families endemic (Castellano and Bougher 1993).

Although observations of sporocarps suggest there can be thousands of ectomycorrhizal fungi associated with any one tree species, there appears to be specificity by the fungi for a range of tree genera. Patterns of association between ectomycorrhizal fungal species and specific tree genera have become apparent through analysis of past reports and pure culture synthesis experiments (Molina and Trappe 1982; Malajczuk et al. 1982, 1984; Molina et al. 1992). For example, *Suillus* and *Rhizopogon* species are only associated with northern hemisphere hardwoods and conifers. Others, like *Hydnangium carneum* and species in the genus *Mesophellia* are only associated with eucalypts. Cross inoculation studies have clearly demonstated that many pine fungi are incompatible on eucalypt roots and vice versa (Malajczuk et al. 1982, 1990). These findings highlight the need for a greater understanding of the question of specificity between hosts and ectomycorrhizal fungi and may explain failures of some inoculation programs where inappropriate symbionts were used.

Although eucalypts from Australia were introduced into China more than 100 years ago, knowledge of eucalypt mycorrhizas in this region is limited. Recent studies by Gong Mingqin (unpubl.) reported the occurrence of only nine species of ectomycorrhizal fungi associated with eucalypt stands in southern China, whereas there are hundreds of mycorrhizal fungal species associated with local pine and hardwoods. This suggests a scarcity of eucalypt mycorrhizal fungal flora and a potential to introduce into this region effective ectomycorrhizal fungi from Australia.

In 1988, a eucalypt mycorrhiza program was established and funded by ACIAR. It involved CSIRO Division of Forestry and the Chinese Academy of Forestry Research Institute of Tropical Forestry. Major objectives of this program were to build up a collection of eucalypt mycorrhizal fungi, to screen these fungi for their effectiveness in colonizing roots and to introduce a selection of these into China to assist the reforestation program.

Benefits of Ectomycorrhizas to Eucalypts

The major benefit of inoculation with ectomycorrhizal fungi is to increase the uptake of nutrients (especially phosphorus) that are immobile in soil (Bougher et al. 1990). Mycorrhizas are probably also involved in uptake of more mobile ions (ammonium, nitrate, sulfate and potassium) in highly competitive situations (e.g. agroforestry) and in young plantations where trees have low rooting densities (Grove and LeTacon 1993).

Although the association of ectomycorrhizal fungi with eucalypt species was realised many years ago it is only relatively recently that the effects of this association on host growth and the ability to take up nutrients have been examined. Early observations indicating the importance of ectomycorrhizas to eucalypts were made when eucalypts were grown outside Australia. For example, attempts to raise various species of eucalypts in nurseries in Iraq in the 1950s were unsuccessful (Pryor 1956). Addition of non-sterile soil from established eucalypt stands to the sterile nursery soil improved growth of the seedlings. Further, the addition of spores of *Scleroderma flavidum* also promoted the growth of seedlings (Pryor 1956).

More recently, inoculation of seedlings with selected strains of ectomycorrhizal fungi produced marked increases in the growth of eucalypts. The largest increases with inoculation are generally observed under controlled environment conditions where seedlings are raised in a partially sterilised medium and where the level of N and P supply is optimal for ectomycorrhizal development but limiting to plant growth (Bougher et al. 1990; Grove et al. 1991). For example, in a partially sterile yellow sand Bougher et al. (1990) observed a strong interaction between effects of inoculum and soil P supply in seedlings of *Eucalyptus diversicolor*. An isolate of *Laccaria laccata* produced a 21-fold increase in seedling dry weight over uninoculated seedlings at a low level of P supply. These marked interactions between effects of ectomycorrhizal fungi and soil nutrients supply indicate that integration of inoculation and P fertiliser practices is likely to be important in the field.

There have been few definitive field studies determining effects of mycorrhizal inoculation on eucalypts. In one of the pioneering studies in Australia, Malajczuk (1988) demonstrated approximately 50% increases in mean height and diameter of 2-year-old *E. diversicolor* seedlings inoculated with two ectomycorrhizal fungal isolates, *Protubera canescens* and *Amanita xanthocephala*, outplanted on a recently clear-felled forest site. Similarly, Garbaye et al. (1988) have demonstrated responses to mycorrhizal inoculation of eucalypts which were planted as exotics in the Congo. Four years after outplanting hybrid eucalypts (*E. urophylla* x *tereticornis*) inoculated with *P. tinctorius* or *Scleroderma aurantium* increased in growth by 30 and 26% respectively over uninoculated trees.

A wider selection of ectomycorrhizal fungi has now been tested in the field in two contrasting environments in south-western Australia (Grove et al. 1991). The early growth increases of karri (*E. diversicolor*) and bluegum (*E. globulus*) inoculated with nine fungal isolates were compared with growth of uninoculated trees at two sites recently cleared of native forest. Inoculation with *Setchelliogaster* sp. and *Amanita* sp. increased above-ground biomass of karri by 66–88% after 1 year in the field at both sites, and *Protubera canescens* and *Descolea maculata* also increased plant biomass at one site. Although the fungi did not significantly affect the biomass of bluegum after 1 year, measurement of the relative biomass increase for the growth period from 6 months to 1 year showed that three fungi were stimulating growth at one site.

Growth of bluegum, either inoculated with two fungal isolates or uninoculated, was also measured in relation to the level of P application at the same field sites (Grove et al. 1991). At one site, biomass of 1-year-old trees inoculated with a *Setchelliogaster* sp. was greater than that of uninoculated trees, even at the higher rates of P application. A similar effect was also observed at the second site. This response to ectomycorrhizal inoculation at the higher P rates suggests that, in addition to enhancing P uptake, other factors associated with the mycobiont may also be stimulating tree growth.

It is to be expected that the largest increases in growth from inoculation with ectomycorrhizal fungi will occur during the first 2 years after outplanting. At this early stage, rooting density is low and factors including the fineness of roots, root hair development, root turnover and association with mycorrhizal fungi determine the effective root length and the efficiency of uptake of nutrients. The introduction of selected ectomycorrhizal fungi onto a site with the seedling can, through a rapid proliferation of ectomycorrhizas and external hyphae, markedly increase the volume of soil from which poorly mobile nutrients can be absorbed by the host.

In fast-growing plantations, early responses to inoculation with mycorrhizal fungi are crucial, as there is a high internal requirement by the host for nutrients in the period up to canopy closure. This is due to the rapid expansion of the crown before heartwood formation begins and it is the stage when the nutrient supply from soil is most likely to limit tree growth (Miller 1981; Grove and Malajczuk 1993). Where a treatment results in increased growth over untreated trees through enhancing nutrient uptake (e.g. fertiliser application, mycorrhizal inoculation), the treatment effect would be expected to persist through the rotation period except where interactions with other growth-limiting factors (e.g. water availability) nullify this effect. It is essential therefore to develop a thorough understanding of factors that affect growth of eucalypts in plantations so that benefits from ectomycorrhizal fungi can be maximised.

Application of Ectomycorrhizas in Forestry

Historically, methods for inoculation of seedlings in new nurseries have relied on natural means, either by the use of soil from under established plantations or by wind-blown spores from adjacent forest areas. However, this method of inoculation has a number of problems, including: (1) irregular and inconsistent inoculation; (2) delays in mycorrhiza formation resulting in lack of uniformity in seedling growth and colonisation; (3) use of fungi from established plantations, which are not necessarily the most effective for young trees; and (4) roots of exotic species (e.g. eucalypts in China) unlikely to be infected by indigenous ectomycorrhiza flora. These problems may be overcome by inoculation with selected fungi, requiring the availability of effective inoculum and an efficient inoculum delivery system.

Spores are the inocula most commonly used by many nursery operations worldwide. However, the practice is restricted to those species producing sporocarps in large numbers. Spores sufficient for inoculation of several million pines annually can be produced by many ectomycorrhizal gasteromycetes (Cordell et al. 1988) but production of such large numbers of spores from most species of mycorrhizal Agaricales and Aphyllophorales is impractical because of sporadic and low sporocarp production. A major disadvantage of using spore inoculum is the inability to determine and to control spore viability and maintain strain purity. Also, initiation of mycorrhizas by spores is slow, allowing time for other fungi to colonise the roots. Soil containing one or more mycorrhizal fungi has also been used successfully as an inoculum , but this form has a number of drawbacks for widespread application including those concerning the introduction of pathogens into nurseries (Castellano 1988).

Techniques for inoculation with pure cultures of selected ectomycorrhizal fungi have been developed for small-scale operations during the past 30 years (Trappe 1977). Mycelium grown in mixtures of peat and vermiculite moistened with mineral and organic nutrients or in cereal-grain-based media has often been used as inoculum (Marx 1980). A number of pine ectomycorrhizal fungi, including *Pisolithus tinctorius*, *Hebeloma crustuliniforme* and *Laccaria laccata*, are now available from suppliers in the United States. However, eucalypt ectomycorrhizal fungi are not available commercially in this formulation.

The most advanced form of inoculum currently available, the vegetative mycelium, is cultured within hydrogel beads (Kuek et al. 1992). Mycelium cultured in beads is physiologically superior to entrapped, fragmented mycelium and acts more rapidly as a propagule. Unlike mycelium grown in peat-vermiculite, mycelium cultured within beads is protected at all stages of the inoculum production process and inoculation procedure. The size of these beads can be varied from 0.5 to 2 mm in diameter. Several species and isolates of *Laccaria*, *Hebeloma*, *Descolea*, *Elaphomyces* and *Pisolithus* have already been successfully produced as inocula with this technique and other genera are being investigated (Dr Clem Kuek, pers. comm.).

In China the ACIAR program has been using all the above forms of inoculum to ascertain the reliable and inexpensive form and method of inoculation for ensuring uniform infection of seedlings under local forest farm conditions (Gong et al. 1992). In conjunction with this, experiments are currently underway in Australia to compare the rate and extent of fungal colonisation on roots of eucalypt species inoculated by these various methods.

Maximising field responses of ectomycorrhiza

Inoculation with ectomycorrhizal fungi is most likely to increase seedling growth where the soil P is limiting (Bougher et al. 1990). On planting sites in southern China, ectomycorrhizal fungi are likely to colonise roots and enhance tree growth due to the low P status of soils and the large growth responses of eucalypts to applied P (Grove and Malajczuk 1993). For example, 3–4-fold increases in tree basal areas were obtained with application of P to three eucalypt species growing on a coarse-textured soil in Yangxi County, Guangdong Province (Figure 2) and even larger responses have been observed on finer textured soils near Kaiping (unpublished data). Application of P at the rates used in Australian forestry will not be adequate to achieve maximum growth on most soils in China, suggesting that in many situations ectomycorrhizal fungi may enhance early growth in the field.

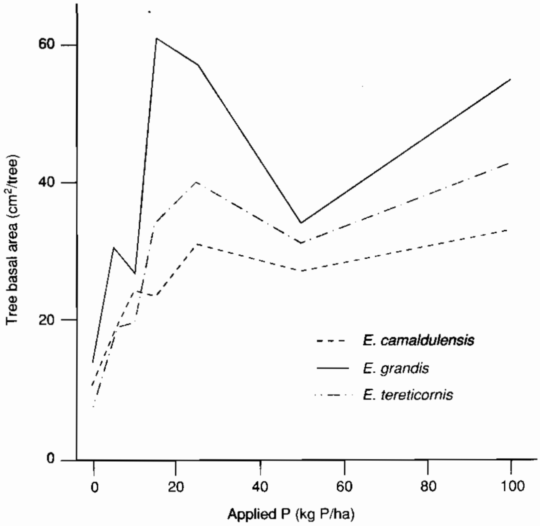

Fig. 2. Effect of rate of broadcast applied phosphorus on the basal area of *Eucalyptus camaldulensis*, *E. tereticornis* and *E. grandis* 2 years after planting, growing on a coarse-textured granitic soil in Yangxi County, Guangdong Province. There were significant differences in mean basal areas between species ($P < 0.001$, SEM 2.27) and between P rates ($P < 0.001$, SEM 4.55).

In contrast to agricultural crops, complete fertiliser (i.e. fertiliser with all the essential macro- and micro-nutrients included) is not used in eucalypt plantations even though it is widely acknowledged that deficiencies of elements other than N, P and K occur. Given the infertile status of many yellow and red earths in China where eucalypt plantations are being established, it is not surprising that secondary micronutrient deficiencies are widely encountered where growth has been enhanced either through inoculation with mycorrhizal fungi or applications of NPK fertiliser. For example, boron deficiency is common in parts of Guangdong and Yunnan Provinces in China.

Deficiency has been observed in *E. globulus, E. grandis*, *E. urophylla*, *E. tereticornis* and various hybrids. Symptoms, which include shoot dieback, pendulous branches, corky and deformed leaves, stem bleeding and poor form, can be very severe in 1-3-year-old trees and the severity varies with time, being worst during the dry season. Foliar analyses support the conclusions based on symptoms. For example, boron concentrations in the youngest fully expanded leaf of 1-2-year-old *E. urophylla* and *E. grandis* established near Kaiping, Guangdong Province ranged from 3 to 20 mg B/kg dry weight in trees showing symptoms of B deficiency, whereas they were 14-26 mg B/kg in fast-growing trees that were free of these symptoms.

Hartley (1976) suggested that a range from 14 to 16 mg B/kg was deficient for *E. tereticornis* in Papua New Guinea and Lamb (1976) measured 30-70 as adequate for *E. deglupta*. Furthermore, the data in Table 1 show that, where micronutrient deficiency causes tip dieback in eucalypt plantations, the level of boron in leaves is consistently low. Since Stone (1968) recognised boron deficiency as the most common micronutrient limiting the growth of forest plantations, several workers have shown that treating young plantations with boron fertiliser can significantly improve growth and stem form (Cooling and Jones 1970; Kadeba 1978). Stone (1990) stated that even single episodes of deficiency can cause severe stem defect and loss of wood quality.

Table 1. Concentrations (mg/kg dry wt) of manganese, copper, zinc and boron in the youngest fully expanded leaves of three species of eucalypts in a 3-year-old eucalypt trial plantation at Yangxi, Guandong Province.

Species	Element	Mean	Std Error	Range
E. urophylla	Mn	154.5	37.3	94.8-284.4
	Cu	4.4	0.02	4.3-4.4
	Zn	32.4	2.1	29.4-38.6
	B	12.1	0.2	6.3-15.9
E. grandis	Mn	420.1	98.8	193.4-479.7
	Cu	5.3	0.5	4.3-6.6
	Zn	39.0	3.5	33.5-42.1
	B	6.5	0.09	4.4-8.3
E. tereticornis	Mn	380.3	81.0	189.2-671.6
	Cu	3.1	2.1	2.1-4.4
	Zn	36.3	1.7	27.2-51.3
	B	9.0	0.7	4.5-13.6

In the future, more attention should be given to the correction of boron deficiency in plantation establishment in China. But tip dieback in eucalypts can also result from non-nutritional factors such as adverse climatic conditions and pathogens, so care must be taken to ensure that diagnosis of B deficiency is accurate. As ectomycorrhizal fungi do not require boron for their growth it is unlikely that inoculation of eucalypts will correct any boron deficiencies encountered in the field. However, it is likely that extra-matrical hyphae can assist nutrient uptake of other micronutrients such as Cu and Zn, as with phosphorus.

Little is yet known about deficiencies of the micronutrients in forest plantations in China, even though deficiencies may be commonly encountered in field crops on nearby soils. Work is currently under way to determine how early identification and correction of secondary micronutrient disorders can maximise the benefits of inoculating eucalypts in China with Australian ectomycorrhizal fungi.

Conclusions

The selection of suitable provenances of Australian eucalypts has, in many cases, led to improved production in plantations, although productivity is often severely limited by low nutrient status of the soil. In their native habitats, roots of eucalypts are associated with symbiotic ectomycorrhizal fungi which enhance nutrient uptake by the tree. In plantations located outside the natural distribution of eucalypts, such as in China, compatible ectomycorrhizal fungi are usually absent. The introduction of eucalypt ectomycorrhizal fungi to eucalypt plantations in China may increase tree resistance to environmental stresses as well as increasing timber yields. Each species of ectomycorrhizal fungus has unique ecophysiological characteristics, and consequently the screening of diverse ectomycorrhizal fungi is essential to identify isolates most suited to specific conditions in China.

Furthermore, management of ectomycorrhizal fungi should be considered as part of the overall nursery operations for which inoculation techniques should be developed taking into consideration local conditions for seedling production. The effectiveness of nursery inoculation practices in improving plantation productivity is likely to depend largely on details of nutrient limitations to growth at planting sites, and on the development of fertiliser practices conducive to the development of the fungal-tree association. Regular monitoring of nutrients in foliage of eucalypt stands will enable the forester to anticipate nutrient stress and predict any requirement to apply micronutrients such as boron to maximise tree growth and ensure best value from the ectomycorrhizal inoculation.

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Frost Tolerance Variation amongst 25 Provenances of *Acacia mearnsii*

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Abstract

Twenty-five provenances of *Acacia mearnsii* — selected to represent the climatic and geographic range of the natural distribution of the species — were screened for variation in frost tolerance. Provenances were assessed for frost tolerance in the laboratory. Leaf samples from winter-hardened seedlings were exposed to three test temperatures. The extent of frost damage was then assessed by measuring the electrical conductivity of leachates from the samples. Significant variation in frost tolerance between provenances was found. The least tolerant provenances were from the most northerly coastal locations represented in the trial (Nowra, Batemans Bay and Bawley Point in New South Wales). The most tolerant provenances were from inland, high altitude NSW (Bungendore, Bombala and Cooma), western Victoria (Minhamite) and Tasmania (Apsley River Bridge).

SINCE 1985 forestry research collaboration between Australian and Chinese scientists under ACIAR-funded Projects 8458 and 8849 has focused attention on patterns of genetic variation within *Acacia mearnsii*. This species has been selected by Chinese scientists for plantations in southern China to provide wood and tannin. *A. mearnsii* provenance and progeny field trials in China (Gao et al. 1991, Gao and Li 1991), seedling morphology trials in Australia (Bleakley and Matheson 1992) and climatic analyses (Booth and Jovanovic 1988; Booth et al. 1989; Booth and Yan 1991) have all examined variation in the species as a basis for sampling and selection of desirable genotypes for plantation establishment. Frost tolerance has been identified as an important factor in determining plantation success.

Patterns of genetic variation in frost tolerance within *A. mearnsii* have been examined in field trials in South Africa using different damage assessment methods (e.g. points systems to score frost damage with a frost damage index being derived by dividing the total points allocated by the number of seedlings surviving and percentage of trees alive after winter). Results from three field trials in South Africa using Australian provenance material have been published by the Institute for Commercial Forestry Research (ICFR), formerly the Wattle Research Institute (WRI), Pietermaritzburg, Natal, South Africa (WRI 1962; WRI 1963; WRI 1964; Hagedorn 1987, 1989). The first *A. mearnsii* frost tolerance trials in South Africa were based on seed collections arranged by S.P. Sherry during a trip to Australia in 1957. Seed was collected from 25 locations in New South Wales, Victoria, South Australia and Tasmania.

Most of these collections were from single trees and great emphasis was placed on selection of potentially frost-tolerant trees by sampling populations from high altitudes and latitudes. Seed from 12 Australian provenance collections was planted in 1959 together with South African seedlots, and eight other provenances were planted in November 1961. Trial results indicated the Australian material generally had thinner bark and lower tannin, and was more branchy and less vigorous than the South African material. A collection from one tree near Cooma (latitude 36°16′S) from an elevation of c. 970 m above sea level was the only seedlot that was significantly more frost tolerant than the other Australian provenances. The progeny however had extremely poor bark yield (Hagedorn 1989).

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On the basis of these trials, which used very limited genetic material, it was concluded that the locally collected commercial stock was more frost tolerant than the Australian collections. Three Australian families however were fairly vigorous and were subsequently included in the ICFR breeding program. Also as a result of these early trials, the most recent ICFR-funded collection (1985) placed emphasis on northern New South Wales provenances with Tasmanian provenances being excluded. This collection was used for a series of frost tolerance trials planted in early 1986 (Hagedorn 1987).

The 1986 trials included nine Australian provenances (represented by 89 individual tree collections and two bulk seedlots) planted out with four South African controls on three sites (Bloemendal research farm in Natal; Iswepe and Commondale in southeastern Transvaal). Heavy frosts damaged the trial at Iswepe during the first winter so this trial was assessed for frost tolerance after winter when the trees were c. 6 months old (Hagedorn 1989). The percentage of trees left alive after this first winter was used as an index to rank the genotypes. Hagedorn's results from the *A. mearnsii* trial at Iswepe are presented in Table 1.

Iswepe results indicated that the most frost tolerant provenances were collected from the highest altitudes; from Lake George and Mittagong in NSW with 88 and 56% survival respectively. The provenances damaged most severely were the low-altitude collections (less than 200 m asl) from Batemans Bay and Merimbula along the coast of NSW and Stratford (lowland Victoria) with mean percentage survival of 14, 24 and 23% respectively. It is of interest to note however that one Merimbula family had a survival of 87%. Frost damage to the trial seriously affected height growth; the most resistant provenance, Lake George, had the best height growth (Hagedorn 1987).

Research on frost tolerance in Australia (CSIRO Division of Forestry Canberra) has focused on laboratory-based screening of genotypes using a non-destructive, electrical conductivity screening technique (Raymond et al. 1986; Owen and Raymond 1987; Raymond et al.1992). This technique was developed for *Eucalyptus* species but has been extended and adapted for use with *Acacia* species. Searle et al. (1991) briefly described results from an experiment which examined within-provenance variation in frost tolerance of *A. mearnsii* using two provenances (4 km west of Cooma (Mt Gladstone) (36°15′S 149°05′E, 925–1070 m asl) and 8–23 km west of Bodalla (36°11′S 149°58′E, 15–40 m asl)) represented by 15 families each. Between-family variation was found to be highly significant as was variation between the provenances. The higher-altitude provenance was more frost tolerant than the coastal provenance (Bodalla). These two provenances were subsequently included in the wide-ranging provenance trial reported in this paper.

Throughout the natural distribution of *A. mearnsii* in southeastern temperate Australia the lowest and most damaging temperatures are caused by radiation frosts over the winter months (June–August). Trees are hardened to some degree when

Table 1. Ranking for frost tolerance (percentage trees alive after winter) of *Acacia mearnsii* provenances at Iswepe, South Africa (Hagedorn 1987, 1989).

Location	State	No. of families	Latitude (S)	Longitude (E)	Altitude (m)	Trees alive (%)	Rank
Lake George	NSW	10	35°05′	149°22′	700	89	1
Mittagong	NSW	8	34°25′	150°25′	640	56	2
Cann R-Orbost	Vic	6	37°34′-37°42′	148°28′-149°09′	45-200	43	3
Seed orchard	RSA*	1				42	4
Omeo Hwy	Vic	10	37°10′-37°32′	147°50′-147°50′	200-500	35	5
Commercial	RSA*	2				33	6
Bombala	NSW	12	37°09′	149°20′	500	32	7
Kyneton	Vic	8	37°12′	144°28′	500	29	8
Merimbula	NSW	6	36°55′	149°54′	20	24	9
Stratford	Vic	8	37°44′-38°23′	146°59′-148°04′	20-200	23	10
Cape	RSA*	4				17	11
Batemans Bay	NSW	6	36°20′	150°13′	40	14	12

* RSA = Republic of South Africa

the lowest temperatures occur. In China unseasonal advective frosts resulting from large-scale cold air incursions from the north are the most damaging. For example *A. mearnsii* provenances in a trial in Xishing county, northern Guangdong province, China, were killed as the result of a sudden drop in minimum temperatures e.g. from above 0° to −7.6 °C overnight in December 1991 (Yang et al. these proceedings) when the plants did not harden sufficiently to cope with the freezing temperatures.

The aim of this trial was to examine the significance of genetic variation in frost tolerance amongst 25 provenances of *Acacia mearnsii* and to rank the provenances in order of their relative frost tolerance.

Materials and Methods

Provenance selection

Twenty-five provenances of *A. mearnsii* were selected to represent the climatic and geographic distribution of the species in southeastern Australia (Figure 1 shows the natural distribution of the species). The seed collections had been undertaken by private seed collectors and the Australian Tree Seed Centre (CSIRO Division of Forestry) over the previous 6 years as the basis for research for the ACIAR projects. Table 2 presents the seedlot numbers and collection locations of the provenances used in the trial and Figure 2 maps their location in southeastern Australia.

Each provenance was represented by a bulked collection from a minimum of five and a maximum of 50 parent trees. Seed was collected from trees growing more than 50 m apart with the aim of minimising the relatedness of sampled trees within each provenance.

Trial establishment

Sowing took place on 26 March 1991. The seeds had been pretreated with boiling water and left to stand overnight. Three to four seeds were sown per pot and seedlings were progressively thinned, on the basis of size, to leave the largest seedling per pot by May 31.

One-litre black plastic 'planter bags' were filled with a mixture of medium-grade sand, perlite and vermiculite in the ratio of 2:1:1. The medium had

Table 2. Locations of *A. mearnsii* provenances used in frost tolerance trial.

Treat no.	Seedlot no.	Location	State	Latitude (S)	Longitude (E)	Altitude (m asl)	No. trees in bulk
1	17927	Tantanoola	SA	37°41′	140°28′	30	30
2	17236	Minhamite	Vic	37°57′	141°51′	80	11
3	16257	13 km N of Bega	NSW	36°34′	149°50′	15	10
4	16258	Towamba 13 km N Eden	NSW	37°05′	149°43′	100	8
5	16381	9.5 km N Tambo Crossing	Vic	37°27′	147°50′	175	10
6	17930	E of Lorne	Vic	38°28′	144°02′	70	15
7	17929	Dartmoor	Vic	37°55′	141°19′	40	7
8	17937	4 km W Cooma	NSW	36°15′	149°05′	1000	50
9	14725	NE Bungendore	NSW	35°12′	149°32′	760	12
10	17931	You Yangs	Vic	37°58′	144°27′	80	40
11	15850	7 km SE Araluen	NSW	35°42′	149°51′	160	20
12	16974	Bawley Point	NSW	35°31′	150°24′	20	8
13	16623	10 km N Batemans Bay	NSW	35°38′	150°15′	20	10
14	15331	Hobart airport	Tas	42°50′	147°31′	10	23
15	17233	Studley Park	Vic	37°48′	145°01′	20	11
16	17926	Casterton	Vic	37°37′	141°21′	140	25
17	16268	Bombala-Dalgety	NSW	36°40′	149°08′	860	12
18	16379	0.9-2.5 km SE Orbost	Vic	37°43′	148°28′	33	9
19	15329	Apsley River Bridge	Tas	41°56′	148°14′	10	10
20	17932	Bairnsdale	Vic	37°54′	147°28′	40	5
21	16382	24-29 km SE Launceston	Tas	41°31′	147°20′	362	5
22	17938	Mt Rix	NSW	36°45′	148°58′	930	20
23	14925	Blackhill Reserve	Vic	37°12′	144°28′	500	6
24	16246	10 km S Nowra	NSW	34°59′	150°36′	10	7
25	16967	8.1-23.6 km SW Bodalla	NSW	36°11′	149°55′	15	17

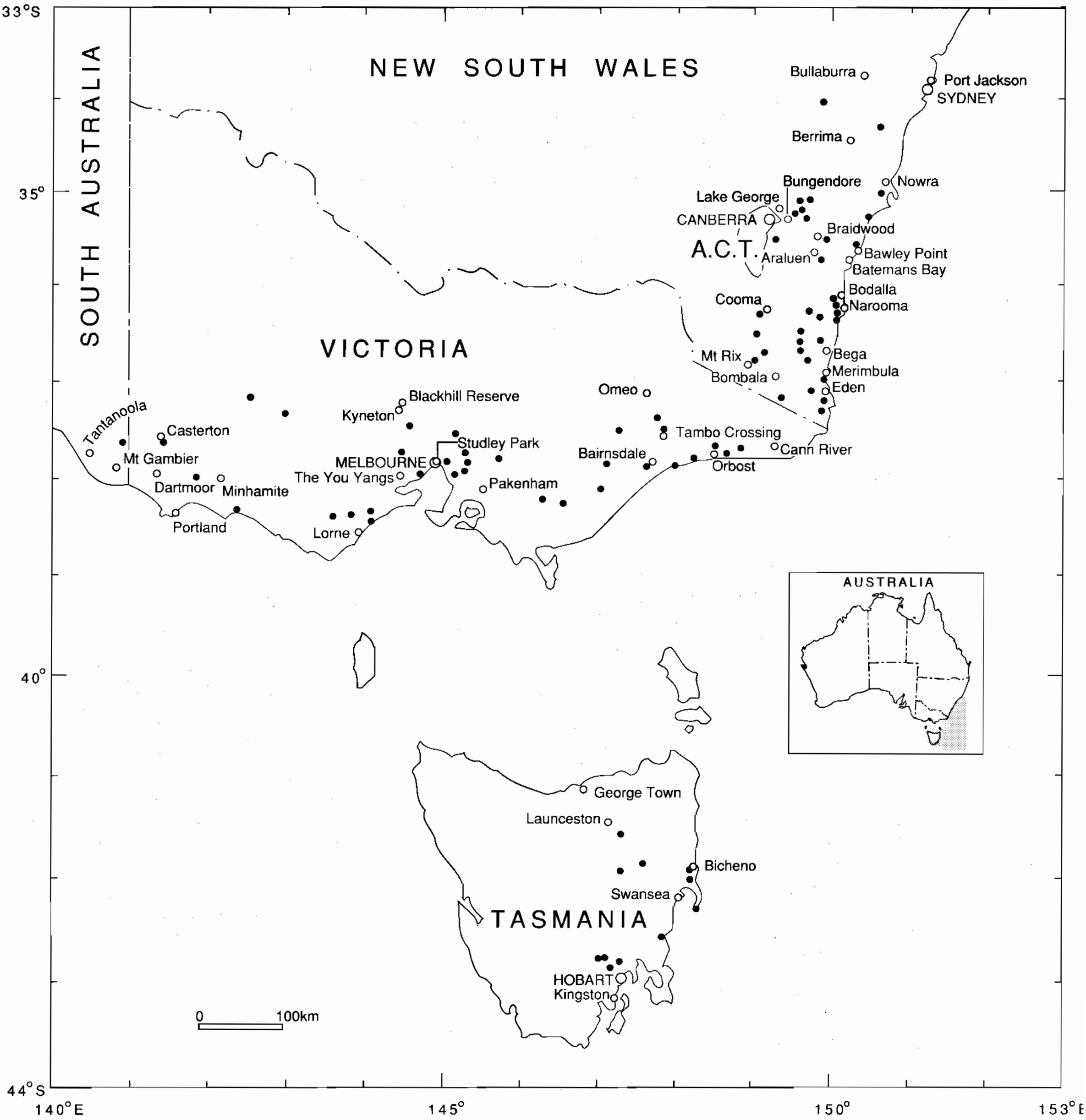

Fig. 1. Map showing the natural distribution of *Acacia mearnsii* as indicated by collection locations of herbarium specimens and seed.

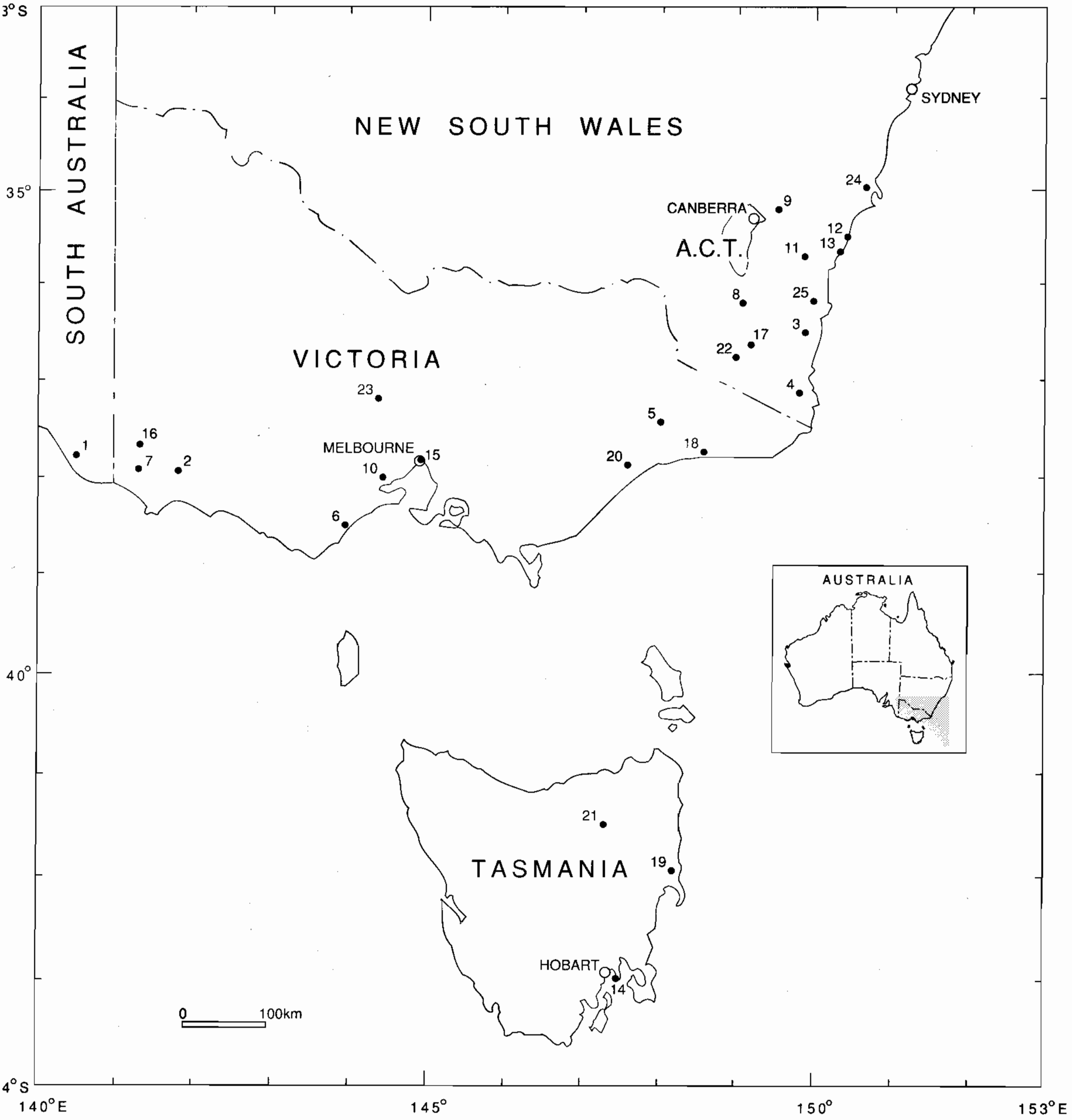

Fig. 2. Map showing location of 25 *Acacia mearnsii* provenances in trial.

been pasteurised at 60 °C for 1 hour. The seedlings were grown initially in a glasshouse with a temperature range of 25/18 °C for an 8-hour day.

Liquid fertiliser (quarter-strength Modified Hoaglands No. 2 Solution (Went 1957)) was applied on 22.4.91 and 29.4.91. From 24.5.91 until 19.7.91 weekly doses of full-strength Hoaglands solution at ca 50 mls per plant were applied.

Trial design

The provenances were arranged in four replicates of a 5 × 5 partially balanced lattice (Cochran and Cox 1957). Each of the replicates was divided into five rows with five plots of ten (5 × 2) seedlings, each plot representing one of the 25 provenances. The position of seedlots within replicates and replicates within the glasshouse and shade house was randomised.

The rows within replicates were oriented at right angles to the direction of the prevailing wind from the south, which is a known source of temperature variation within the shade house. The replicates were arranged so as to minimise the influence of prevailing weather patterns.

Hardening

To reflect natural conditions and induce hardiness, the seedlings were placed in a shade house (22.7.91) to be exposed to the Canberra winter prior to screening. The exposure or hardening enhances the inherent differences in frost tolerance between genotypes (Raymond et al.1986). Temperatures were recorded using minimum temperature thermometers and a thermograph placed amongst the four replicates. Temperatures over the 35 nights varied between 5.1 and −2.1 °C with 34 night temperatures recorded at less than 5 °C. A hardening regime of 28 consecutive night temperatures equal to or less than 5 °C is used as a standard for testing eucalypts to ensure that seedlings are sufficiently tolerant to frost damage to produce a range of frost damage results for comparison (Eldridge 1968).

Frost tolerance screening technique

A non-destructive technique for screening large numbers of eucalypts for relative frost tolerance was developed by Raymond (1986). This technique is fully described by Raymond et al. (1986), Owen and Raymond (1987) and Raymond et al. (1992) who also showed that the results correlated well with those obtained in the field. This technique was applied to screening *A. mearnsii.*

The equipment consisted of plexiglass baths containing aqueous ethylene glycol solution in which racks of test tubes were suspended. Cooling was achieved by pumping liquid at −30 °C from a refrigerated tank through a pressure-regulated copper coil in the test baths with bath temperatures controlled by a thermomix. Pinna samples, 1 cm in length, were placed in each test tube and racks of tubes were placed in the test bath at 2 °C. No liquid was added to the tubes. Bath temperature was lowered at 4 °C per hour to −2 °C when 0.1 g of finely crushed ice (from deionised distilled water) was added to each tube to prevent supercooling. The bath temperature was then lowered to the required minimum and held at this temperature for 1 hour. Racks of tubes were then removed and placed in a refrigerator at 3 °C for a 24-hour post-frost recovery period. Distilled, deionised water (2 ml) was added to each test tube and a 24-hour leaching period was allowed before conductivity readings were taken using a modified conductivity cell. This fits inside the test tube and is attached to a digital-readout conductivity meter. After the first reading (ct — the conductivity for the test temperature) the samples were heated in a water bath at 80 °C for 10 minutes. When cooled the second reading (ck — the absolute conductivity) was taken, by which time the tissue had been killed (Raymond et al.1992). The degree of damage sustained by the leaf tissue is assessed as relative conductivity (rc):

$$rc = ct/ck$$

The method relies on leakage of contents from frost-damaged cells into surrounding water. No discrimination between samples would be expected at non-damaging temperatures nor at those temperatures where all the cells would be killed. Therefore the method depends upon the determination of intermediate test temperatures at which the degree of tissue damage varies between samples. These temperatures are determined from preliminary tests at a wide range of temperatures. In this experiment the winter-hardened *A. mearnsii* seedlings were exposed to test temperatures of −4, −5 and −6 °C.

Sampling strategies

Within trial Replicates were sampled at random. The trial was sampled over seven consecutive days and 20 screening runs. Each replicate of 25 plots was divided into five screening runs (five plots or provenances (50 seedlings) per run). Within each replicate, however, the seedlings were sampled row by row in an order which would enable row or position effects to be separated from time effects related to the day on which the seedlings were sampled.

Within seedling Principal elements of the sampling strategy developed for eucalypt seedlings by Raymond et al. (1992) were used; e.g. for each test temperature, four leaf samples (two pinna pairs) per seedling were cut from two leaves. The sample leaves were the youngest fully-expanded leaf and the leaf immediately below that. The position of these leaves varied between seedlings but most samples were taken from between the fourth and eighth leaf pairs above the epicotyl, although samples did range between the third and the tenth leaf pair. The youngest leaf was systematically sampled first. A method for cutting a standard sample from a bipinnate leaf was developed. From each leaf the central pinna pair was sampled. Each pinna was cut into 3 × 1 cm lengths to give six samples per leaf. These were randomly allocated across the three test temperatures with two samples per temperature.

Analysis

Plot means for relative conductivity at each temperature were calculated from data for the four samples from each of the 10 seedlings. Examination of residuals from preliminary analysis of variance indicated that at the two higher temperatures the values of the residuals tended to increase with increasing fitted values. A logarithmic transformation was made so as to improve the homogeneity of the variance. For this study the index of frost damage used was log (rc). The data were then analysed for each of the test temperatures using Residual Maximum Likelihood (REML) in Genstat 5.2 (GENSTAT 5 Committee 1990). This contrasts with the procedure used by Raymond et al.(1986) who found with eucalypts that there was an inverse relationship between the mean of the relative conductivity, rc, and its variance. Since this was statistically undesirable they used an alternative variable for their analysis:

$$RC^* = (1 - rc)^{0.5}$$

Results

At $-4\,^{\circ}C$ the range in relative conductivity (rc) for provenance means was 0.09–0.14, indicating little or no damage at that temperature. At $-5\,^{\circ}C$ the range was 0.11–0.43 and at $-6\,^{\circ}C$ it was 0.21–0.67. Searle (observation) has found that an rc value of 0.40 ($RC^* = 0.79$ or $\log(rc) = -0.92$) corresponds to 50% tissue death surrounding the sampled pinna. Thus those with RC* values less than 0.79 were classified as dead; those with values above were classified as alive. Using this criterion it is apparent that no provenances were killed at $-4\,^{\circ}C$.

Table 3 shows the analysis of variance for log (rc) values for each test temperature. At each temperature the effect of provenance on log (rc) values was very highly significant (Table 4).

Table 3. Analysis of variance of log(rc) values for provenance means.

Source of variation	d.f.	−4 °C m.s.	−5 °C m.s.	−6 °C m.s.
Replicate stratum				
Replicate	3	0.218	0.030	0.342
Replicate.row stratum				
Provenance	16	0.154	0.263	0.202
Replicate.row*Units*				
Provenance	24	0.033	0.266	0.257
Residual	56	0.011	0.041	0.041
Variance ratio		2.87	6.51	6.27
Significance		0.001	0.001	0.001

The most frost-tolerant provenances across all three test temperatures were Bungendore (NSW), Bombala (NSW), Cooma (NSW), Minhamite (Vic.) and Apsley River Bridge (Tas.) (Table 4). The least frost-tolerant provenance across all test temperatures was Nowra and together with the other northerly coastal NSW provenances (Batemans Bay and Bawley Point) formed the least frost-tolerant grouping. The lowest temperature ($-6\,^{\circ}C$) was the best discriminator between provenances because the data showed a wide range of rc values for the provenance means and included more provenances classified as dead (> -0.92). At the higher test temperatures the range of values was smaller as most of the provenances were relatively undamaged.

There was an inverse relationship between the mean log (rc) and the three test temperatures; as the test temperature decreased, the mean log (rc) values increased. The provenance means of log(rc) at −5 and $-6\,^{\circ}C$ were highly correlated ($r = 0.94$). The correlations between the means at $-4\,^{\circ}C$ and those at −5 and $-6\,^{\circ}C$ were 0.81 and 0.74 respectively.

Discussion

It was expected that the provenances from high-altitude, inland NSW would be the most frost tolerant because this region is the coldest within *A. mearnsii's* natural distribution. Research with 18 Australian acacia species (including eight bipinnate acacias) exposed to both controlled and natural frosts in New Zealand (Pollock et al. 1986) found

Table 4. Relative conductivity log (rc) values and rankings for *Acacia mearnsii* provenances tested at three temperatures.

Treatment no.	Provenance name	State	−6 °C log(rc)	Rank	−5 °C log(rc)	Rank	−4 °C log(rc)	Rank
9	Bungendore	NSW	−1.58	1	−2.16	1	−2.37	2
17	Bombala	NSW	−1.47	2	−2.06	2	−2.28	10
2	Minhamite	Vic	−1.40	3	−1.91	6	−2.31	5
8	Cooma	NSW	−1.38	4	−2.03	3	−2.38	1
19	Apsley River	Tas	−1.30	5	−1.97	4	−2.24	14
4	Eden	NSW	−1.18	6	−1.85	8	−2.32	4
21	Launceston	Tas	−1.17	7	−1.92	5	−2.27	11
22	Mt Rix	NSW	−1.10	8	−1.78	10	−2.30	6
11	Araluen	NSW	−1.09	9	−1.75	12	−2.19	17
18	Orbost	Vic	−1.06	10	−1.78	9	−2.19	18
20	Bairnsdale	Vic	−1.03	11	−1.69	15	−2.29	7
3	Bega	NSW	−1.02	12	−1.77	11	−2.28	9
1	Tantanoola	SA	−0.98	13	−1.86	7	−2.17	19
7	Dartmoor	Vic	−0.98	14	−1.74	13	−2.26	12
23	Blackhill Reserve	Vic	−0.94	15	−1.72	14	−2.29	8
25	Bodalla	NSW	−0.92	16	−1.62	18	−2.15	21
15	Studley Park	Vic	−0.91	17	−1.62	16	−2.26	13
5	Tambo Crossing	Vic	−0.85	18	−1.62	17	−2.21	16
14	Hobart airport	Tas	−0.82	19	−1.51	21	−2.11	23
6	Lorne	Vic	−0.78	20	−1.58	19	−2.22	15
16	Casterton	Vic	−0.77	21	−1.55	20	−2.34	3
10	You Yangs	Vic	−0.75	22	−1.41	22	−2.13	22
12	Bawley Point	NSW	−0.70	23	−1.21	24	−2.04	24
13	Batemans Bay	NSW	−0.68	24	−1.35	23	−2.16	20
24	Nowra	NSW	−0.39	25	−0.87	25	−1.96	25
	Overall mean		−1.01		−1.69		−2.23	
	SED*		0.153		0.155		0.083	

SED* = Standard errors of differences between combined provenance means

there was a tendency for seedlots with greater frost tolerance to originate from higher altitudes, higher latitudes or greater distance from the sea. The results obtained here generally conform with this finding. High-altitude *A. mearnsii* NSW including Bungendore (35 °12 'S, 760 m), Bombala–Dalgety (36 °40 'S 860 m) and Cooma (36 °15 'S 1000 m) were in the most frost tolerant group. However, so were Apsley River Bridge (41 °56 'S 10 m — Tasmania) and Minhamite (37 °57 'S 80 m — Victoria) and there was no significant difference between the five. Without further information it is not possible to explain the presence of the Apsley River Bridge and Minhamite provenances in the most frost-tolerant grouping.

Results from this laboratory screening accord with the results from the frosted field trial at Iswepe in southeastern Transvaal, South Africa, where tableland or higher-altitude NSW provenances were significantly more frost tolerant than low altitude NSW and Victorian provenances. There are five geographically similar provenances and in some cases identical seedlots in common between the trials, and their relative ranking with respect to each other within the trials is the same, e.g. NE of Bungendore/Lake George, Orbost/Cann R. — Orbost, Tambo Crossing/Omeo Hwy, Blackhill Reserve/Kyneton, Batemans Bay/Batemans Bay.

This laboratory trial demonstrates that variation in frost tolerance amongst *A. mearnsii* provenances is highly significant. If frost tolerance in *A. mearnsii* is under additive gene action, as has been found in *Eucalyptus grandis* (van Wyk 1976), it can be included as a character for selection for breeding programs.

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Field Evaluation and Selection of *Acacia mearnsii* Provenances

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Abstract

A trial of 30 *Acacia mearnsii* provenances, 13 ha in area, was laid out on five sites in four southern provinces in China. The 5-year results showed there are significant differences between provenances in growth rate, tree form and bark thickness. Stem volume of superior provenances is 1.5–3.8 times that of inferior ones, 32–69% higher than the controls and 25–40% better than the overall mean. No significant interaction was found between sites and provenance performances. Highly significant differences were found between provenance performances at both the third and fifth years after planting, indicating the possibility of evaluation at an early age.

BLACK wattle (*Acacia mearnsii* De Wild.), rich in tannin, is a fast-growing Australian tree found from 33°43′ to 42°58′S and from 140°42′ to 151°16′E, with altitudes from almost sea level to 1050 m (Searle 1991). Different soil and climatic conditions and ecological variations in the natural range of the species provide a good basis for provenance selection. Supported by the Australian Centre for International Agricultural Research (ACIAR), collaborative research has been carried out between the Chinese Academy of Forestry (CAF) and the CSIRO Division of Forestry since 1986, aiming to improve the quality and yield of *A. mearnsii* tannin in China. This paper presents results from trials at half rotation age in which 30 provenances from Australia, South Africa, Brazil and local areas were tested at five sites located in Fujian, Jiangxi, Zhejiang and Guangxi. The Australian and South African seedlots were provided by the CSIRO Australian Tree Seed Centre.

Materials and Methods

Seed sources

The origin of the 30 provenances tested is given in Table 1, 22 from Australia (representing eight climatic zones), two from South Africa, one from Brazil and five from local areas as controls.

Trial sites

The five trial sites represent the major climate and soil types in areas suitable for wattle growing in China. Their geographic locations are shown in Table 2.

Designs

Balanced incomplete blocks designs and randomised complete blocks designs were used at different sites with 25-tree plots (5 × 5 trees) and from three to six replications. In addition, seedlings were compared at some sites by a randomised complete blocks design with 100-tree plots and three replications.

Establishment and maintenance of trials

Seedlings were raised in plastic sleeves and transplanted at 4–5 months of age. Trial sites were prepared by digging planting holes 60 cm in length and 40 cm wide and deep. Trees were planted at a spacing of 2 × 2 m, giving a stand density of 2500

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Table 1. Geographic locations of the provenances tested.

Seed-lot	Locality	Lat. (° ')	Long. (° ')	Alt. (m)
14394	14 km towards Candelo NSW	36 45 S	149 40 E	80
14927	Sth Gippsland Vic	38 00 S	147 00 E	100
14725	NE of Bungendore NSW	35 12 S	149 12 E	760
14770	Polacks Flat Ck NSW	36 39 S	149 35 E	260
15087	Harding Natal Sth Africa	30 35 S	25 51 E	932
15458	Mt Gambier SA	37 50 S	140 47 E	60
14769	Googong Reservoir NSW	35 29 S	149 16 E	670
14397	6 km S of Bodalla NSW	38 08 S	150 05 E	75
14925	Blackhill Reserve Vic	37 12 S	144 28 E	500
14922	NW of Braidwood NSW	35 15 S	149 38 E	720
14416	Dargo Vic	37 8 S	147 15 E	200
14398	4 km N Batemans Bay NSW	36 20 S	150 13 E	40
14926	Omeo Highway Vic	37 20 S	147 45 E	300
14924	Merimbula NSW	36 55 S	149 54 E	20
15088	Natal South Africa			
14395	Lake George NSW	35 15 S	149 20 E	700
14771	S of Cooma NSW	36 28 S	149 01 E	940
14923	S of Braidwood NSW	37 09 S	149 20 E	500
14928	Cann R and Orbost Vic	37 40 S	150 49 E	100
Brazil				
15326	Georgetown Tas	41 07 S	146 52 E	60
C22	Yunnan China	23 51 S	150 10 E	1540
15327	Bicheno Tas	41 54 S	148 18 E	30
15328	Avoca Tas	41 49 S	147 35 E	220
15331	Hobart Airport Tas	42 50 S	147 31 E	10
15330	Boyer W of Hobart Tas	42 46 S	147 08 E	60
C21	Wenzhou, Zhejiang China	28 01 N	120 40 E	50
C24	Tongjiang, Sichuan China	31 56 N	107 14 E	690
C25	Jiangbian, Yunnan China	24 20 N	103 20 E	1600
C23	Ganzhou, Jiangxi China	25 51 N	123 08 E	150

Table 2. Planting sites of the provenance trials.

Trial Site	Lat. (° ')	Long. (° ')	Alt. (m)	Mean ann. temp. (°)	Mean ann. rainfall (mm)
Nanping, Fujian	26 39 N	118 10 E	92	19.6	1679
Changtai, Fujian	24 49 N	117 52 E	109	21.0	1658
Ganzhou, Jiangxi	25 51 N	114 50 E	124	18.0	1434
Nandan, Guangxi	24 59 N	107 32 E	697	18.0	1559
Wenzhou, Zhejiang	28 01 N	120 40 E	50	17.9	1698

trees/ha. Fertiliser containing N, P and K was applied before planting and two months after. Sites were weeded three times in the first and second years after planting.

Data collection and treatment

Seedling height and diameter at ground level were measured before planting. Tree height, dbh, flowering, disease incidence and frost damage were observed at the end of each year. Tree form and bark quality assessment commenced at 3 or 4 years of age. Tannin content in bark was analysed by the wattle extract laboratory in CAF RICPUFP (Nanjing). DATACHAIN and GENSTAT programs were used for analyses of variance, correlation and regression.

Stem volume was calculated as follows (Lin et al. 1987):

$$V = 0.0000353 \times (0.27 + D)^{2.15} \times H^{0.0876}$$

Bark yield was estimated by the formula developed by Lin et al. (1989)

$$W = 0.0458D^2H + 0.000205D^3H - 0.000696D^2 - 0.02524D^2H\log H)\ 2500Ki$$

where W is the fresh bark yield (kg/ha)
Ki is the final survival (as a fraction)
2500 is initial planting density (stems/ha)
H is overall mean height (m)
D is overall mean diameter (cm)

The performance stability of the provenances was determined as described by Finlay (Ma 1982).

Each provenance was evaluated using a multi-trait selection formula as follows (from the collaborative team for Chinese fir provenance tests of fourteen southern provinces, 1984):

$$P_i = \sqrt{\Sigma k_j(1 - a_{ij}/a_{oj})^2)}$$

where k_j is the weighting coefficient for jth trait
a_{ij} is the ith provenance mean for the jth trait
a_{oj} is the best provenance mean for the jth trait

Results and Analysis

Growth rate

Seedlings Analyses of height of seedlings at 4 or 5 months of age show highly significant differences between provenances at each site. Two Australian provenances, 14725 (NE Bungendore NSW) and 14416 (Dargo Vic), and two South African (Natal) ones, 15087 and 15088, were among the best in height. There are no significant correlations, however, between height of seedlings and that of the young trees in subsequent years.

Stands Variance analyses of results at 5 years of age show that provenances differ significantly in growth rate (Tables 3 and 4). Australian provenances 14928, 14925, 14927, 14398 and 14922, and the Brazilian one are among the best. The Australian provenances from Tasmania and No. 14769 rank last, with the two South African ones in the middle.

The same provenances show considerable differences in growth rates between planting sites (Fig. 1), reflecting marked differences in soil conditions. Trees grew much faster at Nanping than at Ganzhou and Changtai where soils are stony, infertile and poorly drained. In general, black wattle favours deep, well-drained, fertile soils.

Correlations of height in successive years Table 5 indicates that significant correlations of height first appeared between the second and third years and have persisted until the fifth year. This suggests the possibility of assessment and selection of black wattle provenances at 3 years of age.

Selection for rapid growth There are obvious opportunities to select for growth, which differs markedly between provenances tested. The mean stem volume of single trees at 5 years of age of six provenances ranking the best in growth rate is 132–169% higher than that of the control, 121–142% more than the overall mean and 154–384% more than that of the three provenances ranking last (Table 6).

Table 3. Variance analysis of tree growth rate.

Trial site	Character	Degrees of freedom	Computed F	$LSD^{0.05}$	$LSD^{0.01}$
Changtai	height (h)	24	4.54**	0.80	1.0552
	dbh	24	5.66**	1.05	1.3928
	volume (v)	24	5.70**	0.0030	0.0041
Ganzhou	h	24	3.49**	0.5594	0.7402
	dbh	24	5.26**	0.6287	0.8319
	v	24	3.20**		
Nanping	h	24	1.56*	1.4197	1.8785
	dbh	24	1.53*	2.0691	2.7379
	v	24	1.42*	0.0196	0.0259
Nandan	h	20	6.35**		
	dbh	20	6.74**		
	v	20	6.15**		

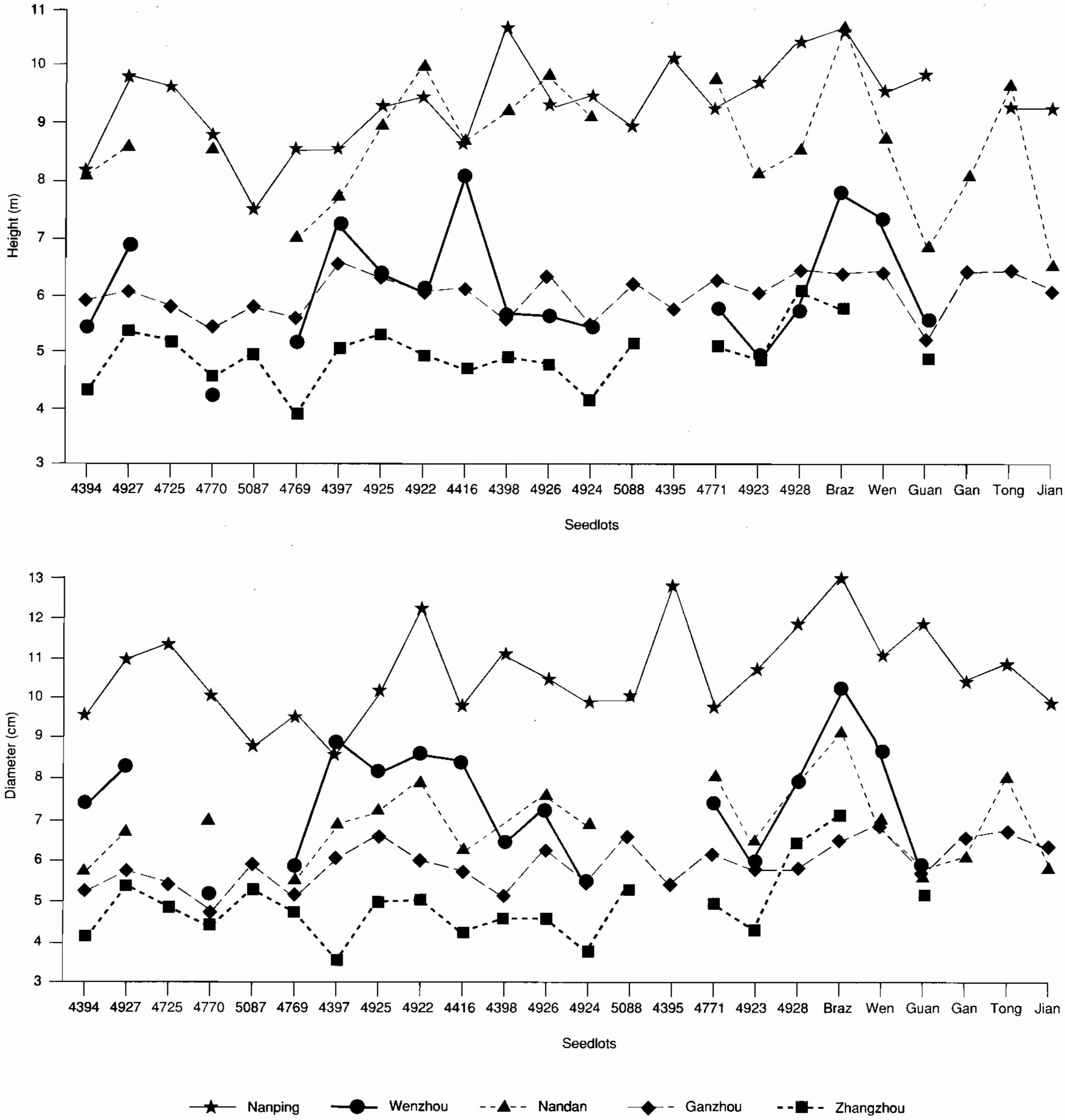


Fig. 1. Differences in growth rates of the provenances tested.

Table 4. Variance analysis of growth to 5 years of the 19 provenances each grown at Changtai, Ganzhou and Nanping sites.

Character	Source of variation	Degrees of freedom	Mean squares	Computed F
Height (m)	Site (S)	2	390.6	304
	Provenance (P)	18	2.9	2.29**
	S x P	36	1.13	0.88
	Error (E)	228	1.26	
Dbh (cm)	S	2	660.7	312**
	P	18	5.9	2.78**
	SxP	36	2.3	1.07
	E	228	2.1	
Volume (m^3)	S	2	0.0263	245**
	P	18	0.000216	2.02*
	S x P	36	0.000139	1.30
	E	228	0.000107	

Table 5. Correlation of height growth in successive years at four sites.

Site	Year	1. 1986	2. 1987	3. 1988	4. 1989	5. 1990
Ganzhou	1. 1986	1	0.49	0.36	0.17	0.03
	2. 1987		1	0.84**	0.70**	0.64**
	3. 1988			1	0.88*	0.77**
	4. 1989				1	0.83**
Nanping	1. 1986	1	−0.02	−0.23	−0.03	−0.08
	2. 1987		1	0.72**	0.70**	0.79**
	3. 1988			1	0.66**	0.67**
	4. 1989				1	0.76**
Nandan	1. 1986	1	0.34	0.17	−0.00	0.06
	2. 1987		1	0.70**	0.79**	0.73**
	3. 1988			1	0.84**	0.84**
	4. 1989				1	0.86**
Changtai	1. 1986	1	0.16	0.17	0.24	0.25
	2. 1987		1	0.70**	0.71**	0.70**
	3. 1988			1	0.87**	0.78**
	4. 1989				1	0.95**

Table 6. Outcome of selection of single trees for growth rate, based on the mean timber volume. The volume of each individual tree has been corrected for block effects at each site.

Site	Mean of the best 6 / Control (%)	Mean of the best 6 / Overall mean (%)	Mean of the best 6 / Mean of the worst 3*	Number of provenances higher than control	Percentage of provenances higher than the control
Nanping	169	136	211	19	76
Ganzhou	168	127	177	19	76
Nandan	184	121	180	20	95
Changtai	138	142	384	6	24
Wenzhou	132	121	154	17	94

* Worst 3 refers to the three worst-performing provenances

Table 7. Variance analysis of bark quality.

Character	Source of variation	Degrees of freedom squares	Mean F	Computed
Bark thickness	site	2	0.0564	
	provenance	18	0.0060	3.76**
	error	36	0.0016	
Percentage tannin	site	2	182.2	
	provenance	18	39.1	4.23**
	error	36	9.3	
Fresh bark yield (kg/ha)	site	2	$5.23*10^9$	
	provenance	18	$8.61*10^7$	1.97*
	error	36	$4.37*10^7$	

Bark thickness and tannin content

Bark quality is an important criterion for black wattle selection. Bark samples were taken from the trial at 4 or 5 years of age; laboratory tests and analyses (using the hide-powder method for tannin analysis) showed highly significant differences in bark thickness and tannin content between provenances tested (Table 7).

Trees planted at Ganzhou tend to have higher tannin contents than those at other sites (Fig. 2). Local provenances showed higher content than most of the exotic ones and, among exotic provenances, the Brazilian one, two South African ones and five Australian (Nos 14927, 14925, 14416, 14926 and 14395) provenances had the highest tannin contents.

Table 8 presents the correlations between key traits. Strong positive correlations, significant at 1% level, are found between tree height and dbh, and between bark thickness and tannin content. No significant correlations exist between other combinations.

The provenances higher in bark and tannin yield than the control are given in Table 9. Provenance 14928 (Cann River-Orbost) produces both the highest fresh bark and tannin yields, which are respectively 1.80 and 1.83 times that of the control (Yunnan) and 5 and 10% higher than Wenzhou land race, the best among the local ones.

Table 8. Correlation matrix among tree height, dbh, bark thickness and tannin content.

Trait	Dbh	Bark thickness	Tannin content
Height	0.84**	0.40	0.20
Dbh		0.43	0.31
Bark thickness			0.73**

Table 9. Bark and tannin yields (using the hide-powder method for tannin analysis) of the selected and control provenances averaged across sites*.

Seedlots	Fresh bark yield (kg/ha)	Water content (%)	Air-dry bark yield (kg/ha)	Tannin content (%)	Tannin yield (kg/ha)
14928	27490	45.1	15100	37.7	5690
Brazil	27071	51.2	13200	39.9	5270
Wenzhou	26050	52.1	12480	41.5	5180
14922	25998	51.0	13260	37.7	5000
14398	19002	54.3	8680	36.8	3196
14927	18955	54.2	8680	41.1	3570
14725	18635	50.6	9200	34.7	3190
Yunnan	15267	53.1	7165	43.5	3100

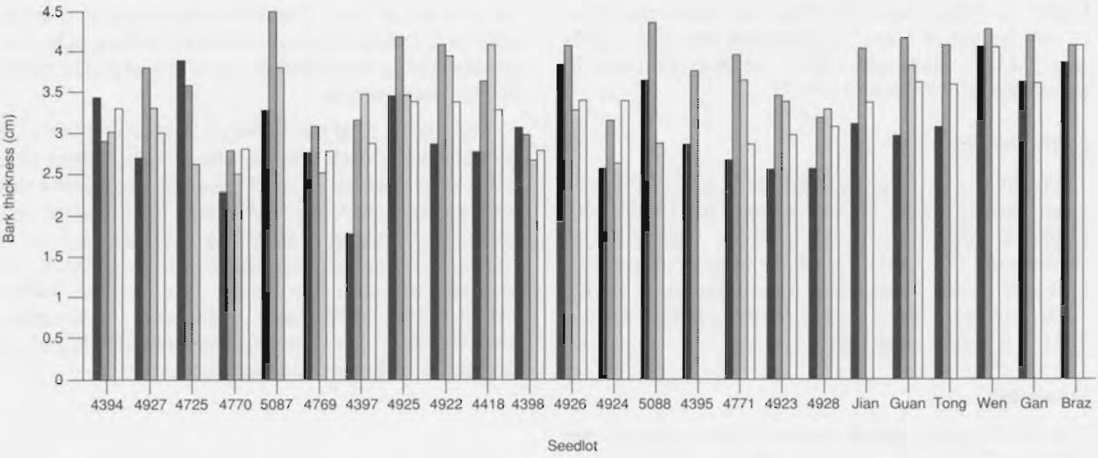
* Data are average values of Changtai, Ganzhou, Nanping and Nandan, except for seedlot Wenzhou, which has average values for Ganzhou, Nanping and Nandan, and seedlot 14725, which has average values for Changtai, Ganzhou and Nanping.

Stem straightness

Tree and stem form have obvious effects on quality and yield of timber and on tannin yield. The percentage of trees with straight stems varies with provenances and planting sites. In general, exotic and fast-growing provenances have good tree form. The Brazilian provenances and Australian 14922, 14925, 14771, and 14769 are among the best.

Gummosis incidence

Gummosis, the most destructive and widespread disease on black wattle, is considered a physiological reaction of the trees to environmental pressure. The incidence of the disease is low at sites with good soil conditions. At Ganzhou site where soil conditions are poor, in contrast, 22.3% of trees in the trial suffer from severe gummosis and significant differences are found between provenances, with



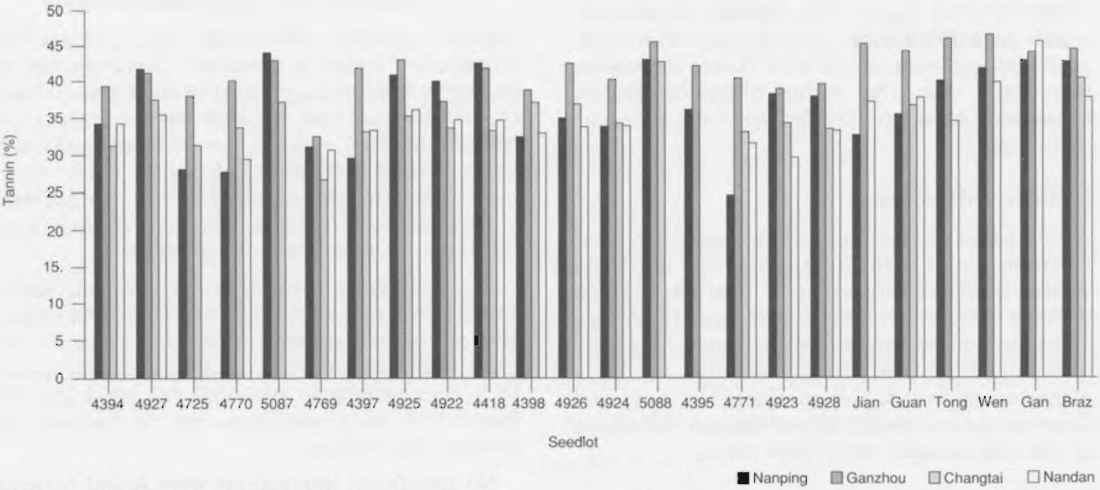


Fig. 2. Tannin content in the bark of the provenances tested at four sites.

higher incidence in exotic ones. The lowest incidence of the disease is found in provenances C22, 14394 and 14397, and the most severe damage in provenances 14769 and 14925.

Frost tolerance

There has been frost damage only at Nanping. A snow storm there in the winter of 1988, with absolute temperature of −5.2 °C, caused some damage to the trial. The following provenances, however, were found free from damage: 14394, 14769, 14927, 14922, 14398, 14924, 14395, 14771, 14923, 20, C21 and C23.

Flowering

The provenances tested appear to have one of two different flowering patterns. Trees of the exotic provenances commenced flowering generally at 3 years of age and have a distinct flowering season from March to April. The Chinese provenances mostly started flowering in the second (even the first) year after planting. Trees may flower throughout the year, with two main flowering seasons respectively from April to May and from November to December.

Multiple-trait selection

A multi-trait selection process is used to evaluate performance of each provenance. The traits considered and their contribution vary slightly with planting sites, but typically growth rate (height, dbh and volume) contributes 60% and stem straightness and bark quality contribute 40%. Resistance to gummosis or frost is also considered at some sites. Based on the evaluation, six provenances are selected as the best at each site (Table 10).

Analysis of provenance x site interaction and provenance performance stability

These analyses are based on growth rate of the 19 provenances included at each of Changtai, Ganzhou and Nanping sites. There are no significant interactions between provenances and planting sites, suggesting high genetic stability and adaptability of the provenances tested.

Regression analysis between timber yield of each provenance at each planting site, and the mean yield of all provenances at each planting site, shows that most of the regression coefficients are below or very close to the mean stable line (Fig. 3), indicating stable performance for the provenances tested. Of special note are Australian provenances 14922, 14928, 14725, 14398 and 14925 and the Brazilian one, which all grew fast and showed stable performance at different planting sites.

Conclusions and Recommendations

Highly significant differences exist between the provenances tested in the major characteristics of economic importance, thus providing a good basis for effective selection of black wattle provenances. At half rotation age, the best provenances have much greater timber volume than either those ranking last or the controls. Marked improvement in tree form and bark quality, as well as in cold resistance, is expected from selection.

The average growth rates for each site differ appreciably. Although black wattle appears to survive and grow normally on a wide range of soil types, only with good soil conditions can the species fully demonstrate its potential for rapid growth. Favourable soils maximise the productivity of selected provenances.

No significant interactions were found between provenances and planting sites. Most provenances show high performance stability.

Selection based on characters of major economic importance and performance stability suggests that

Table 10. The best and better provenances selected at each site on the basis of multiple traits.

Site	Best provenance	Better provenances
Nanping	14922, 14925, 14395, 20, C21, 14725	14926, 14928, C22
Changtai	20, 14928, 15088, 14927, 14725, C22	14922, 14771, 14725, 14926, 14398
Ganzhou	14925, 15088, C21, 14922, 14771, 14926	20, 14927, C24, 14398, 14725
Nandan	14922, 14925, 14397, 20, C24, 14923	14927, 14771, C21, 14398
Wenzhou	20, 14922, 14416, C21, 14927, 14397	14925, 14926

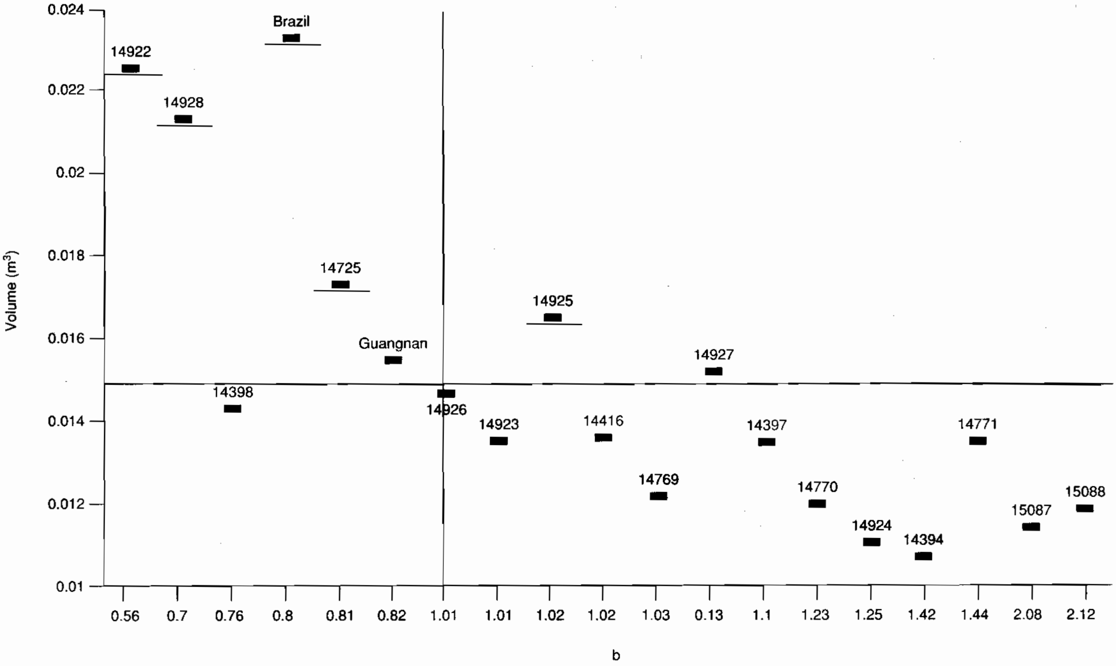


Fig. 3. Scatter diagram of timber volume and regression coefficients (b).

provenances 14922, 14927, 14925, 14928, 14398 and the Brazilian one provide a suitable base for large-scale plantation establishment in China.

The highly significant correlation of height in successive years indicates the possibility of early assessment and selection at 3 years of age in future breeding programs of the species. Selection of individual trees within superior provenances is especially recommended because of considerable variation between trees within provenances found in the trial. Seed orchards should be established by using material from superior families.

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Breeding *Acacia mearnsii* in Southern Brazil

A.R. Higa and M.D.V. Resende*

Abstract

The *Acacia mearnsii* De Wild. breeding program, in southern Brazil, aims to increase tannin and timber yield. Volume production in commercial plantations has improved 10–15% using seed from a seed production area. Genetic parameters, estimated for growth and tannin content, were used to choose a selection strategy for families and trees in a progeny trial established with open-pollinated seed collected from trees selected in commercial plantations. Genetic gains of 18% in volume and 3.1% in tannin were predicted if the best 30% families and the best 17% of trees within family were to be selected. These estimates are based on selection using independent culling for diameter at breast height (dbh) and tannin.

Recently introduced germplasm is being studied in a combined provenance and progeny trial planted in two sites. Batemans Bay provenance is showing best growth, followed by Bega and Bodalla. Genetic variability for dbh, height and survival in these introduced provenances was greater than that determined for existing germplasm. Genetic variation for these traits was highly significant, but the genotype x environment interaction was not. Between- and within-family selection at 25 and 20% respectively should increase volume by 15% in relation to the control (commercial seed).

ACACIA mearnsii De Wild. is the third most-planted forest tree species in Brazil. More than 200 000 ha have been planted in the State of Rio Grande do Sul by a few private companies and by more than 20 000 small farmers.

Despite their economic and social importance in that region, little effort has been made to improve the productivity and quality of black wattle plantations. Until now, most seed used has been harvested without any kind of selection from trees introduced around 1930.

A breeding program was started in 1984 by EMBRAPA and TANAC, a private company which owns 20 000 ha of acacia plantations and a tannin industry. This program aimed to produce genetically improved seed from seed production areas and seedling seed orchards, using existing genetic resources and new introductions from Australia. Information about this program is presented in this paper.

Seed Production Area

A seed production area was established in 1983. A 30-ha commercial stand was selected for growth, straightness and freedom from gummosis disease following visual screening of 10 000 ha of commercial plantations. Around 120 kg of seed has been collected every year.

Volume productivity of commercial plantations established in the last 4 years using seed collected in this seed production area (Stein, P.P., Brazil, pers. comm.) has increased by 10–15%.

Seedling Seed Orchard with Existing Genetic Resources

Patterns of genetic variability and genetic parameters for height, dbh and tannin concentration in the bark (tannin) of a local population of *A. mearnsii* were determined (Resende et al. 1992a). The information was used to choose a selection strategy to convert a progeny trial into a seedling seed orchard. The one-tree-plot progeny trial was planted in a randomised blocks design, with 92 families and 40 replications, in Montenegro, State of Rio Grande do Sul. High heritability values, estimated for all

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traits at the fourth year, showed encouraging prospects for response to selection. This result agrees with Nixon (1969). Genetic correlations for growth traits (height and dbh) and tannin do not appear to be significant. Genetic gains of 2.4% in dbh and 3.1% in tannin were estimated for the top 30% of families for both traits, using independent culling. An additional 3.6% in dbh is obtainable from within-family selection at 1:6 intensity. Estimates of effective population size indicated that enough genetic variability is maintained for seed production in advanced generations.

Seedling Seed Orchard with Newly Introduced Genetic Resources

Forty-six families from five Australian provenances (Table 1) were planted at two sites in Montenegro, State of Rio Grande do Sul, Brazil. The trials were established using a randomised blocks design, with five replications and five plants per plot. Spacing was 3.0 × 2.0 m.

Height, dbh and survival were evaluated at 3 years of age. The best growth was observed for local germplasm (control) and Batemans Bay. Among the other introduced germplasm, Bega and Bodalla provenances performed better than Bungendore and Braidwood (Table 2).

Individual analyses for height, dbh and survival revealed genetic variability at the provenance level for all traits except survival on site 2 (Resende et al. 1992b). Highly significant genetic variability at progeny/provenance level was also detected for all traits at both sites. Selection of the 11 best families, based on height, confirmed the pattern of results presented in Table 2; seven families were from Batemans Bay, three from Bega and one from Bodalla.

Genetic parameters estimated for all traits at both sites are presented in Table 3. Higher values for heritability at family means level indicated that better results should be obtained using between- and within-family selection, than selection at individual level.

Table 2. Height, dbh and survival at 3 years of age (average for both sites). Standard deviation of means within parenthesis.

Provenance	Height (m)	Dbh (cm)	Survival (%)
1. Bungendore	7.2(0.3)	5.8(0.3)	84(5)
2. Braidwood	7.0(0.3)	5.6(0.3)	93(3)
3. Bega	7.8(0.3)	6.4(0.3)	89(4)
4. Bodalla	7.9(0.3)	6.2(0.4)	89(4)
5. Batemans Bay	8.4(0.3)	6.7(0.3)	93(3)
6. Control (local)	8.7(0.3)	7.4(0.3)	87(4)

Values for coefficients of genetic variation were higher than those obtained for the local seed source (Resende et al. 1992b), showing that this introduced germplasm is more suitable for selection.

An analysis combining sites also indicated no significant interaction between families and sites, showing that a single breeding zone would suit both sites (Resende et al. 1992b).

Simulated selection strategies, involving all traits and both sites, indicated that genetic gains of 30% in volume per ha over the general mean of provenances should be obtained, based on the average of sites for height (Resende et al. 1992b).

Future Directions

A review carried out in 1992 indicated that significant gains could be obtained using genetically improved seed produced in this program. A second phase is now being planned involving two more private companies. This new cooperative breeding program aims to introduce and evaluate new germplasm in a variety of sites, to study the possibilities in using hybrids, and to develop techniques for vegetative propagation. The overall objectives are to improve productivity and quality of wood and tannin.

Table 1. Provenances of *Acacia mearnsii* used in this study.

Provenance	Lat.	Long.	Altitude (m)
1. Bungendore	35°55′-35°15′	149°04′-149°06′	700
2. Braidwood	35°25′-35°35′	149°55′	640–700
3. Bega	36°30′-35°45′	149°40′-149°15′	80–120
4. Bodalla	36°08′	149°55′-150°05′	15
5. Batemans Bay	36°20′-36°25′	150°13′	40

Table 3. Narrow-sense heritability at family/provenance level (h^2_x), at within-family level (h^2_d), and at individual level (h^2_i); and coefficient of genetic variation (CV_g) estimated for height, dbh and survival, for both sites.

	Site 1			Site 2		
Parameters	Height	Dbh	Surv (%)	Height	Dbh	Surv (%)
h^2_x	0.67	0.74	0.55	0.71	0.70	0.46
h^2_d	0.23	0.25		0.30	0.34	
h^2_i	0.27	0.31		0.34	0.37	
CV_g (%)	5.96	9.37	6.98	6.63	10.30	5.76

Acknowledgment

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Screening of Black Wattle Families from Open-pollinated Progenies in Native Stands

Ren Huadong*, Gao Chuanbi*, Zheng Fangji*, Li Jiyuan*, Liu Shijun and Fang Yulin*****

Abstract

One hundred and sixty-nine open-pollinated black wattle (*Acacia mearnsii*) seedlots collected from 19 provenances in native stands in Australia were tested in a provenance/progeny trial planted in 1988 at Meipen Forest Farm, 4 km E of Chenxiang, Changtai County (Fujian) and Taihe Forest Farm, 25 km from Nankang (Jiangxi). This paper compares provenance performance in growth rate and analyses the genetic variance of half-sib progenies in the trial at 3 and 4 years of age. Highly significant differences occurred among the provenances. Height and dbh growth of the best provenance are 1.4 times that of the worst. The growth of the families present at both sites shows significant genotype–environment interactions. Thirty-five families were selected by using a breeding value calculation.

PROGENY testing is indispensable in tree breeding because it permits selection of the best families, thus providing a basis for developing a breeding population and seed orchards; and it provides an understanding of the genetics of important characteristics. Such work has not previously been undertaken for black wattle in China, although the species has been grown there since the early 1950s. There are still no orchards producing improved seed, thus hindering development of the wattle industry in this country. The marked variation between trees in the present plantations and trial stands indicates great genetic variance in the species. Large genetic gains would be expected from progeny tests for family selection. Under these circumstances, a large provenance/progeny trial funded by the ACIAR and the Chinese Academy of Forestry was established in 1988 in collaboration with CSIRO Division of Forestry, with seed provided by the Australian Tree Seed Centre. This paper follows an earlier report by Gao et al. (1991) and presents the preliminary analyses of family performance, aiming to provide experimental data for further improvement programs.

Materials and Methods

Materials and field design

The provenance/progeny trial tested 169 open-pollinated seedlots within 19 provenances individually collected from native stands in Australia (Table 1) (Raymond 1987) and several Chinese seedlots as the controls. Seedlings were raised in October 1987 and transplanted in March 1988 at Meipen Forest Farm, Changtai county, Fujian province and Taihe Forest Farm, Nankang county, Jiangxi province. The trial design was a 13 × 13 balanced incomplete block (BIB) design, with single-tree plots and 20 replicates at each site.

Data collection and treatment

Growth was measured for each tree at the end of each year. Tree form, crown width, flowering and gummosis incidence were assessed from the fourth year after planting. Variance and correlation analyses were used to determine provenance and family mean performance and correlations among characters observed. Families present at both sites were used to analyse interactions between families and environments.

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Table 1. Origin of provenances and number of seedlots by which they are represented in field trials.

Provenance No.	Locality	No of seedlots	
		Meipen	Taihe
14394	Candelo, NSW	13	13
14769	Googong Rsvr, NSW	12	12
14922	NW of Braidwood, NSW	10	12
14923	S of Bombala, NSW	12	13
14924	Merimbula, NSW	4	4
14925	Blackhill Reserve, Vic	6	6
14926	Omeo Highway, Vic	9	9
14927	Sth Gippsland, Vic	7	7
14928	Cann R & Orbost, Vic	6	6
15326	George Town, Tas	10	10
15328	Avoca, Tas	10	10
15329	Apsley River, Tas	10	10
15330	Boyer, Tas	6	6
15331	Hobart Airport, Tas	10	10
15858	St Leonards, Tas	6	6
17233	Studley Park, Vic	11	11
17234	Watsonia, Vic	9	9
17235	Dandenong, Vic	10	10
17236	Minhamite, Vic	7	4
Wen-1	Wenzhou, China	1	1

The breeding value for family selection was calculated based on diameter at breast height (dbh) (Kung 1979):

$$Z = Y + C(y - Y)$$

where: Z is the breeding value
Y is the overall mean of dbh
y is the family mean of dbh
C is the correction coefficient
(C = 1 - 1/F, where F is the computed F in variance analysis)

Results and Analyses

Variance analysis of growth rate

Highly significant differences were found in tree height and dbh between provenances (Table 2), with coefficients of variation for height and dbh 7.71 and 12.03% at Meipen Forest Farm and 8.67 and 13.16% at Taihe Forest Farm. The provenances performing best are Nos 14927 (Sth Gippsland Vic), 14928 (Cann R and Orbost Vic), 14922 (NW of Braidwood NSW) and 14769 (Googong Rsvr NSW) at Meipen, and 14927, 14925 and 14926 (Omeo Highway Vic) at Taihe.

The familes tested differ very significantly in growth, especially in dbh, with coefficients of variation for height and dbh 11.11 and 19.51% at Meipen, and 8.47 and 13.52% at Taihe. There are five and 10 families significantly different at 5% level from the overall mean in height at Meipen and Taihe; and 10 and seven families perform better than the overall mean in dbh at the two sites respectively. The families with rapid growth are mostly found in the best provenances.

Table 2. Variance analysis of diameter and height of the families planted.

Site	Source of variation	Degrees of freedom	Dbh (cm)				Height (m)			
			Range	CV (%)	MS	F	Range	CV(%)	MS	F
Meipen	Replication	19			66.15	23.21**			55.74	55.19**
	Provenance	18	4.91–7.86	12.03	25.44	2.98**	4.52–5.98	7.71	24.05	3.33**
	Families	149	4.05–9.91	19.51	8.54	2.99**	3.63–6.71	11.11	7.23	7.16**
	Error	3173			2.85				1.01	
Taihe	Replication	19			48.66	41.59**			46.99	83.91**
	Provenance	18	3.29–5.19	13.16	51.16	7.28**	3.91–5.02	8.67	24.54	7.96*
	Families	149	2.48–6.48	13.52	7.03	6.01**	3.28–5.70	8.47	3.21	5.73**
	Error	3173							0.56	
	Sites	1			4300.36				598.75	
	Replicates	19			226.79				81.23	
	Families	164	3.07–7.56	17.08	29.13	1.48**	3.44–7.11	10.83	10.80	1.94**
	Families*site	164			19.57	6.69**			5.57	4.88**
	Families*replic.	3116			3.72				1.41	
	Error	3135			2.92				1.14	

** significant at 1% level; *significant at 5% level

Estimates of superiority following selection

Because of the need to maintain a broad genetic base in the breeding program, high-intensity selection is not appropiate. Considerable improvements are expected as plantations are established with seeds to be collected from the retained families. Further genetic gain will be obtained from further testing and selection.

Interaction between family and environment

Significant genotype-environment interactions for height and dbh are indicated by variance analysis of growth rate of the 165 families present at both sites (Table 2).

Family selection

Thirty-five families with breeding values higher than the overall mean of the trial in dbh were selected. Most of them were found in provenances Nos 14927, 14928 and 14922 which performed best in the provenance trial planted in 1986. The breeding values based on dbh of the families selected at each site are shown in Table 3. These families can be retained for converting to seed orchards, providing the basis of a breeding population for the next generation and producing seed or vegetative material for extensive seed orchard establishment.

Table 3. Families selected at each site.

Meipen Forest Farm			Taihe Forest Farm		
Seedlot	Observed diameter (cm)	Breeding value	Seedlot	Observed diameter (cm)	Breeding value
15329-1	9.9	8.56	14922-4	6.5	6.08
14928-2	9.8	8.50	14927-7	6.4	6.03
17235-9	9.3	8.14	14926-3	5.8	5.52
17233-9	8.7	7.75	14922-6	5.8	5.51
14928-1	8.7	7.74	14922-10	5.8	5.49
17233-6	8.5	7.64	14928-1	5.7	5.46
14927-5	8.5	7.62	14925-3	5.6	5.36
15326-9	8.4	7.52	14926-9	5.5	5.31
15927-6	8.3	7.46	14925-1	5.5	5.28
17235-8	7.9	7.19	17235-9	5.8	5.53
15331-7	7.9	7.20	14927-5	5.4	5.21
14925-5	7.9	7.18	14923-12	5.4	5.20
14922-11	7.8	7.15	17235-3	5.4	5.17
14927-1	7.8	7.12	17235-1	5.3	5.14
15329-9	7.7	7.09	14923-10	5.4	5.18
14922-1	7.7	7.08	14922-5	5.4	5.16
14922-2	7.7	7.07	14926-7	5.3	5.15
17233-11	7.6	7.04	14924-4	5.3	5.11
14927-3	7.6	7.03	14925-2	5.2	5.01
14927-4	7.5	6.93	14925-5	5.2	4.99
17234-5	7.4	6.85	17235-4	5.1	4.97
17233-1	7.3	6.83	14927-2	5.1	4.96
14926-6	7.3	6.78	14924-3	5.0	4.89
17236-7	7.1	6.70	14923-7	4.9	4.78
17234-1	7.0	6.63	14925-6	4.9	4.77
14394-11	6.9	6.56	14922-3	4.9	4.75
15329-7	6.9	6.56	14927-3	4.9	4.75
14926-3	6.8	6.50	14927-6	4.8	4.73
14394-8	6.8	6.49	14923-5	4.8	4.73
14769-8	6.8	6.48	14926-8	4.8	4.72
17234-9	6.7	6.40	14922-12	4.8	4.72
14923-6	6.7	6.39	17233-8	4.8	4.72
15858-7	6.6	6.36	15858-6	4.8	4.71
14769-6	8.3	6.46	14925-4	4.8	4.67
17236-7	7.1	6.70	14923-1	4.8	4.66

Conclusions and Recommendations

1. The significant differences in growth are found mainly between provenances as well as between families. There is great genetic variation among families.
2. The high genotype x environment interaction found in the trial indicates the need to undertake progeny tests in all major growing regions to select families specifically adapted to the local environment, or alternatively, families which perform well across a range of sites.
3. The present provenance/progeny trials should be converted to seedling seed orchards by a two-stage thinning process. The first thinning is undertaken at 5 years of age, roguing both the poorest families and the worst trees in families to be retained. Seed collections then can be made to provide the basis for progeny tests of the next generation; this seed should have male parents which are both improved and representative of the rogued trial as a whole. The second thinning will convert the trial stands to seed orchards at 6 years of age. Only the very best trees will be retained to ensure that high quality seed is produced for seed orchard or plantation establishment.
4. It is intended to establish seedling or vegetative seed orchards with reproductive material from families finally retained in the present trial.

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Pollination studies and breeding system in *Acacia mearnsii*

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Abstract

This paper reviews data, collected over 3 years, of aspects of flowering in *Acacia mearnsii*. Significant loss of reproductive potential may occur because of the pollination system, the requirement for outcrossing and resource allocation within a tree. For *A. mearnsii* the result is poor seed production. The success rate of functional hermaphroditic flowers in producing pods was 0.1% in 1987/88, 0.09% in 1988/89 and 0.04% in 1989/90. These figures are influenced by the number of male flowers, the level of pollination, the requirement for outcrossing, the presence or absence of pollinators and resource allocation within the tree as well as environmental factors.

ABORTION of flowers, fruits and seeds is a general phenomenon in plants. Variation in flower to fruit and ovule to seed ratios is inherent among species (Bawa and Webb 1984). Knowledge of the pattern of variation in pollination and seed set, and the breeding system of a particular species is important when manipulating the species for human purposes. Study of these patterns will identify factors that can be most easily and profitably modified.

The genus *Acacia* is widespread, with the greatest species diversity occurring in Australia (Sedgley 1987; Kenrick and Knox 1989). *Acacia mearnsii* flowers are grouped into spherical balls which are themselves grouped into racemes. Flowers within an inflorescence can either be truly hermaphroditic, with functional male and female parts, or the individual flowers can be functionally male with the ovary reduced or absent and a short or absent style. Pollen is aggregated into a polyad structure which for *A. mearnsii* contains 16 pollen grains (Kenrick and Knox 1982). The polyad is the product of a single primary sporogenous cell which undergoes two mitotic divisions followed by meiosis to form the 16-cell polyad (Knox and Kenrick 1983). Coupled with the 16-grain polyad is an ovary that has a number of ovules equal to or less than the 16 pollen grains in the polyad. Theoretically, one polyad is able to pollinate all the ovules in the ovary. As well the stigma surface is cup-shaped and ideally formed to take one polyad (Sedgley 1987; Kenrick and Knox 1982). In practice, more than one polyad per stigma has been reported for a number of *Acacia* species (Knox and Kenrick 1983; Muona et al. 1991).

This study of the pollination and breeding system of *A. mearnsii* commenced in the 1987–88 flowering season. Aspects of the study have been presented elsewhere (Moncur et al. 1989; Moncur and Somerville 1989; Moncur et al. 1991). This paper reviews data on pollination, seed production, the breeding system and the effect of introduced pollinators over all three seasons that the natural population of *A. mearnsii* was studied.

Materials and Methods

Population studies

The main population studied is located 16 km north-east of Bungendore, New South Wales (NSW; Lat. 35°10′S: Long. 149°35′E: Alt. 800 m). The site is undulating and partly cleared with scattered trees of *Eucalyptus dives*, *E. pauciflora* and *Allocasuarina littoralis* amongst the *Acacia mearnsii*.

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The second population (Tarago), used in 1988–89 for a comparison of pollination levels, was located 10 km east of Tarago, NSW.

Estimation of pollination levels

For the 1987–88 season the level of pollination was estimated from a sample of deep frozen flowers. For 1988–89 and 1989–90 flowerings, randomly collected racemes were placed in 1:2 lactic acid:ethanol for 3 days and then transferred to 70% ethanol.

For 1987–88 estimates, stigmas from five hermaphroditic flowers from 10 balls (each from a different raceme) from eight trees (= 400 flowers) were studied. For 1988–89, stigmas from 10 hermaphroditic flowers from each of 20 balls (each from a different raceme) from 10 trees (= 2000 stigmas) were studied. For 1989–90, five hermaphrodite flowers from each of 20 balls for each of 10 trees (= 1000 stigmas) were studied.

To assess the number of polyads on stigmas, flowers were dissected and stigmas stained in 0.1% decolorised aniline blue, squashed and observed under UV fluorescence.

Estimation of number of functionally male flowers

On each tree one ball was selected at random from 15 different racemes. Every flower in the ball was scored either as a perfect flower or as a functional male flower (i.e. no ovary was present). This was done for 10 trees in each of the three flowering seasons.

Estimation of outcrossing rates

Twenty germinated seedlings per tree were assayed for 10 variable isozyme loci. These arrays of progeny genotypes were used to obtain estimates of outcrossing rates using the method of Ritland and Jain (1981).

Estimation of flower-to-seed sequence

On 10 trees three primary branches were selected; on each primary branch five racemes were labelled. On each raceme the number of globular heads at each developmental phase was recorded (Moncur et al. 1989), as well as the number of pods initiated, the number of pods matured and the number of seeds per pod.

Results

Table 1 shows the population data collected for *A. mearnsii*. The outcrossing rates for the three years studied were very high, with nearly all the viable offspring resulting from an outcross pollination. The percentage of male flowers (56.3%) was highest in the 87–88 year, and similar for years 88–89 and 89–90 (24.8 and 26.5% respectively). However the number of inflorescences per raceme was similar for 87–88 at 61.5 and 89–90 at 61.6. Both these seasons were considered to be 'heavy' flowering years. In 88–89 flowering was 'light' and the number of inflorescences per raceme was 9.9. The level of pollination was similar in the 87–88 and 88–89 flowering seasons. In the 1988–89 season the tree population at Tarago without bee hives was used to compare the level of pollination with the population at Bungendore that had bee hives introduced. The Tarago population without bees had 28.7% of stigmas pollinated while the Bungendore population had 43.6% of stigmas pollinated.

Table 2 shows production at the different levels of organisation from the number of racemes studied, through the number of functional hermaphrodite flowers to the number of seeds per pod. In the heavy flowering years 87–88 and 89–90 not only are there more inflorescences per raceme, a similar proportion of flowers were pollinated, 16 and 14% respectively. In 88–89, the light flowering year, approximately twice as many hermaphrodite flowers were pollinated.

For the seasons 88–89 and 89–90 beehives had been placed within the population. In both these seasons many more pods were initiated than matured. Of pods initiated only 13% matured in 88–89 and 22% in 89–90 while in 87–88; when there were no introduced beehives, 98% of pods that were initiated matured.

Some individual trees appear to behave as male in that they produce a large number of functionally male flowers and few pods. An example of a 'male' tree would be Tree 28 (Table 3). In contrast Tree 22 produced only a small proportion of male flowers in each of the three years studied (1.86, 8.2 and 9.2%), and produced pods in all three years. Other trees appear to be more flexible e.g Tree 19 (Table 3) which produced 97.1 and 57.4% male flowers in the heavy flowering years and only 12.5% male flowers in the light flowering year.

The number of inflorescences and the number of mature pods produced by individual trees is shown in Table 4. This table identifies individual trees that consistently produce pods e.g. Tree 29 and Tree 22. The range of production over the three years varied from nil to 6.1% of inflorescences producing pods.

Table 1. Reproductive data for natural populations of *A. mearnsii* at Bungendore NSW.

	Year		
	87-88	88-89*	89-90*
1. Outcrossing rate			
mean + s.e.	0.94 ± 0.02	0.94 ± 0.30	
range	0.87-0.98	0.76-0.97	
2. Male flowers (%)			
mean ± s.e.	56.3 ± 28.9	24.8 ± 30.4	26.5 ± 25.7
range	1.9-97.1	5.4-82.0	1.0-63.5
3. Pollinated stigmas (%)			
mean ± s.e.	36.6 ± 14.9	43.6 ± 13.1	19.4 ± 7.0
range	22-26	23-60	12-36
4. Inflorescences per raceme	61.5	9.9	61.6

* bee hives had been placed within the natural stand

Table 2. Pod and seed yields 1987-1990 for a population of *A. mearnsii* at Bungendore, NSW.

Attribute	Flowering season		
	87/88	88/89	89/90
Total racemes	150	135	120
Total inflorescences	9 228	1 338	7 396
Total flowers*	257 461	37 338	206 348
Functional female flowers	112 510	28 072	151 666
No. of flowers pollinated**	41 179	12 239	29 423
Pods initiated	117	187	242
Pods matured	115	25	54
Seeds possible***	1 495	325	702
Seeds matured	727	122	313
Seeds matured			
Seeds possible	49%	37%	45%
Seeds/pod	4.71	5.27	5.8
Pods matured			
Pods initiated	98.3%	13.3%	22.3%
Pollinated flowers			
initiating pods	0.28%	1.53%	0.82%
maturing pods	0.28%	0.20%	0.18%
Functional female flowers			
initiating pods	0.10%	0.67%	0.16%
maturing pods	0.10%	0.09%	0.04%
Inflorescences			
initiating pods	1.27%	13.98%	3.27%
maturing pods	1.25%	1.87%	0.73%

* assumes 27.9 fls/head (Moncur et al. 1988), ** based on % pollination for each year (Table 1), *** assumes 13 ovules per ovary (unpublished data).

Table 3. Fraction of flowers which are male (%), fraction of stigmas pollinated and number of pods formed on individual trees in each of three years.

Tree No.	87/88			88/89			89/90		
	Male (%)	Poll'n (%)	No. pods	Male (%)	Poll'n (%)	No. pods	Male (%)	Poll'n (%)	No. pods
1	67.7	22	1	15.8	23.0	2	30.7	22	0
19	97.1	24	1	12.5	60.0	4	57.4	26	0
22	1.8	66	37	8.2	51.0	4	9.2	12	5
28	58.4	44	0	73.6	56.0	0	63.5	17	0
41	58.0	24	4	9.5	36.5	2	27.6	17	0
Mean	56.6	36		23.9	45.3		37.7	18.8	
s.e.	±30.9	±17		±25.0	±13.7		±20.1	±4.8	

Table 4. The number of inflorescences and of mature pods on individual trees of *Acacia mearnsii* in each of three years.

	87–88			88–89			89–90		
Tree No.	No. infl.	No. pods matured	Fraction (%)	No. infl.	No. pods matured	Fraction (%)	No. infl.	No. pods matured	Fraction (%)
7	832	1	0.12	139	2	1.44	1282	0	0
19	1101	1	0.09	198	4	2.02	1245	0	0
22	1074	37	3.44	136	1	0.73	740	5	0.68
23	873	7	0.80	67	0	0	—	—	—
28	931	0	0	146	0	0	1111	0	0
29	892	27	3.03	168	3	1.79	806	49	6.08
40	1051	0	0	—	—	—	—	—	—
41	767	4	0.52	143	2	1.40	852	0	0
45	644	28	4.35	114	3	2.63	592	0	0
48	1063	10	0.94	227	10	4.40	768	0	0
Total	9228	115		1338	25		7396	54	

Discussion

The polyad system in *Acacia* has advantages and disadvantages compared to normal pollination. The advantage is that when a polyad lands on a stigma it is able to pollinate all the ovules in the ovary; the disadvantage is that the flower essentially only gets one chance at a successful pollination. *A. mearnsii* appears to be a self-incompatible species; there is a range of estimates for its outcrossing rate. For *A. mearnsii* in plantations in South Africa, estimates of outcrossing average 69, 82 and 85% (Moffett 1956; Moncur et al. 1989). For natural populations in Australia, Kenrick and Knox (1989) estimated an outcrossing rate of 100% based on lack of pods produced from selfing, while for this study the mean outcrossing rate indicated that about 94% of seedlings result from a random mating.

The perception of 'heavy' and 'light' flowering seasons has a basis in the number of inflorescences per raceme and hence the number of flowers produced. In the heavy flowering years there were significantly more inflorescences per raceme than in the light flowering season. Similarly Kenrick et al. (1987) found highly significant differences in the numbers of inflorescences per raceme in representative trees in a montane population and in a valley population of *A. terminalis* in the same flowering year. The number of male flowers was not directly correlated with the increase in total flowers produced, as was suggested by Moncur and Somerville 1989 and Moncur et al. 1989.

The number of seeds set per pod (about five) was similar for the three seasons and indicated that about 43% of ovules in a pod matured into seed. In an *A. mearnsii* population from Somers in Victoria the mean seed number per pod was 5.1 (Kenrick and Knox 1982), while Moffett and Nixon (1974) report 7.8 seeds per pod for a population of *A. mearnsii* in South Africa.

The introduction of 12 bee hives containing about 400 000 potential pollinators into the second and third year of the study did not appear to have a significant effect on the number of stigmas pollinated in or on the numbers of pods set (Moncur and Somerville 1989). In the first 2 years the level of pollination was similar but in the third it was somewhat lower overall. For 87–88, a heavy flowering year without bees, 16% of total flowers were pollinated and for 89–90, a heavy flowering year with bees, 14% of total flowers were pollinated. The numbers of pollinated flowers yielding mature pods were similar in the years with bees (0.20% and 0.18%) and slightly higher in the year without bees (0.28%). The number of pods initiated was significantly higher when bees were present than when bees were absent (187 and 242 cf 117).

The proportion of pods matured compared with pods initiated could be an effect of the bees. Without bees 98.3% of the pods initiated matured, while with bees 13.3 and 22.3% of initiated pods matured despite the difference in the numbers of total flowers. A possibility is that bees, while not increasing the total level of pollination, effect more self-pollination which may cause pods to initiate but not mature. In 1988–89 all the flowers in the inflorescence did not open simultaneously as in 87–88 (Moncur et al. 1989) but opened gradually (unpublished observation), meaning that the anthers from one flower may have shed pollen while the stigma of another flower in the inflorescence was receptive. Therefore bees collecting pollen in an inflorescence could easily have increased the frequency of self-pollination, although each flower in the inflorescence is protogynous (Moncur et al. 1989)

We found individual trees that produced an excess of male flowers and produced no seed. Kenrick and Knox (1989) noted two trees of *A. mearnsii* that set no pods when open or hand pollinated, but both these trees produced viable seed when used as pollen parents. Milton and Hall (1981) noted that certain individuals, in a population of *A. longifolia* in South Africa, seemed to have chronically low fruit yields. Although in a study on *A. nilotica* (Tybirk 1989) the overall fraction of male flowers for six trees was 71.4% the range was 0–84.1%, indicating that some trees probably contribute mostly pollen to the next generation.

In the population at Bungendore, some trees consistently produced more pods per inflorescence than others although the average for the population was low (0.73–1.87%). For *A. nilotica* 9% of open-pollinated inflorescences set pods (Tybirk 1989) while for *A. mearnsii* Kenrick and Knox (1989) obtained 5% production of pods from cross-pollinated inflorescences. The best result from an individual tree in this study was 6% of open pollinated inflorescences producing pods. This represents 0.2% of flowers producing pods, which compares well to results of other studies on *Acacia*. Milton and Hall (1981) found 0.01–0.6% of all flowers in five species of *Acacia* produced mature pods. Zapata and Arroyo (1978) were able to obtain 0.19% fruit from crossed flowers of *A. macracantha*. Bawa and Webb (1984) suggested that a species may produce excess flowers to increase the male component of fitness and to optimise selection among pollen genotypes.

The level of pollination observed for both populations here compares with that found for other *Acacia* populations. In *A. retinoides* at Cape Schank in Victoria 37% of stigmas were pollinated (Knox and Kenrick 1983) and in *A. nilotica* in Kenya more than one third of stigmas were pollinated (Tybirk 1989). For *A. melanoxylon* in the Brindabella Ranges in the Australian Capital Territory 46% of stigmas were pollinated (unpublished data).

Although there is a large loss in reproductive potential from flower to seed in *Acacia mearnsii* this study may indicate that a way of improving seed production in an orchard situation would be to select trees that consistently produce pods and have a lower proportion of male flowers. Introducing bees would not have the desired effect of increasing the proportion of stigmas pollinated or producing more mature pods.

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Stand Density of *Acacia mearnsii* Plantations

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Abstract

This paper deals with stand growth, development and economic return of *Acacia mearnsii* planted at spacings ranging from 1 × 1 to 2 × 2 m to age 5 years. The trial stand was planted in a randomised complete block with four replicates and five density treatments. Height, diameter, bark yield, volume and economic returns were determined for the trial stand from 1 to 5 years after planting. The trial showed that: height and diameter increment at age 3-5 years decreased as density increased; bark and wood yield per unit area increased with increased stand density; and economic returns (judged by output/input) at the wider spacings (treatments A and B) was better than that at the denser spacings (treatments C,D and E).

Lower densities are desirable for longer rotations, under which conditions the stand needs lower investment and produces greater log volume and economic returns. In contrast, higher densities are more suitable for short-term management, but incur higher establishment costs, produce lower log volume and poorer economic returns, although maturing early.

STAND density is an important aspect of intensive plantation management. The desirable stand density should balance the full utilisation of space by the population with the desire to ensure that each individual tree has space and time to produce a maximum yield of high quality produce. The balance must be evaluated in both biological and economic terms.

The aim of this study was to determine the effects of different stand densities on stand growth, production and economic return, and to suggest strategies for scientific management of wattle plantations. The tannin content of wattle bark is an important factor which contributes to decisions on rotation length, but we were not able to assess this characteristic.

Materials and Methods

Site description

The trial stand was established on Chengxiang Forestry Farm at Changtai, Fujian, at 24°49′N latitude, 11°54′E longitude and 109 m above sea level. The site has a northern aspect in undulating forest land and slopes which range from 10 to 15°. Mean annual temperature and absolute minimum temperature are 21 and −1.7 °C respectively. The mean annual rainfall is 1660 mm with a relative humidity of 78%. Soil is loose red loam more than 0.7 m deep, pH 5.8, 0.21% organic matter, 0.06% total N and 0.07% total P. Readily available N, P and K were 4.93, 0 and 1.19 mg per 100 g of soil, respectively.

Experimental design

The design is a randomised complete block with four replicates and five density treatments. Details are given in Table 1. The total area was 1.34 ha.

Establishment

Seedlings were grown in the plastic containers in October 1984 with seeds collected in Wenzhou, Zhejiang Province and stocks were planted out in

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Table 1. Experimental treatments of density.

Treatment	Spacings	Stems/ha	Stems per plot (each plot 44 × 15 m = 0.066 ha)	Measured row details	
				Stems measured	Area (ha)
A	2.0 × 2.0	2 050	167	22	0.0098
B	2.0 × 1.5	3 335	222	22	0.0066
C	2.0 × 1.0	4 995	333	22	0.0044
D	1.5 × 1.0	6 670	444	29	0.0033
E	1.0 × 1.0	10 005	667	44	0.0044

March 1985. Planting holes (60 × 40 × 40 cm) were dug after clearing the field. Fertiliser (50 g calcium magnesium phosphate) was added to the hole prior to planting. An additional 50 g of fertiliser (ammonium bicarbonate) was added in a circle near each tree. Tending was carried out twice in the first year and once both in the second and third years after planting.

Data collection

Each treatment was ranged into a fixed single row (the central row within a plot) in a replicate. Height, diameter, crown width and clear bole height were measured at the end of each December for years 1 to 5. Volume overbark, based on height and diameter of the tree, and bark yield were estimated from two tables developed by Fujian Forestry College in Nanping (Lin et al. 1987).

Table 2. Mean height, results of analysis of variance and LSD.

Treatment	Mean height# (m)				
	1 yr	2 yr	3 yr	4 yr	5 yr
A	2.3	5.2	6.9a	8.2a	9.3a
B	2.4	5.2	6.6ab	8.1a	9.0a
C	2.5	5.3	6.2b	7.8a	8.8ab
D	2.5	5.3	6.1b	7.4ab	8.5b
E	2.7	5.5	6.1b	7.0b	7.8c
F-test	2.57ns	2.12ns	3.77**	4.19**	7.48**
LSD 0.05	—	—	0.5	0.8	0.7

Means having the same symbol are not significantly different (5%).

Results and Analysis

Effects of density on height growth

Stand height in years 1 and 2 tended to increase with increasing stand density, after which the trend reversed and differences between treatments became significant (Table 2).

At 5 years the average height at densities A and B were 9.3 and 9.0 m respectively, 1.5 and 1.2 m higher than those at the lowest spacing.

Effects of density on diameter

Mean diameter growth declined as density increased at every annual measurement, although differences between treatment became significant only in year 3 (Table 3).

At 5 years, average diameter at wider spacings (A and B) were 2.4 and 1.7 cm greater than those at lowest spacing (E).

Effects of density on bark yields and volume

Bark yields and volume per unit area increased with increasing density (Tables 4 and 5). The analysis of variance revealed that treatment means at 2–3 years were highly significantly different, but subsequently the differences became progressively relatively smaller and were not significant.

Effects of density on volume increment and small-sized log volume

Both current and mean annual volume increments of densities A and B continue to rise at age 5 years (Figs 1 and 2). Current measurements for densities C, D and E culminated at age 3 or 4 years (Figs 3, 4 and 5). At the highest density (E) the curves intersected at 5 years of age, indicating that the stand has already reached ‘quantitative maturity’.

The volume of log produced decreased as density increased (Table 5).

Table 3. Mean diameter, results of analysis of variance and LSD.

Treatment	Mean diameter# (cm)				
	1 yr	2 yr	3 yr	4 yr	5 yr
A	3.0	4.3	5.8a	6.8a	8.4a
B	3.0	4.2	5.4b	6.5a	7.7a
C	3.0	3.8	4.6c	5.7b	6.6b
D	2.9	3.7	4.6c	5.5b	6.5b
E	2.8	3.6	4.5c	4.9c	6.0c
F-test	3.24ns	2.94ns	11.28**	17.21**	18.64**
LSD 0.05	—	—	0.4	0.6	0.7

Means having the same letter are not significantly different (5%).

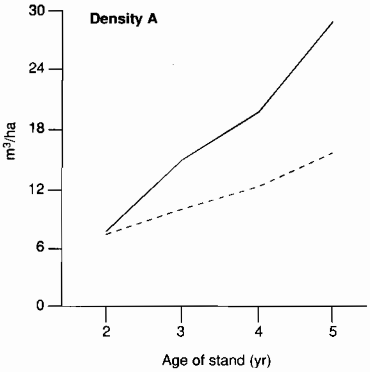

Fig. 1. Annual volume increment for density A.

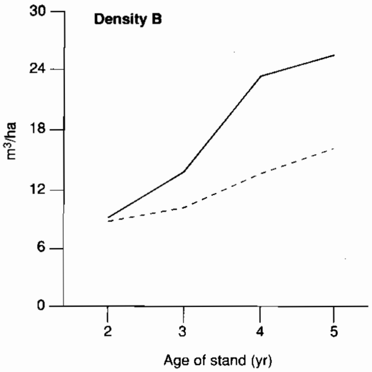

Fig. 2. Annual volume increment for density B.

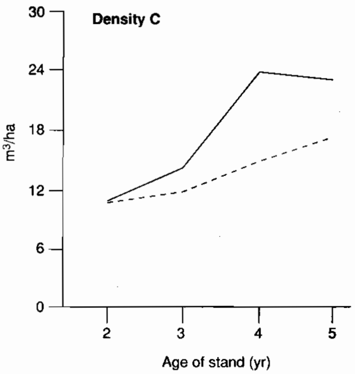

Fig. 3. Annual volume increment for density C.

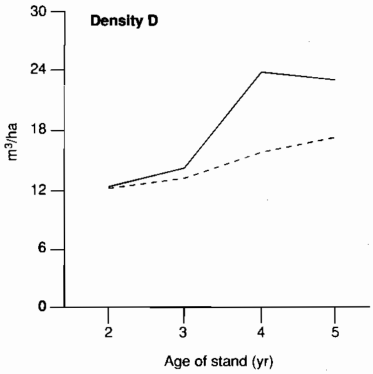

Fig. 4. Annual volume increment for density D.

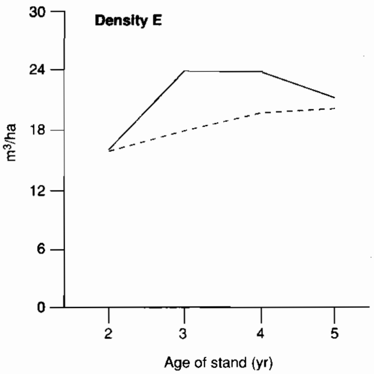

Fig. 5. Annual volume increment for density E.

—— Current annual volume increment
- - - Mean annual volume increment

Table 4. Bark yield, results of analysis of variance and LSD.

Treatment	Bark yield (t/ha)#			
	2 yr	3 yr	4 yr	5 yr
A	2.14c	3.97b	6.45	9.95
B	2.45bc	4.26b	7.84	9.98
C	2.92bc	4.90b	7.67	10.53
D	3.90b	5.46b	8.90	11.58
E	4.67a	7.35a	9.70	12.25
F-test	12.75**	5.67**	2.93ns	1.59ns
LSD 0.05	0.84	1.73	—	—

Means having the same letter are not significantly different (5%).

Effects of density on economic return

The ratio of the value of output to input is a useful index with which to assess economic return. Table 6 indicates that the economic gains at densities A and B, assessed with this ratio, were superior to those at the other three densities.

Discussion and Conclusions

Height and diameter growth at 3–5 years of age decreased with increasing density while the yield of bark and wood increased. Significant differences in diameter were found between density treatments at 5 years of age, but no significant difference in height. The rankings in diameter were A > B > C > D > E. The stands at lower densities (A and

Table 5. Stem volume, results of analysis of variance and LSD.

Treatment	Stem volume# (m^3/ha)				Product at 5 years (m^3/ha)	
					log	firewood
	2 yr	3 yr	4 yr	5 yr		
A	14.6c	28.7c	47.7	75.5	64.0	11.5
B	16.8c	30.1bc	52.9	78.3	61.9	16.4
C	21.1bc	34.3bc	57.6	80.1	55.3	24.8
D	25.3ab	39.9b	64.9	89.5	53.7	35.8
E	31.9a	54.1a	76.2	96.5	52.8	43.7
F-test	6.61**	8.08**	3.06ns	2.08ns	—	—
LSD 0.05	8.3	11.1	—	—	—	—

The means having the same letter are not significantly different (5%).
** ($p < 0.01$), NS = Not Significant

Table 6. Analysis of economic return of stands of different densities, omitting the cost of land.

Treatment	Costs # (yuan/ha)							Value of production # (yuan/ha)						
	Seedlings	Fertiliser	Pesticide	Establishment	Harvest	Interest	Total value	Bark	Logs	Fire wood	Total value	Net* value	Mean ann. value	Output/ input
A	75	78	30	560	4762	539	6044	7960	19 200	1725	28 885	22 841	4568	4.8
B	100	110	33	626	4929	590	6388	7984	18 300	2460	28 744	22 356	4471	4.5
C	150	115	100	760	5057	670	6852	8420	16 590	3720	28 730	21 919	4388	4.2
D	200	207	79	893	5662	806	7847	9264	16 110	5370	30 744	22 897	4579	3.9
E	300	310	120	1160	6192	1052	9134	9800	15 840	6555	32 195	22 940	4588	3.5

prices for bark, small-sized logs and firewood were 800 yuan/t, 300 yuan/m^3 and 150 yuan/m^3, annual interest rate was 6% (based on 1985 figures).
* net = total production value minus total costs

B) produced less bark than those at higher densities (C, D and E).

The stands at lower densities (A and B) yielded greater economic returns (judged by the ratio of output to input) than those at higher densities. The ratios for densities A–E were 4.8, 4.5, 4.2, 3.9 and 3.5 respectively.

Of the five treatments the lower densities (A and B — 2 × 2 and 2 × 1.5 m respectively) were more desirable for long-rotation management (8–10 years). In contrast, higher densities are more suitable for shorter term (5–7 year) investments.

In retrospect it is possible to offer guidelines for future research on stand density and by implication, rotation length.

1. Care is needed in selecting fertiliser treatments, especially on infertile sites. If a standard amount of fertiliser is applied to each tree, the rate of application per hectare increases as stand density increases. This confounds any fertiliser effect with stand density per se.
2. It is important to ensure that the range of treatments (spacings) selected extends well beyond those now thought to be operationally desirable, so as to cater fully for unforeseen changes in markets. The widest spacings should certainly extend beyond those used in this study (2 × 2 m). Systematic designs are available which provide data for a wide range of spacings at modest cost (e.g. Nelder 1962; Cameron et al. 1989).
3. In addition to simple analyses of growth and yield of a single rotation, one must also be concerned with the sustainability of yield over rotations. Nutrient drain by plantation crops is significant and is greater, on an annual basis, for short rotations than for longer ones. Thus any apparent gains to be had from the high yield of biomass from short dense rotations must be assessed quite carefully.
4. The period of observation of the trial reported in this paper is clearly not significant to obtain all the useful data which may be available, especially on the growth and yield (in both quantity and quality) of trees at wider spacings.
5. The existence or development of markets in which large logs are worth more than small logs, or bark with a high tannin content has a higher price than bark with less tannin, will affect the choice of stand density and rotation length significantly.

Acknowledgments

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Effect of Low Temperatures on *Acacia*

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Abstract

Nineteen species of *Acacia* from latitude 26–43 °S in Australia were planted at Longdouxie State Forest Farm, Shixing county, northern Guangdong province (24 °58 'N, 115 °05 'E) in April 1989. All species died from cold injury except *Acacia dealbata*, but the same species planted at lower altitude with open terrain in Hekou State Forest Farm about 40 km north of Longdouxie in April 1991 survived the winter. The extent of cold injury reflected a combination of genetics, physiology and environmental factors. The growth of *Acacia* in these cold situations varied with provenance, tree age, position of any injury on the trees and state of health. Performance was also affected by temperature gradients within and between different trial sites. Thus the relationship between acacias and low temperatures is complex. The extremely low temperatures which occurred at the end of 1991, unknown for decades, provided an exceptional opportunity to select cold-resistant species and provenances of *Acacia*.

THE most cold-resistant acacias originate from temperate areas of Australia (26–43 °S). They have been introduced into subtropical areas of China, where temperatures on average may be similar to or above those in their areas of origin but may fall quite low in winter. A trial of various species and provenances was established at two state forest farms similar in latitude but different in terrain, topography and altitude. Species/provenances and management strategies used in the two trials were similar. The results indicate the adaptability of *Acacia* as a basis for its introduction and cultivation.

Winter Climate

Usually, there is little winter rain in the northern region of Guangdong province. Annual mean temperature is about 19 °C. When cold air comes from the north, the temperature drops suddenly and rises slowly afterwards. Extensive snow and severe frost, as occurred at the end of 1991, had not been encountered in the past 50 years in the province; most areas experienced record low temperatures.

Low Temperature Characteristics

The low temperatures at the end of 1991 exceeded the tolerance of certain cultivated and wild subtropical plants in the area, causing the deaths of species like *Musa balbisiana*, *Aralia decaisneana*, *Cinnamomum burmani*, a 17-year-old *Grevillea robusta* growing in Longdouxie and *Litchi chinensis* with 40 cm dbh, *Dimocarpus longan* and *Sinocalamus becheeyana* in Meixian city. Compared to previous years, the low temperatures were unusual in the following respects:

Low temperature over a wide area The occurrence of low temperatures over such a wide area is rare in southern China. The temperature in Guangzhou dropped to − 1.5 °C, the lowest for 50 years, and in Shixing county it was − 7.6 °C at Longdouxie State Forest Farm and − 6 °C at Hekou State Forest Farm, the lowest readings for 10 years. The lowest temperatures for decades occurred in other provinces, e.g. Fujian, Guangxi, Hunan and Jiangxi.

Rapid fall of temperature Records in Shixing county show temperatures above 0 °C and sunny weather the day before the cold wave arrived . Temperatures then fell rapidly fell to below 0 °C and it began snowing.

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Long duration The cold wave culminated in 12 days with a temperature of −5 °C from 10:00 p.m. to 8:00 a.m. each day; the previous 5–7 days experienced a shorter period of such cold each day.

Injury from Low Temperatures

Condition of trial sites

Acacia mearnsii, which was introduced into Shixing county in the 1970s, grew well without cold injury for years. When the 1991 cold wave occurred, however, tissues were damaged and trees planted above 400 m also suffered from snow damage (see Table 1).

The Longdouxie State Forest Farm is located at 24°57′N, 115°05′E and at 480 m altitude. Annual mean rainfall is 1830 mm, and the annual mean frost season is 15 days. Soil is yellow laterite derived from granite. The trial site is beside a big pit caused by an ancient meteorite. With steep terrain, the only exit is along a railroad beside a stream.

The Hekou State Forest Farm is located at 24°58′N, 114°08′E and at 250 m altitude. Annual mean rainfall is 1500 mm and the annual mean frost season is 10 days. The trial is on a northeastern slope and its soil is a yellow laterite derived from granite.

According to the records of the Shixing county weather station, the temperature had not dropped below −4.3 °C from 1971 to 1992 (see Table 2).

Nature of cold injury

When the cold wave occurred, tree leaves gradually withered due to ice forming in their cells and colour changed to greyish white. Commonly the tree gradually withered from the top of the stem, but underground parts were normal.

In other cases the base of the tree withered first. The young trees planted in April 1991 at Longdouxie State Forest Farm were damaged in this way. At that time, snow reached a depth of 20 cm and remained 7 days, so the cambium at the base of the plant was injured and the effect gradually extended to other tissues. (A trial planted at the same time in Hekou State Forest Farm survived the cold wave because the snow was only half the depth of the former.)

Relation of Injured Young Plants to Environment

The degree of injury to young trees differed between sites, even at similar latitude. The main reasons were:

Topography The cold air accumulated quickly and dissipated slowly in lowlands, so the duration of low temperatures varied between Hekou and Longdouxie.

Altitude This was the main factor determining the degree of injury to plants. The temperature gradient would have been −0.6 °C with every rise of 100 m in elevation. There was a significant difference between Longdouxie (480 m) and Hekou (250 m).

Slope and aspect Usually, plants are injured least on slopes facing away from freezing wind, but this effect of aspect disappears when the wind abates and cold air accumulates. Sometimes on a sunny day a slight difference existed between eastern and western aspects because the temperature rises faster on the eastern slope.

Tending and management

Nitrogen fertilisation ceased before winter and was replaced with potash and boron fertiliser to enhance the woodiness of plants. The damaged parts were removed after the cold wave had passed, and temperature maintained by covering stumps with soil until spring. Damaged *Acacia* had a higher sprouting rate when 20 cm of stem was left after trimming and surrounding vegetation was eliminated.

Discussion and Conclusions

Cold injury of *Acacia* is related to the following factors:

Biological characteristics of each tree species/provenance Provenances of *A. dealbata* had the greatest ability to resist cold, with *A. parramattensis* second. *A. fulva* was poor and had no ability to recover by sprouting after damaged parts were trimmed away.

Characteristics of low temperature The lower the temperature and the longer the duration of cold, the greater was the injury to the plants.

Latitude and altitude Even at the same latitude and altitude, inland weather is very different from that in coastal areas. Also weather in the northern hemisphere differs from that in the southern hemisphere. Coastal areas are affected by oceanic influences and temperatures are mild. For example, *A. melanoxylon* from areas about 35°S in Australia was difficult to establish in Lianyungang (34°N, 119°E) and Linyi (35°N, 118°E) in China, and the growth of *A. dealbata* was limited when introduced into 32°N coastal areas of China.

Table 1. Degree* of cold injury of *Acacia* observed in March 1992.

Species	Seedlot No.	Locality of origin		Lat.	Long.	Alt. (m)	Location and date of planting		
							Longdouxie April 1989	*Longdouxie* April 1991	*Hekou* April 1991
A. cardiophylla	6611	Coonoo State Forest	NSW	31°00′	149°00′	300	II	/	/
A. dealbata	15538	E of Melbourne	Vic	37°48′	146°16′	900	I	/	/
	16267	32 Mile Road	Vic	37°25′	148°37′	350	I	/	O
	16269	26 km S of Cooma	NSW	36°28′	149°07′	910	I	/	O
	16271	Errinundra Plateau	Vic	37°11′	148°52′	960	O	/	O
	16376	22–18 km WNW Bemboka	NSW	36°37′	149°26′	1035	O	/	O
	16383	43–48 km NW Swansea	Tas	41°55′	147°56′	615	I	/	O
	16384	18.6 km S Orford	Tas	42°41′	147°52′	120	II	/	O
	17070	Maribyrnong	Vic	37°46′	144°51′	40	/	/	O
	16473	NE New Norfolk	Tas	42°43′	147°09′	300	/	/	O
	16385	6–15 km SSE Snug	Tas	43°06′	147°14′	143	O	/	O
	17123	Paddys R Rd, Pierces Ck	ACT	35°22′	148°57′	600	I	/	O
A. deanei	5933	Warialda	NSW	29°30′	150°36′	300	III	/	/
	9697	Gilgandra District	NSW	31°00′	148°00′	300	III	/	/
	17538	Durikai Scrub	Qld	28°12′	151°37′	500	I	/	/
A. decurrens	14768	N of Goulburn	NSW	34°38′	150°09′	660	III	/	/
	14726	SW of Goulburn	NSW	34°53′	149°17′	685	III	/	/
A. elata	15848	Buxton — hill top	NSW	34°17′	150°31′	410	I	/	/
A. falciformis	15502	S of Warwick	Qld	28°32′	151°58′	900	III	/	/
A. filicifolia	15841	19 km SW of Singleton	NSW	32°41′	151°01′	150	II	/	O
A. fulva	15843	Howes Valley	NSW	32°52′	150°52′	240	IV	IV	O
A. glaucocarpa	17152	Bains Gully	Qld	26°48′	151°51′	400	III	/	/
A. irrorata	17145	Mt Mee	Qld	27°07′	152°45′	250	IV	/	/
A. mearnsii	14725	NE of Bungendore	NSW	35°12′	149°32′	760	III	/	/
	14771	S of Cooma	NSW	36°28′	149°01′	940	III	/	/
	14922	NW of Braidwood	NSW	35°15′	149°38′	720	II	/	/
	16378	3–6 km SSW Merimbula	NSW	36°55′	149°54′	30	III	/	/
	14925	Blackhill Reserve	Vic	37°12′	144°28′	500	III	/	/
	15850	7 km SE of Araluen	NSW	35°42′	149°51′	160	III	/	/
A. melanoxylon	15863	Blackwood Park, Lileam	Tas	40°57′	145°10′	250	III	III	O
	16358	Bli Bli	Qld	26°37′	153°02′	95	III	III	O
	17288	E of Captains Flat	NSW	35°37′	149°32′	700	III	III	O
A. parramattensis	14723	SW of Bungendore	NSW	35°19′	149°25′	730	I	/	/
	14767	NE of Marulan	NSW	34°42′	150°02′	550	I	/	/
A. pruinosa	6879	Pilliga Scrub	NSW	31°00′	150°00′	360	IV	/	/
A. silvestris	16260	30 km W of Narooma	NSW	36°14′	149°48′	570	III	/	/
A. trachyphloia	14229	Monga State Forest	NSW	35°36′	149°55′	710	I	/	/
A. binervata	9973	Robertson	NSW	34°36′	150°36′	550	III	/	/
	17260	1.5 km from Springbrook	Qld	28°12′	153°16′	500	III	/	/
A. implexa	14740	SW of Cooyar	Qld	27°05′	151°46′	600	III	III	I
	17198	Maldon	Vic	36°59′	144°04′	440	III	III	I
	15832	Swansea	NSW	33°05	151°37′	10	III	III	I
	17429	Sydenham Organ Pipes	Vic	37°40′	144°46′	90	III	III	I
A. pycnantha	17317	3 km E of Toolernvale	Vic	37°37′	144°37′	90	IV	/	/
A. confusa (control)	C.K.	China					IV	/	/

* Cold injuries were divided into the following five degrees:
O: no, or very little, injury
I: injury less than 25% of top leaves, no injury found in young branches
II: stem injured
III: all trees injured, but an ability to sprout after cutting
IV: trees died
/ = not in trial

Table 2. Lowest temperatures recorded from 1971 to 1992 at Shixing county weather station*.

Month	Year	71	72	73	74	75	76	77	78	79	80	81
Dec		0.7	3	−4.3	0.3	−3.4	−1.3	2.5	1	1.4	−1.1	−0.9
Jan		/	−0.4	−0.3	−2.8	0.8	−3	−2.1	−2	0.8	−2	−1.5
Feb		/	−2.5	6.2	−2.1	3.2	0.2	−0.8	−1	−1	−0.3	2.9

Month	Year	82	83	84	85	86	87	88	89	90	91	92
Dec		−1.3	0.2	−3	−2.4	1.1	−1.4	−0.1	2.1	1	−2.1	/
Jan		−0.7	−1.2	−2.4	1.1	−2.3	−0.8	2.4	0.3	0.8	2.5	−1.1
Feb		2.9	3.4	−1.8	1.6	−0.4	1.9	3	0.3	0.1	3.1	4.5

* Weather station data are for reference only. Longdouxie State Forest Farm is 90 km from the weather station, and Hekou Forest Farm is 45 km away.

Micro-environment The cold weather is also influenced by micro-environment. Plants were easily injured in small depressions, valleys and at the bottom of steep slopes — places where cold air amassed easily — and at high-altitude sites. Trees on eastern and northern slopes were injured relatively easily, due to the large diurnal temperature range or rapid water loss.

Examination of the effect of cold on these trials revealed that cold injury to *Acacia* was most related to topography and terrain, and less affected by altitude. Trees planted in environments such as the lowlands at Longdouxie State Forest Farm, where cold air tended to settle, suffered the greatest injury. Young plants at Hekou State forest farm were unaffected, although the trial site was in a windy zone.

Low temperature was the key factor in *Acacia* injuries. As the effects of low temperatures on plants are very complex, however, it is necessary to consider the characteristics of the whole environment as well as the micro-environment in any analysis of reasons for cold injuries to *Acacia*.

Acknowledgments

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Provenance Trials of *Acacia aulacocarpa*

Zeng Yutian and Yang Minquan*

Abstract

The 5-year performance of five provenances and 3-year performance of 10 different provenances of *Acacia aulacocarpa* at Baishiling Forest Farm, Hainan Island and Longdong State Forest Farm, Guangdong Province show obvious variation between provenances. Provenances from Queensland and Northern Territory have multiple stems, are slow growing and show poor form. The best performer from 10 provenances at 3 years is 15651 and the best from five provenances at 5 years is 13689, both from Oriomo, Papua New Guinea. Average height and dbh of provenance 15651 at 3 years are 6.7 m and 6.5 cm respectively, while those of 13689 are 13.0 m and 13.6 cm respectively.

ACACIA *aulacocarpa* grows well in cool areas with fertile soils. The species comes from moist areas of tropical and subtropical rain forest, and grows to a height of 35 m and dbh of 1 m. The species has been classified into varieties, var. *fruticosa*; var. *aulacocarpa*; var. *brevifolia*; and var. *macrocarpa* (Pedley 1987). Natural occurrence is from northern New South Wales into Papua New Guinea, and up to 1000 m altitude. Mean temperature of the hottest month is 29–38 °C and of the coldest month 10–21 °C. The main distribution is frost free; 1–5 days of frost occur in the high altitude areas of the southern range. Soil is yellow earth and podzolised yellow or red earth as well as some yellow laterite. Usually, *A. aulacocarpa* grows with eucalypts, and with *A. cincinnata*, *A. mangium* and *A. polystachya* (Turnbull 1986).

The species was introduced into China in 1984. The properties of fast growth and useful wood have been sought through experiments with provenances (Yang 1990). This paper presents data on a range of growth parameters useful for future Chinese introductions and selection of good provenances.

Materials and Methods

Experiments were established in Baishiling Forest Farm of Qionghai County (Hainan Island) in tropical China, and Longdong State Forest Farm (Guangdong Province) in subtropical China. The trial site in Baishiling (19 °N, 110 °15 ′E, altitude 20 m, mean annual temperature 23.9 °C, annual mean rainfall 2070 mm, soil sandy loam with 1.4% humus content from 0–40 cm depth and pH 4.8) previously grew *Eucalyptus exserta*; the trial site in Longdong (23 °15 ′N, 113 °23 ′E, altitude 100–150 m, mean annual temperature 21.8 °C, annual mean rainfall 1690 mm, yellow laterite soil with 1.6% humus content from 0–40 cm depth and pH 4.7) formerly grew *Pinus massoniana*.

The seed was supplied by the CSIRO Australian Tree Seed Centre. Different seedlots were used at each site (Table 1).

The trial site at Baishiling was prepared by tractor with standard 40 × 40 × 40 cm holes; 100 g of phosphate fertiliser was added to each hole before planting with 4-month-old seedlings in April 1985. At Longdong 40 × 40 × 40 cm holes were dug after clearing by fire and 50 g of fertiliser was added to each hole before planting with 3-month-old seedlings in June 1989. Randomised complete block designs were used in both trials, with four replicates and 3 × 3 m spacing; 3 × 3 trees in the centre of a block of 5 × 5 trees were selected for measuring and two guard rows were planted around the trial site. Height, dbh, number of stems per plant, stem form,

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crown width and survival after planting were assessed in June and December in the first year then once a year from the third year after planting.

Stem volume (V) was calculated as

$V_{tree} = \pi/120000.d^2.h\ m^3$

or

$V_{ha} = \pi/120000.d^2.hx10000/3\times3 = \pi/108.d^2.h\ m^3$

Where:

h = tree height (m)

d = dbh (m)

Results and Analysis

Comparison of height, dbh and volume

Height, dbh and volume measurements of 10 3-year-old provenances at Longdong Forest Farm and five 5-year-old provenances at Baishiling Forest Farm were subjected to separate analyses.

The results showed that there are significant differences among provenances (Table 2). Multiple comparisons of means are shown in Table 3.

Table 1. Origins of provenances.

Trial site	Seedlot	Origin	Latitude (° ')S	Longitude (° ')E	Altitude (m)
Baishiling Forest Farm	13687	Iokwa Prov., PNG	8 41	142 29	35
	13688	Keru Prov., PNG	8 32	141 45	40
	13689	Oriomo River, PNG	8 48	143 09	20
	13865	Buckley L.A., Qld	17 09	145 37	720
	13866	Garioch, Qld	16 40	145 18	400
Longdong State Forest Farm	15649	Keru, PNG	8 33	141 45	30
	15651	Oriomo, PNG	8 50	143 09	15
	16112	W Morehead, PNG	8 42	141 34	30
	16113	S Keru to Mata, PNG	8 35	141 45	30
	15715	N of Borroloola, NT	15 38	136 25	3
	16168	6.1 km S Gove Airport, NT	12 19	136 49	60
	16180	14 km S Maningrida, NT	12 11	134 18	40
	16136	Piccaninny Creek, Qld	13 09	142 48	40
	17151	Hills Rd off Noosa Rd, Qld	26 16	152 48	200
	17154	18 Mile Ck, Qld	25 33	152 28	50

L.A. = Logging area

Table 2. Difference analysis of growth for height (H), dbh (D) and volume (V) per hectare.

	Source of variation	Longdong Forest Farm (3 years)			Baishiling Forest Farm (5 years)		
		d.f.	MS	F-ratio	d.f.	MS	F-ratio
H	Prov.	9	4.92	12.49**	4	32.20	28.18**
	Block	3	2.87	8.54**	3	2.28	2.00
	Residual	27	0.34		12	1.14	
	Total	39			19		
D	Prov.	9	8.03	13.34**	4	58.93	59.23**
	Block	3	5.51	9.15**	3	5.19	5.22**
	Residual	27	0.60		12		
	Total	39			19		
V	Prov.	9	42.69	7.88**	4	24.40	36.15**
	Block	3	40.57	7.49**	3	2.80	4.14**
	Residual	27	5.41		12	0.67	
	Total	39			19		

* Significant at 95% level ** Significant at 99% level

Table 3. Comparison of mean growth for height, dbh and volume per hectare at the two experimental sites.

Year	Seedlot	Height (m)	Dbh (cm)	Volume (m^3/ha^{-1})
	15651	6.7	6.5	9.60
3	16113	6.1	6.4	7.57
	15649	6.1	6.1	7.37
	16112	5.7	5.4	6.40
	15715	4.5	3.8	1.93
	17154	4.3	3.7	1.83
	17151	4.3	3.5	1.68
	16168	4.3	3.5	1.61
	16180	4.1	3.1	1.25
	16136	3.9	3.1	1.22
Mean		5.0	4.5	4.06
	13689	13.0	13.6	71.0
5	13688	11.8	10.8	41.2
	13687	10.5	10.7	41.2
	13865	6.4	5.1	5.9
	13866	7.4	5.0	5.4
Mean		9.8	9.0	32.0

The average height, dbh and volume of 3-year-old trees were 5.0 m, 4.5 cm and 4.1 m^3/ha respectively. The performance of four provenances — 15651, 16149, 16113 and 16112, all from Papua New Guinea — is better than the average, while the other six, which come from Queensland and the Northern Territory, is below average. The height, dbh and volume of the best provenance (15651) are respectively 1.7, 2 1 and 5.6 times as much as that of the worst provenance (16136).

The height, dbh and volume of 5-year-old trees of five provenances in Baishiling Forest Farm are 9.8 m, 9.0 cm and 32 m^3/ha respectively. The growth of three provenances — 13689, 13688 and 13687, which are all from Papua New Guinea — is more than the average value, and the two provenances from Queensland are less than average. The height, dbh and volume of the best provenance (13689) were respectively 1.8, 2.7 and 13.2 times that of the worst performer (13866).

Comparison of stem number and stem form

There are significant differences in stem number and stem form between different provenances of *A. aulacocarpa* (Table 4). When the data were subjected to analysis (Table 5) the number of stems per tree and the fraction of stem form class I were transformed by the arc-sine. The results showed significant differences among provenances in stem number and stem form.

Provenances from Papua New Guinea usually produce single stems and good stem form. The provenances from Queensland and the Northern Territory usually produce multiple stems and poor stem form. There is no significant difference between the 3-year and 5-year performance in relation to stem form, i.e. the heredity of stem form of provenances for *A. aulacocarpa* is very stable and not easily affected by environment.

Observations on environmental factors and seedlot traits

Correlations between latitude or altitude of seedlots and height, dbh, volume, multiple stems or stem form were calculated. There are significant negative correlations between latitude and height, volume and stem form of 3-year-old provenances, and no significant correlations between altitude and height, dbh or volume. Correlations between stem numbers and latitude or altitude are not as strong. There are significant negative correlations between latitude and altitude and height, dbh, or volume of 5-year-old provenances, and significant correlation between latitude or altitude and stem numbers. Thus provenances from low latitudes, e.g. 15651 and 13689 from Papua New Guinea, can grow fast and produce good stem form and single stems. Provenances from high latitude, e.g. 13866 and 16136 from Queensland, perform poorly and show inferior stem form (Table 6).

Relationship among observed traits

Correlations between height, dbh, volume, stem form and number of stems in a tree of 3 or 5 years were calculated (Table 7). There are significant, favourable correlations among these traits: provenances which produce multiple stems, e.g. 13866 and 16136, exhibit slow growth and poor form, while provenances that have single stems, e.g. 13689 and 15651, exhibit fast growth and good stem form.

Conclusions

There are significant or highly significant differences among provenances in growth and other characteristics in provenances in both 3-year-old and 5-year-old plantations. Provenances from Papua New Guinea mostly grow fast and produce single stems and good stem form, while those from Queensland and the Northern Territory show poor

Table 4. Number of stems per tree and stem form at the two experimental sites.

Year	Seedlot	No. of stems	Stem form				Note
			I	II	III	IV	
3	15649	1.03	69	31	0	0	
	15651	1.08	86	14	0	0	I straight stem
	16113	1.03	89	11	0	0	
	16112	1.19	72	28	0	0	II stem with some curves and forks
	15715	1.17	0	72	23	5	
	17154	1.45	0	57	34	9	
	17151	1.67	0	56	33	11	III stem curved and forked
	16168	1.11	0	83	17	0	
	16180	1.14	3	78	19	0	IV without obvious main stem
	16136	2.00	0	47	32	21	
5	13689	1.14	77	23	0	0	
	13688	1.24	65	35	0	0	unit: %
	13687	1.50	50	50	0	0	
	13866	2.89	0	24	36	40	
	13865	2.28	0	29	42	29	

Table 5. Analysis of stem number and fraction of stems in class 1.

Sources of variation		3 years			5 years		
		d.f.	MS	F-ratio	d.f.	MS	F-ratio
No. stems	Prov.	9	0.41	8.08**	4	2.26	13.68**
	Block	3	0.38	7.38**	3	0.60	3.65**
	Residual	27	0.05		12	0.16	
	Total	39			19		
Class I stems	Prov.	9	4326	50.90**	4	3613	110.49**
	Block	3	29	0.35	3	61	1.86
	Residual	27	85		12	33	
	Total	39			19		

Table 6. Correlation of traits with latitude and longitude of seed origin.

	3 years					5 years				
Factor	H	Dbh	No. stems	V	I#	H	Dbh	Sprouts	V	I#
Lat.	−0.61*	−0.58	0.55	−0.63*	−0.63*	−0.94**	−0.95**	0.95**	−0.87*	−0.98**
Alt.	−0.37	−0.37	0.47	−0.37	−0.26	−0.93**	−0.89*	0.98**	−0.82*	−0.95**

Fraction of stems in stem form class I

Table 7. Correlations between traits.

	3 years				5 years			
Factor	dbh	V	I	No. stems	dbh	V	I	No. stems
H	0.99**	0.99**	0.87**	−0.71*	0.98**	0.96**	0.98**	−0.98**
dbh		0.99**	0.99**	−0.70*		0.91**	0.98**	−0.93**
V			0.92**	−0.65*			0.94**	−0.89**
I				−0.64*				−0.95**

growth, produce multiple stems, and exhibit inferior stem form.

The fastest-growing provenance at 3 years was 15651 and that at 5 years was 13689. Both are from Oriomo in Papua New Guinea. Multiple stem forms are inferior in height and dbh to the straight single-stem forms in *Acacia aulacocarpa*. Provenances which grow as single stems produce good stem form and are fast growing, and these provenances are usually from low-latitude localities.

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Above-ground Net Primary Production and Nutrient Cycling of a Young Plantation of *Acacia mangium*

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Abstract

In this paper, above-ground growth, biomass accumulation and distribution among different diameter classes and tree components, net primary production, nutrient concentration in different tree components in two seasons and nutrient cycling (not including leaching) of a 24–30 month plantation of *Acacia mangium* are discussed. The above-ground biomass of 2-year and 2.5-year-old plantations were 19.9 and 31.6 t/ha respectively. Net primary production in the half-year was 18.04 t/ha. Nutrient concentrations of tree components differed in winter and summer seasons. Except for P and K, more than 60% of nutrient uptake was returned to the plantation floor as litter. Some suggestions are made for forest farmers and forest policy makers.

ACACIA *mangium* has been planted extensively in tropical and subtropical China. It is used in short-rotation plantations for wood production and protection of water and soil resources. In 1992, a few thousand hectares of plantations of *A. mangium* were established, and more will be planted in future. Knowledge of growth, net primary productivity (NPP), the accumulation of biomass and nutrition in tree components in relation to tree age and nutrient cycling is required for better management and further development of *A. mangium* plantations. In this preliminary study, above-ground growth, biomass accumulation, NPP and nutrient up-take, accumulation and return in a young plantation of *Acacia mangium* are estimated.

Site Description

The experiment was conducted in Longdong State Forest Farm (23°06′N, 113°23′E), 20 km northeast of Guangzhou in southeastern China. The site is 100–150 m asl with a southeastern aspect on a slope of about 15 degrees. Annual average temperature is 21.8°C. The coldest month is January (average temperature 13.3°C and minimum 0°C). The hottest month is July (average temperature 28.4°C and maximum 28.1°C). Annual rainfall is 1694 mm with 82% occurring between April and September. The soil has developed over granite and 0–30 cm surface soil has the following characteristics: pH (water) 4.6; organic matter 1.7%; total N 0.33%, P 0.016, K 0.575; available N 41.4, P 0.16, K 7.7 mg/kg soil.

The site was cleared of a poor stand of *Pinus massoniana* by cutting and burning the old vegetation. Hole (40 × 40 × 30 cm) planting was adopted, with 100 g superphosphate being placed in each hole. The trees were spaced at 2 × 1.5 m, planted in June 1989, and tended in October 1989 and May 1990.

Materials and methods

A 400 m^2 fixed sample plot was marked in the plantation. Trees in the plot were numbered, and diameter (dbh) and height of each tree were measured every half year. Twelve trees outside the plot from different diameter classes (1 cm interval) were selected (two trees for middle classes and one tree for small or large classes) for measurement of above-ground biomass. The fresh weight of each tree component was determined in the field. Sub-samples (750–1000 g) from the upper, middle and lower stratum of each tree component were brought to the laboratory and dried to constant weight at 80°C.

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Six equations relating dry weight of each component to diameter (D) and D^2H were examined, and the best (Tables 1 and 2) chosen to estimate biomass of each component. Mean biomass (by components) for each D class was multiplied by the number of trees in the D class and stand biomass calculated by summing the biomass values across D classes. Leaf area was estimated by calculating the extent of leaf area per unit dry weight.

As there were very few understorey plants (because of the dense canopy) their biomass was not estimated. Litter was collected monthly by placing 10 litter traps randomly on the plantation floor. Each trap was 75 × 40 cm with a plastic net bottom.

Samples of each tree component were obtained from all selected trees for chemical analysis. Nitrogen content was determined by the Kjeldahl method, phosphorus by molybdenum blue calorimetric method, potassium by flame photometry and others by atomic absorption spectrophotometry.

Results

Growth of trees

Height growth (Table 3) was similar in the first and second halves of each year; most of the growth occurred in the rainy season which fell into both half-years. The growth of H in 1991 was 3.4 m, greater than the 2.4 m growth in 1990. Variation in H among trees in the fixed sample plot increased slowly from 24 to 30 months; the rate of increase before tree canopy closure (24 months) had been much greater. The pattern of D growth was similar to that of H. Variation in D among trees increased quickly in the last half year; the rate of increase before tree canopy closure had been much less. When the canopy closed at 24 months, competition among individual trees affected diameter more than height growth.

Relationship between biomass, diameter and height

Individual trees of *Acacia mangium* were not as uniform as other trees, such as *Eucalyptus urophylla*. Thus the relationship between biomass of different tree components and D or D^2H was not as close as has been found in some other species. Because of competition between individual trees, biomass distribution among different tree components changed over time. Relationships for 30-month trees were quite different to those for 24-month trees. The biomass estimates given by equations 3 and 4 or 8 and 9 were smaller than the biomass estimated by equations 12 and 13 or 16 and 17 (Tables 1 and 2). For example, for a 6.5 cm diameter tree, the branch and leaf biomass estimated by equation 3 and 4 were 1.77 and 1.46 kg, but the branch and leaf biomass by equation 12 and 13 were 2.04 and 2.55 kg. The estimated stem and above-ground biomass of 24- and 30-month trees was not as different as was leaf and branch biomass.

In this young plantation of *Acacia mangium*, tree canopy closure and the strong competition among individual trees means that the same equation cannot be used for trees of different ages.

For stem biomass, equations using D^2H gave better estimates than equation using D. For leaf and above-ground biomass, equations using D alone were more accurate. The above-ground biomass estimated by equation 2, 3, 4 and 6 was similar to the result from equation 5. The difference between the above-ground biomass estimated by equation 13, 15 and 16 and the biomass by equation 14 was 120 kg/ha, 0.6% of total biomass. If the equation for total above-ground biomass is used to estimate the biomass of trees of different sizes, results will be better than from the equations for different components.

Biomass components and distribution

Tables 4 and 5 show estimates of biomass and its distribution. There were nine D classes in the 30-month plantation and seven in the 24-month plantation. In Table 4, average D class had more trees than any other D class and the percentage of trees was higher than the percentage of biomass. The D class just above the average D class had more biomass than any other D class. More than 50% of biomass occurred in just two diameter classes — the average D class and the D class just over average. In Table 5, results were quite similar to those in Table 4.

For the 30-month plantation, biomass of stemwood, bark, branch and leaves was 52, 10, 21 and 17% of total biomass (31.6 t/ha). For the 24-month plantation, biomass of stem (wood and bark), branch and leaves was 49, 23 and 28% of total biomass (19.9 t/ha). It is clear that the biomass of stems increased quickly from 24 to 30 months. Biomass of branches increased more slowly than the stems, and the fraction of branches contributing to total biomass fell. Biomass of leaves decreased from 5.6 to 5.4 t/ha. Thus in the period from 24 to 30 months, because of strong competition among canopies of individual trees, the growth of branches was very slow and growth of leaves restricted, most growth being contributed by the stem.

Table 1. Equations for estimating 30-month tree biomass from D and D^2H.

Component	No.	Equation	Coefficient r^2	F	Standard deviation S
Stem wood	1	$Y = 0.0296D^{2.629}$	0.94	172	0.76
Stem bark	2	$Y = -1.005 + 0.286D$#	0.96	246	9.81
Branch	3	$Y = -1.753 + 0.542D$#	0.85	55	0.38
Leaves	4	$Y = -1.557 + 0.465D$#	0.79	38	0.41
Above-ground	5	$Y = -11.588 + 3.111D$#	0.93	128	1.48
Stem wood	6	$Y = -0.222 + 0.013D^2H$#	0.95	215	0.68
Stem bark	7	$Y = -3.731 + 0.806\mathrm{Ln}(D^2H)$	0.94	157	0.12
Branch	8	$Y = -6.965 + 1.532\mathrm{Ln}(D^2H)$	0.84	51	0.41
Leaves	9	$Y = -6.001 + 1.310\mathrm{Ln}(D^2H)$	0.77	34	0.42
Above-ground	10	$Y = 1.475 + 0.021D^2H$	0.92	112	1.58

$F_{(0.01)} = 9.7$ # used for biomass estimation later Y:kg, D:cm, H:m

Table 2. Equations for estimating 24-month tree biomass from D and D^2H.

Component	No.	Equation	Coefficient r^2	F	Standard deviation S
Stem (wood and bark)	11	$Y = 0.274e^{0.435}$	0.91	100	0.96
Branch	12	$Y = 0.121e^{0.435}$	0.60	10	1.13
Leaves	13	$Y = -1.839 + 0.676D$#	0.62	12	0.75
Above-ground	14	$1/Y = 0.191 + 2.002D$#	0.84	55	2.16
Stem (wood and bark)	15	$Y = -0.243 + 0.19D^2H$#	0.91	1	106.98
Branch	16	$Y = -0.260 + 0.0098D^2H$#	0.61	11	1.11
Leaves	17	$Y = -5.471 + 1.439\mathrm{Ln}(D^2H)$	0.58	10	0.58
Above-ground	18	$Y = -0.007 + 0.034D^2H$	0.82	46	2.32

Table 3. The height and diameter of trees in the fixed sample plot.

Time	Jan. 1990 6 months	Jul. 1990 12 months	Jan. 1991 18 months	Jul. 1991 24 months	Jan. 1992 30 months
Average H (m)	1.5	2.7	3.9	5.5	7.3
Standard deviation	0.35	0.44	0.56	0.80	0.86
Average D (cm)		2.3	3.6	5.0	6.5
Standard deviation		0.83	0.92	1.17	1.57

Table 4. Biomass and biomass distribution of 30-month plantation.

Diam class (cm)	Av. H (m)	Av. D (cm)	Trees/ ha	Frequency (%)	Biomass (kg/ha)					
					Stem	Bark	Branch	Leaves	Total	%
3–3.9	6.0	3.7	222	6.0	281	14	56	36	386	1.2
4–4.9	6.6	4.6	444	12.0	886	139	328	258	1161	5.1
5–5.9	6.7	5.5	611	16.5	1708	347	750	611	3417	10.8
6–6.9	7.1	6.4	1000	27.0	3917	825	1714	1419	7875	24.9
7–7.9	7.7	7.4	806	21.8	4494	894	1817	1517	8722	27.6
8–8.9	8.2	8.3	417	11.3	3083	569	1142	958	5753	18.2
9–9.9	8.5	9.5	139	3.8	1383	239	472	397	2492	7.9
10–10.9	9.0	10.3	28	0.8	344	53	106	89	592	1.9
11–11.9	8.7	11.8	28	0.8	433	67	128	108	736	2.3
Total			3695	100	16 530	3147	6511	5394	31 583	100
%					52.3	10.0	20.6	17.1	100	

Table 5. Biomass and biomass distribution of 24-month plantation.

Diam class (cm)	Av. H (m)	Av. D (cm)	Trees/ ha	Frequency (%)	Biomass (kg/ha)				
					Stem & bark	Branch	Leaves	Total	%
2–2.9	4.0	2.8	56	1.5	18	3	3	23	0.1
3–3.9	4.7	3.3	583	15.8	438	147	239	824	4.1
4–4.9	5.1	4.4	1306	35.5	2242	928	1481	4651	23.3
5–5.9	5.9	5.5	917	24.8	2842	1369	1722	5934	29.8
6–6.9	6.3	6.3	694	18.8	3087	1528	1681	6295	31.6
7–7.9	6.5	7.7	83	2.3	582	294	281	1157	5.8
8–8.9	7.5	8.5	56	1.5	551	281	217	1048	5.3
Total			3695	100	9710	4550	5622	19 932	100
%					49.0	22.8	28.2	100	

Although *Acacia mangium* is an evergreen tree, the cold winter weather in Guangzhou may cause a large amount of leaf fall and it is difficult for trees to maintain the same leaf area in winter as in summer. Because is was summer when the trees were 24 months old and winter when trees were 30 months old, the leaf reduction observed was partly due to strong space competition by this pioneer species, and partly due to seasonal effects.

Net primary productivity

Both average biomass production and annual biomass production are often used to indicate net primary productivity of a young plantation, as the litter of a young plantation is generally small. In the 2-year-old plantation of *Acacia mangium*, average biomass accumulation was 10 t/ha/year. In the 2.5-year-old plantation it was 12.6 t/ha/year. It is clear that the average biomass production at 2.5 years was considerably greater than that at 2.0 years; the last half-year being very productive (11.65 t/ha/0.5 year). But net primary production was 18.0 t/ha/0.5 year, much larger than average or annual biomass production. Of net primary production, one third was contributed by litter (6390 kg/ha/0.5 year). Thus if average annual biomass production is used to represent net primary production of young plantations, the amount of litter should be included.

The leaf area index of the plantation was 3.3 at 24 months and 3.2 at 30 months. In the half year, the net assimilation of the plantation was 567 g/m^2.

Seasonal nutrient concentrations in tree components

Table 6 shows the nutrient concentrations of *Acacia mangium* in two seasons. The concentrations of N, P and K in the leaves of 30-month-old trees (winter) were only slightly lower than the concentrations in the leaves of 24-month trees (summer). But Ca, Mg and Mn concentrations at 30 months were much higher, and Zn and B were a little higher than those at 24 months. N, P, K and Cu concentrations in branches of 30-month-old trees were much higher than those in branches of 24-month-old trees, but the Ca, Mg, Mn, Zn and B concentrations were lower.

In stems (wood and bark) of 30-month trees nutrient concentrations with the exception of P were lower than those in 24-month trees, but the difference was not as large as that in leaves and branches. The nutrient concentrations in litter in summer were higher than those in winter, indicating that nutrient retranslocation from old leaves to other components in winter was greater than in summer. Winter also produced a larger amount of fallen leaves. Nutrients in branches were more concentrated in winter than in summer except for Ca, Mg and Mn. Lower concentrations of Ca, Mg and Mn in branches and higher concentrations in leaves may help leaves avoid cold damage in winter. In winter branches hold a nutrient pool which assists rapid development of new foliage in the following spring.

The litter of *A. mangium* had a higher N content than that of *Eucalyptus urophylla* (Table 6) and is thus more valuable.

Nutrient cycling

Leaf material made up most of litterfall as few dead branches were shed. N uptake in the half year was 154 kg/ha and return to forest floor was 102 kg/ha (Table 7). Although the part returned in throughfall has not been included, these quantities are rather larger than those found in other major plantations in southern China. The uptake of most trees that are not N-fixing is commonly no more than 100 kg/ha/year. This does not mean that *Acacia mangium* could absorb more available N from soil. The N absorbing ability of *Acacia mangium* is not as great as that of non-fixing species, such as *Eucalyptus urophylla*. Some N uptake was coming from N-fixation. N return was much larger than reported for other young plantations, and will make a valuable contribution to the N supply in the plantation ecosystem.

Phosphorus uptake and return were 5.0 and 1.5 kg/ha respectively. The turnover rate was quite low. More P fertilisation would be very helpful to improve P supply in the ecosystem. K uptake and return were 55 and 12 kg/ha, but these amounts for this mobile nutrient are under-estimates as throughfall has not been included. K fertilisation could be considered. The turnover rate for other nutrients was quite good. In young plantations of *Acacia mangium*, nutrient cycling quickly becomes established, and explains why the yellow colour of the plantation of *Acacia mangium* became green after 3 years.

The N, P and K accumulated in living trees in the 2.5-year-old plantation was 254, 10.3 and 137

Table 6. Nutrient concentration in components of *Acacia mangium* in two seasons.

Components	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Mn (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	B (mg/kg)	Time
Leaves	2.550	0.082	0.93	0.370	0.174	599	27.4	17.4	16.5	July
Branch	0.438	0.014	0.30	0.276	0.197	149	28.9	7.8	9.3	July
Stem & bark	0.395	0.015	0.28	0.211	0.040	76	13.0	6.9	9.6	July
Litter	1.854	0.030	0.30	0.644	0.280	869	33.1	21.9	25.0	July
Leaves	2.479	0.078	0.87	0.523	0.263	862	27.7	17.3	18.0	Jan.
Branch	0.851	0.039	0.77	0.110	0.148	145	24.0	18.0	8.0	Jan.
Stem & bark	0.327	0.018	0.20	0.140	0.024	68	10.0	5.2	3.6	Jan.
Litter	1.341	0.016	0.08	0.200	0.156	675	23.8	20.0	20.0	Jan.
Litter of *Eucalyptus urophylla*	0.584	0.015	0.27	1.061	0.218	1483	22.2	6.2	33.5	Jan.

Table 7. Nutrient uptake (U), accumulation (A) and return (R) (kg/ha) in litterfall by different tree components in the period of 24–30 months.

	Stem			Branch			Leaves			Above-ground			Turn-over
Nutrient	U	A	R	U	A	R	U	A	R	U	A	R	Rate
N	25.9	25.9	0	35.5	35.5	0	92.4	−9.7	102.1	153.8	51.7	102.1	0.66
P	2.07	2.07	0	1.9	1.9	0	1.07	−0.41	1.47	5.04	3.57	1.47	0.29
K	12.3	12.3	0	36.4	36.4	0	6.7	−5.4	12.1	55.4	37.9	12.1	0.21
Ca	7.4	7.4	0	−5.4	−5.4	0	34.4	7.4	27.0	36.4	9.4	27.0	0.74
Mg	0.77	0.77	0	1.46	1.46	0	18.3	4.4	13.9	20.5	6.63	13.9	0.68
Mn	0.60	0.60	0	0.26	0.26	0	6.18	1.28	4.9	7.04	2.14	4.9	0.70
Zn	0.07	0.07	0	0.03	0.03	0	0.18	0	0.18	0.28	0.10	0.18	0.64
Cu	0.03	0.03	0	0.08	0.08	0	0.13	−0.01	0.14	0.24	0.10	0.14	0.82
B	−0.02	−0.02	0	0.01	0.01	0	0.15	0.01	0.14	0.14	0	0.14	1.00

kg/ha respectively. Ca, Mg, Mn, Zn, Cu and B accumulations were 63, 28, 6.9, 0.5, 0.3 and 0.2 kg/ha respectively. The N accumulation in living trees was much higher than that in some other young plantations too.

Suggestions and Discussions

Early growth, biomass production and net primary production of *Acacia mangium* are quite high compared with that of other popular plantation trees; this tree closes canopy at 2 years of age. Afforestation with this species will be valuable in restoring forest cover on some poor pine plantation land and barren land. Moreover, this species will play an important part in supplying industial wood and establishing efficient agroforestry ecosystems. Establishment of plantations can enhance biodiversity in an area.

The amount of leaf-fall in the plantation was relatively large, and the leaf turnover time was only 5.2 months. A year's fallen leaves can absorb 40 tonnes of water per hectare. This would be very good for water and soil protection. Also, this litter would improve the ecosystem conditions for small soil animals and micro-organisms, as most forest lands in China are short of organic matter.

Uptake, accumulation and annual return of nutrients in this plantation of a pioneer species are higher, and nutrient cycling was established earlier than reported for other plantations. This early establishment of nutrient cycling is very valuable in maintaining the fertility of forest lands, because after site preparation fires some nutrients in organic matter and soil become readily available and can be lost unless quickly taken up. The large amount of N returned in litterfall, some of which comes from N fixation, is very valuable in improving N supply, a major limitation for the productivity of tropical and subtropical tree plantations.

A spacing of 2 × 1.5 m is too close for this fast-growing pioneer tree species, and early thinning should be carried out. In future afforestation programs, spacings of 2 × 2, 2 × 3 and 3 × 3 m can be considered according to different land fertility and the purpose of the planting. P and K fertilisers, either basal or added in the first 3 years of growth, are recommended.

Acknowledgments

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Quality Assurance in Pulpwood Testing: The Sample

V. Balodis*

Abstract

Traditional quality control in pulpwood testing laboratories has been confined to pulp testing according to standard test methods. Pulpwood evaluation embraces many aspects not covered by industrial standards. For *quality assurance* (QA) of pulpwood test results, the whole process from sample collection to the reporting of results must be subject to quality control. The paper outlines procedures for (a) sampling of ACIAR trials and export chip shipments, (b) preparation of replicate chip mixtures, (c) measurement of basic density, and (d) reporting of results.

A PULPWOOD testing laboratory, using laboratory-scale equipment such as the multiple-vessel air-bath digester (Balodis et al., in press) can pulp only small chip samples weighing a few hundred grams. The sample size belies the importance of the test results. Species selection for pulpwood plantations and the economic planning of pulp and paper mills could well depend on the laboratory tests. Because of the importance of the results, great care must be taken with selection, preparation and processing of test samples.

The pulp and paper industry has standard methods for testing wood, pulp and paper. These have been developed to provide mills and their customers with a basis for specifying product quality, and for resolving disputes on pulp and paper quality. Many of the standard methods have been adopted in pulpwood testing laboratories and used to ensure that, for example, laboratory handsheets are made correctly, conditioned and tested according to industry standards and the results reported to a specific number of decimal places.

However, pulp testing is only one of many activities in a pulpwood assessment laboratory. As yet there are no standard procedures for ensuring that the pulpwood sample represents the resource, that it is pulped and bleached correctly, and that results are reported in a form useful to economic planners, mill engineers and plantation managers. There is an urgent need to introduce quality management in pulpwood testing laboratories.

Standards for quality management have been published by the International Standards Organization (ISO 9000–9004). These standards outline a philosophy of quality management and set out detailed rules for the formal implementation of the system in product and service industries.

It is beyond this paper to set out a program for formal adoption of these standards in a pulpwood testing laboratory. An outline of the steps required to achieve accreditation to ISO 9000 by the paper industry is given by Hendry (1990). However, at this stage it may be possible to consider one aspect of quality management from ISO 9000 (Anon. 1987), namely quality assurance (QA). It is defined as '*All those planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality*'.

Quality assurance goes beyond the use of standard test methods; it is a philosophy which specifies that each step in the process is subject to quality control, and that each person is his or her own quality controller. For example, we need to conduct pulpwood quality assessment in a manner which assures our customers that the results represent the resource and that the various tests have been carried out according to the best available procedures. Also, we must present and interpret the results to inform our customers of the findings; it is not sufficient to write reports simply to acquaint other technologists with our activities.

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Sampling

Background

The aim of sampling is to provide a representative sample of the pulpwood resource. For a forest containing many species this can be a complex task (Batchelor et al. 1970; Balodis et al. 1992). For efficient sampling the forest has to be stratified by species and tree size (Balodis and James 1980) and each stratum sampled to provide chips for preparing representative mixtures. It is a simpler problem to sample pulpwood plantations, or species and provenance trials, because there is less variation between trees of the same age (Raymond et al., in press) than between trees in a native forest (Balodis et al. 1992).

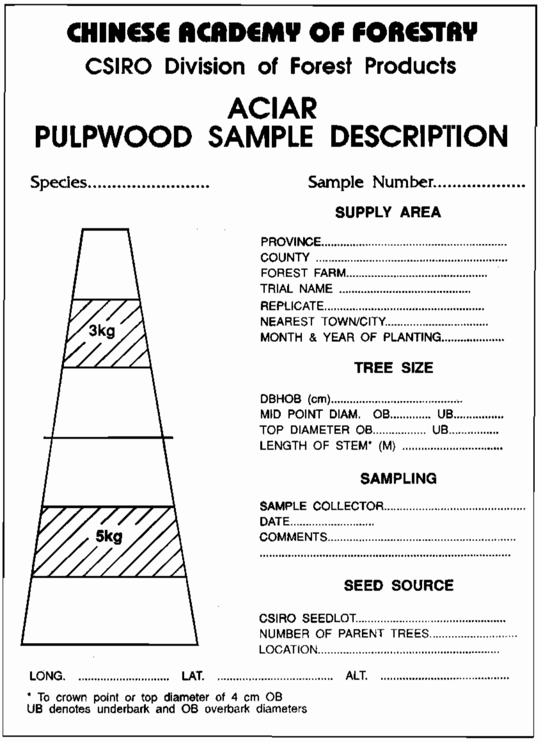
As a generalisation, pulpwood quality varies with species, seedlots, age, site quality, between trees and with position in trees. When sampling is confined to a single seedlot of a species grown on a given site, the primary aim is to reduce the sampling error caused by between-plot, and between- and within-tree variability. This can be achieved by selecting sample trees at random from the available plots and by taking samples from different positions in the tree.

Selection of trees from ACIAR trials

The best species and provenances should be selected from the trials, which should be at least 5 years old. A minimum of four trees are to be selected at random from a provenance at an experimental site. The trees should be numbered on each plot, and depending on the number of plots in each provenance treatment at the site, one or more trees are chosen at random from each plot. It is important that trees are selected at random and not because they are average or represent some extremes in size. Size does not necessarily reflect wood quality. If the chosen tree is severely damaged or exceptionally small relative to the surrounding trees, another should be selected at random to replace it.

Selecting samples from trees

Two samples are taken from each tree — a 5 kg sample from the midpoint of the butt half of the pulplog and a 3 kg sample from the top half as shown in Figure 1. These weights are for debarked wood samples when they are taken from the tree (undried). The different sample weights reflect the greater volume in the butt log compared to the top log. (If the trees are too small at the age of 5 years to average 8 kg of wood per tree, their growth is probably too slow for pulpwood plantations.)



CHINESE ACADEMY OF FORESTRY
CSIRO Division of Forest Products
ACIAR
PULPWOOD SAMPLE DESCRIPTION

Species.......................... Sample Number...................

SUPPLY AREA

PROVINCE.......................................
COUNTY ....
FOREST FARM.......................................
TRIAL NAME ....
REPLICATE.......................................
NEAREST TOWN/CITY.............................
MONTH & YEAR OF PLANTING...................

TREE SIZE

DBHOB (cm).......................................
MID POINT DIAM. OB............ UB...............
TOP DIAMETER OB................ UB...............
LENGTH OF STEM* (M) ....

SAMPLING

SAMPLE COLLECTOR.......................................
DATE..........................
COMMENTS.......................................
....

SEED SOURCE

CSIRO SEEDLOT.......................................
NUMBER OF PARENT TREES..........................
LOCATION.......................................

LONG. .... LAT. .... ALT. ....

* To crown point or top diameter of 4 cm OB
UB denotes underbark and OB overbark diameters

Fig. 1. Form for recording information on pulpwood sample trees.

Recording and numbering samples

The information to be recorded for each sample tree is set out in the Pulpwood Sample Record (see Figure 1). It must accompany each consignment. Each sample must be clearly marked with the tree and sample number. Thin aluminium tags are useful for recording sample details. The tags can be easily nailed or pinned to the end of each sample. It is best to duplicate sample identification because lost or unreadable sample tags can mean lost samples.

Sampling export chip shipments

Woodchip exporters collect chip samples at regular intervals during ship loading for determining moisture content of the wood. This information is used to calculate the oven-dry weight of a shipment, the total weight of which is most often determined by the displacement of the ship. It can usually can be arranged to reserve a portion of the moisture sample for pulping tests. Depending on ship size and the sampling rate, up to 50 chip samples may be collected during the loading of a ship. For reliable estimation of export woodchip quality, samples should be collected during the loading of two or more ships.

Results from such sampling operations show that there is a considerable variation in chip quality throughout a chip pile. To overcome any bias, the chip samples must be numbered consecutively as they are collected. This may require some supervision by laboratory staff. The consecutive samples are combined to provide intermediate mixtures which are used for preparing test samples. If 100 samples were collected during the loading of, say, two ships, then each 10 consecutive samples could be bulked to produce 10 intermediate mixtures (Balodis et al. 1992).

Sample Processing

Sample storage

The recording of sample information and sample storage may be a trivial problem at the start of a project, but it can soon escalate and get into disarray. It is important that adequate space is set aside for sample storage and that a good records system is implemented at the beginning of the project. Racks are required for storing both wood and chip samples. Since air-dry chips are used in laboratory chemical and semi-chemical pulping, the samples are air dried for storage.

Chipping

The wood samples may be chipped with a small commercial chipper or with an improvised laboratory chipper. In the latter case, the wood sample is first cut with a band-saw into discs 25 mm thick which are next cut into strips as shown in Figure 2. The chipper can be constructed using a sharpened car spring as the cutting blade and a small electric motor to drive it (McArthur 1981). The chipper cuts very uniform chips, one at the time. An improved model of the McArthur chipper has been constructed at the Research Institute of Chemical Processing and Utilization of Forest Products, Chinese Academy of Forestry, Nanjing.

Mixture preparation

If the same number of 25 mm thick discs are chipped from each of the two samples from a tree, the chip samples will be self weighting and the chips can be mixed to provide a representative sample for each tree. The tree samples are used for preparing test samples. The replicate test samples representing provenances are individually assembled from the tree samples by including the same weight of air-dry chips from each tree.

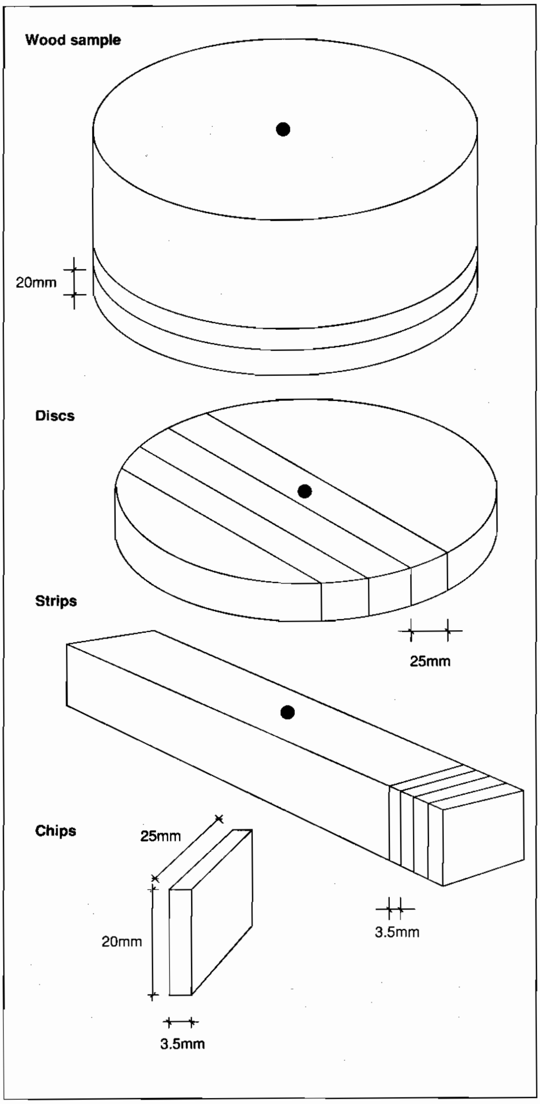


Fig. 2. Cutting sample strips for chipping on a laboratory chipper.

For the export chip samples, each replicate test sample is individually assembled from the intermediate mixtures.

Basic density of chips

Basic density of wood has to be measured for each provenance and, if time permits, for each tree. The basic density values of individual trees can be used to calculate standard deviation of the provenance or species mean and thus assign statistical confidence limits to the mean value.

Basic density is defined as oven-dry weight per unit volume of green wood. Since wood dries during storage, the green volume in the definition can be replaced with soaked volume, i.e., the wood is saturated with water. In practice it is difficult to fully saturate wood, even after extensive soaking (Balodis et al. 1980).

The Australian Standard AS-1301 (Anon. 1979) for the measurement of basic density of hardwood chips is based on the paper by Balodis et al. (1980). Two chip samples are required for density measurement — one for soaked volume, the second for the determination of dry-matter content. For a tree or a provenance, about 1 litre of chips (about 250 g air-dry) is required for volume measurement and about 250 ml for the determination of dry-matter content.

Both chip samples are weighed, the volume sample is soaked for 4 days or boiled for 4 hours; the dry-matter content sample is oven dried at 103 °C for about 24 hours.

After soaking (or boiling) the volume sample is taken from the water and excess water is removed with a towel. This is a very crucial part of the volume measurement since the results depend on the operator's technique. (Operators should be trained using a standard chip sample.) After removal of excess water, the chips are placed in a wire mesh basket and their volume is determined by water displacement on a balance (for details see AS-1301, Anon. 1979).

If the volume of the soaked chips is v cm^3 and the weight of the dried chips w g, both per 100 g of initial weight, the basic density (BD) of the sample is

$$\mathrm{BD} = 1000^{*}w/v \ (\mathrm{kg/m^3})$$

Reporting Results

Guides on report writing, such as the excellent booklet by Lindsay (1989), suggest that the author should identify the reader before setting pen to paper. Reports on pulpwood quality assessment are important to many people. Tree growers, planners of new mills, pulping and papermaking engineers, economists and fellow scientists are some of the potential readers. The author has to try to satisfy the needs of specialists from many different areas. Unfortunately, many publications on pulpwood testing concentrate on pulping and papermaking test results with scarcely any reference to the source material. Here are some suggestions on how to improve the balance of presentation.

If possible, the *title* should include the name of the test species. The *summary* is a mini-paper which should contain the important keywords, results and conclusions from the paper. For example, some of the topics which should be mentioned in a pulping paper are: origin of the samples, species, tree age, basic density of wood, as well as the pulping process(es), bleaching, pulp yield, comments on paper properties and maybe some general conclusions.

The *introduction* provides a background to the paper. It should include a literature survey of related work, especially pulpwood tests on the same species. The introduction is also a convenient section for discussing the growth potential and other attributes of the provenances and species which are being studied. The areas under plantations, plans for industrial development or potential markets for the pulpwood may be items of interest.

Information about the test samples should be presented in the *materials and methods* section. It helps to have a series of sub-heading in this section. Important subheadings for describing the test material could be: *Samples* — origin of samples, species, age, number of trees sampled, sampling procedure, tree size. *Wood processing* — chipping, mixture preparation, wood milling, maceration, etc. *Wood tests* — basic density, solubility tests, fibre-length measurements. These could be followed with a description of *pulping*, *black liquor*, *bleaching*, *papermaking* and *paper testing* procedures.

The *result* and *discussion* section(s) can follow the same sequence as the topics in the materials and methods section, even to the use of some of the same sub-headings. The sub-headings help to break-up the result stream. *Conclusions* should highlight the most important results; the paper has already been summarised in the summary (or abstract).

Concluding Remarks

The proposals to improve pulpwood quality assessment and reporting refer to some of the more neglected aspects of pulpwood testing. Often extensive tests have been carried out on a single piece of wood of doubtful origin. Even when the forestry people have sampled the resource, the final report frequently does not include detailed information of the origin or history of the samples, such as the tree age, size, location of plantation, etc. Forestry information is important for plantation planners and forest managers.

In some reports even basic density of wood is not recorded, and if recorded, the method of measurement is not revealed. As an economic indicator, basic density is the most important wood property — more important than fibre dimensions, extractive content or chemical composition of the wood. For example, wood transport, such as sea freight, is charged on volume basis, so the cost is inversely proportional to wood density (Balodis 1981).

Basic density and pulp yield are required to calculate pulpwood productivity (PP) which is defined as the weight of oven-dry pulp (kg) produced from one cubic metre of wood. PP is used to convert mean annual volume increment to plantation productivity (weight of pulp produced per hectare per year). For a pulpmill of given pulp output, the plantation area to supply the mill can be calculated from plantation productivity (Balodis 1991). Even the size of some mill production units, such as the size of the digester, will depend on PP. Since both pulp yield and basic density of wood are of great economic importance, it is most important to have accurate estimates of these properties.

I hope that, by emphasising the importance of forest and wood data for the assessment of pulpwood quality, more attention will be paid by pulp and paper technologists to the collection of samples and the reporting of pulpwood test data. Let us embrace the spirit of Quality Assurance.

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Pulpwood Potential of Acacias

N.B. Clark*, V. Balodis*, Fang Guigan and Wang Jingxia****

Abstract

Prior to selecting species for pulpwood plantations, the kraft pulping, bleaching and papermaking properties of samples of 13 native-grown acacias were compared with *Acacia mangium* from Sabah, Malaysia and *A. auriculiformis* from Papua New Guinea, and with Australian regrowth eucalypts. The native-grown acacias all had pulp yields within the range of commercial pulpwoods and had good to fair black liquor properties. However, on bleaching, only pulps from *A. aulacocarpa* and *A. dealbata* attained the levels of brightness required for some high grade papers. For the other acacia samples, higher chemical charges or different bleaching sequences would be required. Despite the bleaching difficulties, the paper properties of the acacia pulps were generally good to very good, with several samples having tensile/opacity relationships favourable for fine papers. Overall, only the *A. aulacocarpa* sample was equivalent in pulpwood quality to *A. mangium* and *A. auriculiformis*. These three tropical acacias provide pulpwood of a similar quality to that of temperate-climate regrowth eucalypts.

FIBRE for pulp and paper production is scarce in many countries. Population growth and legitimate aspirations for improvements in living standards ensure that demand will continue to increase. Moreover, in heavily populated countries, most fertile areas are needed for agriculture. Low fertility regions are often the only areas available for forestry.

Several species of the genus *Acacia* survive and grow rapidly in a wide range of environments with low soil nutrients, in part because of their ability to fix atmospheric nitrogen. Wood from acacia plantations could provide fibre for the pulp and paper industry if the wood properties were suitable. Already, a few acacia species are utilised commercially in this way, notably *A. auriculiformis*, *A. mangium* and *A. mearnsii*. However, several other acacias have grown well in species and provenance trials (Brown 1990), but their pulping and papermaking properties are still largely unknown.

Unfortunately, plantation-grown wood from some of these lesser-known acacias is not yet available for testing, since many of the trials have only been recently established. An alternative is to test wood from the native forest.

The conclusions that may be drawn from the results of such tests are limited, but nonetheless valuable. If the samples exhibit poor pulping properties, it tells us little about the potential quality of trees from other locations. However, if the results are positive, then we may assume that trees with the same genetic make-up when grown under the same conditions, would result in a plantation of useful pulpwood. Pulping tests on native-grown trees can be a valuable preliminary step in the selection of species for plantations. It does not eliminate the need to conduct an economic assessment of the pulpwood quality of trees grown in the plantation area.

In this paper, the results of pulping, bleaching and papermaking tests are presented for Australian native-grown acacias from tropical and temperate climates. Some results have been abstracted from the literature, but the majority come from tests carried out as part of ACIAR Project 8849, Subproject D. For comparison, results are included for *A. mangium from* Sabah, Malaysia, and *A. auriculiformis* from Milne Bay, PNG. In addition,

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results are given for a commercial pulpwood resource comprised of regrowth eucalypts from the same region of Australia as the temperate-climate acacias.

Pulping Properties

The pulping tests were conducted on a laboratory scale under conditions simulating the conventional batchwise kraft process used by industry. This process uses sodium hydroxide and sodium sulfide and high (170 °C) temperatures to dissolve the lignin in the wood, allowing the wood fibres to be easily separated into pulp. The process is well known and accepted world-wide, is tolerant to variations in woodchip dimensions and quality, and produces pulp whose quality is acceptable on world markets. For more details of the pulping conditions, refer to Fang et al. (1991).

Table 1 summarises the results of pulping trials for the production of bleachable grade kraft pulps (about Kappa number 20). It can be difficult to assess the implication of these results without reference to the usual range of the various parameters for hardwoods. Balodis (1991) has proposed a grading scale for plantation-grown hardwoods utilised for kraft pulping (see Table 2). For the pulping stage the important parameters are pulp yield, active alkali requirement and pulpwood productivity, i.e. the amount of pulp produced per cubic metre of wood.

Pulp yield is important because wood is the predominant cost of kraft pulp production. For a world-scale kraft pulp mill producing 400 000 tpa, increasing the pulp yield from 48 to 53% would result in a saving of about 140 000 green tonnes of wood per year. At Australian pulpwood prices, this represents a cost saving of $A5.6 million per year (about 22 million yuan).

For pulp yield, all but two of the acacia samples were in the top two grades (more than 48%) of Balodis' scale. Many, particularly *A. aulacocarpa*, *A. decurrens*, *A. elata* and temperate-climate *A. melanoxylon*, were as good as or better than the young eucalypts. The two acacias with low pulp yields were *A. crassicarpa* and *A. flavescens*; the

Table 1. Wood and kraft pulping properties of Australian acacias.

Species	Age (years)	Basic density (kg/m^3)	Active alkali (%Na_2O)	Screened yield (%)	Screen rejects (%)	Kappa no.	PP* (kg/m^3)
Tropical acacias							
A. aulacocarpa[1]	12	598	13.25	55.4	0.6	19.3	331
A. cincinnata[1]	10	580	13.75	53.1	1.3	20.6	308
A. crassicarpa[1]	—	638	17.5	47.2	0.2	20.3	301
A. flavescens	—	768	15.0	46.0	1.2	21.0	354
A. melanoxylon	—	487	12.5	52.2	1.7	20.5	254
A. mangium[2]	9	420	14.0	52.3	0.1	21.0	220
A. auriculiformis[3]	13	516	13.0	53.1	n/a	19.3	274
Temperate acacias							
A. dealbata[3]	mature	553	13.5	52.8	0.7	20.7	292
A. decurrens[5]	9	457	15.0	55.9	n/a	18.7	255
A. elata[4]	—	520	13.0	55.1	1.3	24.0	286
A. leucoclada	—	626	14.0	48.6	0.9	24.4	305
A. mearnsii[4]	—	608	13.0	52.8	1.6	20.0	321
A. melanoxylon	—	502	12.0	55.0	1.5	19.9	276
A. parramattensis	—	606	13.0	51.6	2.8	21.9	313
A. silvestris[4]	—	551	13.0	53.3	1.6	20.3	294
Regrowth euc.[6]	20–30	585	11.5	53.7	0.3	21.2	314

* Pulpwood productivity = Basic density × screened yield/100 (kg o.d. pulp per cubic metre of wood)

[1] Clark et al. 1991

[2] Logan and Balodis 1982

[3] Logan 1987

[4] Fang et al. 1991

[5] Hannah et al. 1977

[6] Mamers et al. 1991

two species with the highest basic density. For eucalypts, there appears to be a critical basic density, above which screened pulp yield decreases significantly with increasing density (e.g. Higgins et al. 1973). While the reason for this correlation is unclear, the same pattern may also apply to acacias.

Table 2. Classification of hardwoods for the production of kraft pulp.

Pulping characteristics (Kappa no. ≈ 20)		
Pulpwood productivity (kg pulp/m^3 wood)		
PP1	Excellent	More than 300
PP2	Very good	271-300
PP3	Good	231-270
PP4	Moderate	191-230
PP5	Low	151-190
PP6	Very low	150 or less
Pulp yield (oven-dry pulp to oven-dry wood)		
Y1	Very good	More than 53%
Y2	Good	48.1-53%
Y3	Moderate	43.1-48%
Y4	Low	43% or less
Active alkali (as Na_2O on o.d. wood)		
AA1	Low	13% or less
AA2	Moderate	13.1-16%
AA3	High	16.1-18%
AA4	Very high	More than 18%
Papermaking properties (freeness not less than 250 CSF)		
Tear index (milliNewtons.m^2/g)		
TR1	Excellent	More than 12
TR2	Very good	9.5-12
TR3	Good	7.0-9.4
TR4	Moderate	4.5-6.9
TR5	Low	Less than 4.5
Tensile index (Newtons.m/g)		
TS1	Excellent	More than 100
TS2	Very good	81-100
TS3	Good	61-80
TS4	Moderate	41-60
TS5	Low	40 or less

From Balodis 1991

The product of basic density and pulp yield is proportional to pulpwood productivity, which is the mass of oven dry pulp produced from a cubic metre of green wood. This parameter is important, (a) for the conversion of volume growth to plantation pulp productivity, and (b) as a measure of digester pulp production capacity. Because of their high densities and high pulp yields, many of the Australian acacia samples had pulpwood productivities higher than 300 kg/m^3, the top of Balodis' grading scale. A few, *A. aulacocarpa*, *A. mearnsii* and *A. flavescens*, were higher than even the exceptionally good regrowth eucalypt sample, but only *A. aulacocarpa* achieved this through higher pulp yield as well as higher density.

Active alkali requirement also has some effect on pulping economics, although not as much as pulp yield or pulpwood productivity. A higher alkali requirement means higher chemical costs, but the magnitude of the increase depends on local chemical prices. As a guide, in Australia active alkali comprises less than 2% of the total costs of operating a bleached kraft pulp mill. This means that even large variations in alkali requirement will not greatly affect the overall cost per tonne of pulp. On Balodis' grading scale, all the acacia samples except *A. crassicarpa* fall into the two top classes.

Bleaching Properties

The methods used to bleach kraft pulp vary widely. For example, modern bleaching sequences often use one or more oxygen stages, whereas traditional bleaching is based largely on chlorine compounds. These differences preclude construction of a common grading scale. In the ACIAR Sub-project D, a conventional four-stage laboratory bleaching process was chosen for consistency with earlier studies. The sequence of stages was: chlorination, alkaline extraction, sodium hypochlorite and chlorine dioxide. This sequence, usually abbreviated as CEHD, is described in detail by Fang et al. (1991).

Table 3 summarises the results. The chemical consumptions show few significant differences, in part because no attempt was made to optimise the chemical charges in the H and D stages for each pulp sample. The yields of bleached pulp (on oven-dry basis) are generally satisfactory, the best being that of *A. aulacocarpa* (97.0%) and the worst that of *A. leucoclada* (93.0%).

The most important result from the bleaching tests is the brightness of the pulp. Bleached kraft market pulp should have a brightness of about 90% ISO, and in Australia, even pulp for use in an integrated paper mill needs a brightness of 84-86% ISO. Using the CEHD sequence, many of the acacia pulps could not be bleached to these brightness levels. With the exception of *A. aulacocarpa*, only pulps from acacias already used commercially (*A. mangium*, *A. auriculiformis*, and *A. dealbata*) approached the brightness level required for an integrated paper mill. For the other acacia pulps, higher chemical charges or different bleaching sequences may be needed to achieve the required brightness levels.

Table 3. Bleaching properties of kraft pulps from Australian acacias.

Species	Chlorine demand# (%)	Total chlorine consumed in C&H stages# (%)	Chlorine dioxide consumed# (%)	Brightness (% ISO)	Yield (%)	
					#	OW
Tropical acacias						
A. aulacocarpa[1]	3.9	4.9	0.34	84.6	97.0	53.8
A. cincinnata[1]	3.3	4.3	0.34	76.7	96.3	51.1
A. crassicarpa[1]	3.7	4.9	0.40	72.2	95.4	45.0
A. flavescens	3.6	5.1	0.26	74.1	95.3	43.9
A. melanoxylon	3.5	5.1	0.34	76.1	96.0	50.1
A. mangium[1]	4.0	5.0	0.35	83.2	95.4	49.2
A. auriculiformis[1]	3.8	5.3	0.34	84.2	95.1	51.8
Temperate acacias						
A. dealbata[2]	3.9	5.2	n/a	84.2	95.7	50.5
A. leucoclada	5.5	7.5	0.33	74.5	93.0	45.2
A. mearnsii[3]	5.1	6.2	n/a	81.2	94.5	49.9
A. melanoxylon	4.5	5.8	0.33	77.7	95.1	52.3
A. silvestris[3]	4.7	5.9	n/a	80.8	94.3	50.2
Regrowth euc.[4]	4.0	4.7	n/a	84.7	94.7	50.9

Based on o.d. unbleached pulp
OW Original wood basis
[1] Clark et al. 1991
[2] Phillips et al. 1989 — 4 hour D stage
[3] Fang et al. 1991
[4] Mamers et al. 1991

It is probable that bleaching may present problems to the use of some acacia species for the production of bleached kraft pulp. However, the limitations of these results must be recognised. Firstly, the results are only for native-grown trees from one location. Trees from other locations, or trees grown in plantations may have different properties. Secondly, the results are based on the outdated CEHD bleaching sequence. While this is a useful sequence for ranking the bleachability of eucalypt pulp samples, different bleaching sequences may be required for acacia pulps. Tests with modern sequences are planned to be carried out during the extension of Sub-project D.

Papermaking Properties

The papermaking properties of the bleached acacia pulps were evaluated by making handsheets and testing them according to the relevant Australian standards. The results of these tests, interpolated to a constant freeness of 250 Canadian Standard Freeness for ease of comparison, are summarised in Table 4.

The most important paper strength properties are tear and tensile indexes. With reference to the proposed hardwood grading scale (Balodis 1991) all the acacia pulps had above average tensile index and all but *A. leucoclada* had above-average tear index.

These results give a general indication of the strength of the acacia pulps compared with other hardwood kraft pulps. However, particular end-uses demand particular combinations of paper properties. For fine papers, which are an important end-use for hardwood bleached kraft pulps, a certain minimum strength, stiffness and surface pick resistance at maximum opacity is required (Rydholm and Gedda 1967). All the acacia pulps tested had higher opacities than the regrowth eucalypt pulp. As we have seen, some of the acacia pulps, such as those from *A. mangium*, *A. auriculiformis*, *A. aulacocarpa* and from tropical *A. melanoxylon*, also had good tensile strengths. It is therefore likely that several of the acacia samples would have advantages for fine paper production.

Black Liquor Properties

Spent liquor from alkaline pulping processes is called black liquor. In the kraft process, black liquor is concentrated and then burned in a furnace to recover cooking chemicals and to raise steam. The best liquors are those which burn well and have low viscosity at high solids content. An indication of

Table 4. Table 4. Papermaking properties of bleached kraft pulps from Australian acacias at 250 CSF.

Species	Bulk (cm^3/g)	Tear index ($mN.m^2/g$)	Tensile index (N.m/g)	Burst index ($kPa.m^2/g$)	Opacity (%)
Tropical acacias					
A. aulacocarpa[1]	1.40	9.3	103	7.5	69.4
A. cincinnata[1]	1.40	7.7	85	5.4	70.5
A. crassicarpa[1]	1.40	8.8	84	5.6	73.0
A. flavescens	1.55	8.5	80	4.8	71.3
A. melanoxylon	1.25	8.7	123	8.0	66.7
A. mangium[1]	1.19	7.4	125	9.3	n/a
A. auriculiformis[1]	1.40	11.3	114	8.0	n/a
Temperate acacias					
A. dealbata[2]	1.42	10.4	78	5.6	69.1
A. leucoclada	1.50	6.1	69	3.8	75.0
A. mearnsii[3]	1.49	7.5	83	4.7	74.8
A. melanoxylon	1.35	7.5	93	6.1	70.9
A. silvestris[3]	1.37	7.2	99	6.5	70.9
Regrowth euc.[4]	1.46	10.9	109	7.4	66.4

[1] Clark et al. 1991
[2] Phillips et al. 1989 — 4 hour D stage
[3] Fang et al. 1991
[4] Mamers et al. 1991

burning properties is obtained by measuring the swelling volume of a liquor when heated (Baklien 1960). The following grading scheme for the classification of black liquors is based on results from the study of eucalypt black liquors by Oye et al. (1977). The two critical parameters are the viscosity of concentrated liquor at 40% total solids and 40 °C, and the swelling volume. Good black liquors from eucalypts have viscosity <16 mPa.s and swelling volume >40 ml/g total solids, fair 60 and 30, and poor >200 and <10 respectively (Fang et al. 1991).

Table 5 lists the results for the black liquors from the acacias. If the classification system for eucalypts applies to acacias, then the black liquors from the acacias would be good to fair, with only the swelling volumes of *A. crasssicarpa* and *A. flavescens* classed as poor.

Future Trends

In this project, conventional kraft pulping and bleaching processes were applied to the acacia samples. However, in future it is likely that concern over the discharge of chlorinated organic compounds from bleached kraft pulp mills will necessitate changes to the methods of pulp production. Pulping will be extended to lower levels of residual lignin, reducing the need to remove organic material during bleaching. In addition, new bleaching sequences will use oxygen, ozone and/or hydrogen peroxide, with chlorine compounds reduced or eliminated.

Will these modified pulping and bleaching processes suit acacias? For most of the species studied in this project, the answer to this question must await the results of further tests. However, for plantation-grown *Acacia mangium*, some figures are already available. Lundgren (1991) gives results using a laboratory-scale simulation of the Modified Continuous Cooking (MCC) technology marketed by the Swedish company, Kamyr AB. Pulp yields were 53.5–54.5% at kappa numbers of 15.5–20.5. After oxygen delignification to kappa numbers 9–11, followed by a four stage (DC)(EO)DD bleaching sequence, a pulp brightness above 90% ISO was achieved. Papermaking properties were described as superior to those of Scandinavian birch, but in most respects a little inferior to those of plantation-grown *Eucalyptus globulus* from Portugal. *A. mangium* did have one papermaking advantage — higher opacity. This was ascribed to the low coarseness of the pulp fibres and consequent high number of fibres per unit weight. This observation agrees with data for 8-year-old plantation-grown *A. mearnsii* from Zimbabwe (A. Muneri, pers. comm.) which had a significantly lower coarseness than *E. grandis* from the same country.

Table 5. Properties of kraft black liquors from Australian acacias.

Species	Pulp Kappa no.	Total solids of unevaporated black liquor (%)	Swelling volume (ml/g.T.S.)	Viscosity at 40% T.S. (m Pa.s)
Tropical acacias				
A. aulacocarpa[1]	19.3	13.8	47	20
A. cincinnata[1]	20.6	13.9	33	26
A. crassicarpa[1]	20.3	17.0	5	20
A. flavescens	21.0	14.7	7	89
A. melanoxylon	20.5	13.1	14	45
A. mangium[1]	20.9	14.1	45	21
A. auriculiformis[1]	19.8	14.0	35	18
Temperate acacias				
A. dealbata[2]	20.7	15.2	54	15
A. leucoclada	24.4	15.4	22	66
A. mearnsii[3]	20.0	14.4	25	47
A. melanoxylon	19.9	13.9	13	53
A. silvestris[3]	20.3	14.3	48	43
Regrowth euc.[4]	21.7	14.7	24	159

[1] Clark et al. 1991
[2] Phillips et al. 1989
[3] Fang et al. 1991
[4] Mamers et al. 1991

From these results, it is clear that plantation-grown *A. mangium* is well suited to modified pulping and bleaching processes. It has high pulp yield, good bleachability and papermaking properties particularly suited to the manufacture of fine papers.

Conclusions

The kraft pulp yields of most of the native-grown acacia samples were within the range of commercial pulpwoods. Only *A. crassicarpa*, *A. flavescens* and *A. leucoclada*, three high basic density samples, had yields below 50%. Over half of the acacia samples had pulpwood productivities above 300 kg/m^3, giving them an important advantage for pulp mills with limited digester capacity. On bleaching, only the pulps from *A. dealbata* and *A. aulacocarpa* attained the brightness levels required for some high grade papers. For the other samples, higher chemical charges or different bleaching sequences might be required. Despite these bleaching difficulties, the paper properties of the acacia pulps were generally acceptable, with several species having tensile/opacity relationships favourable for fine papers. Black liquor properties would be classed as good to fair, indicating few problems in the recovery process. Overall, only the *A. aulacocarpa* sample was equivalent in pulpwood quality to *A. mangium* and *A. auriculiformis*. These three tropical acacias provide pulpwood of a similar quality to that of temperate-climate regrowth eucalypts.

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Bark Quality of *Acacia mearnsii* Provenances from Different Geographic Origins Growing in South China

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Abstract

Bark samples were collected from trees in four *Acacia mearnsii* provenance trials in Ganzhou (Jiangxi), Nandan (Guangxi), Nanping (Fujian) (6 years of age) and Changtai (Fujian) (5 years). Ninety-three samples from these trials represented 30 provenances from Australia, South Africa, Brazil and China. The yields of hot water extractives were determined. The ultra-violet spectrophotometric method, in conjunction with the yield of hot water extractives (total solids), was used to estimate Stiasny values of the extractives and tannin and polyflavanoid contents of the bark samples.

Bark quality of genetically improved seedlots from South Africa and Brazil at age 6 was superior to that of Australian native provenances, while quality of local seedlots was similar to that of provenances from Victoria and better than that from New South Wales. As barks of provenances from Victoria, South Africa, Brazil and China contained more tannin and polyflavanoids than that of NSW provenances, they are more suitable for leather tanning and waterproof wood adhesives. This work provides important data which can complement other results, for example on growth and cold tolerance, in selection and breeding.

BLACK wattle (*Acacia mearnsii*), a native of southeastern Australia, was first introduced into China in the 1950s, but no improvement activities were attempted until the 1980s. Since 1980 rapid development of the local tannin market has led to large-scale establishment of black wattle plantations in southern China, although the genetic quality of the seed has been inferior. In 1985 and 1988, two forestry cooperative projects (ACIAR 8458: Wattle silviculture and utilisation of tannin extract, and ACIAR 8849: Wattle silviculture and pulping studies) started selection of outstanding *Acacia mearnsii* provenances with fast growth, good quality bark and greater suitability to diverse environments in southern China. This paper reports results of bark quality assessments in provenances at 5–6 years of age on four sites across southern China.

Materials and Methods

A. mearnsii provenance samples

Bark samples were collected from provenance trials at Changtai (5 years old) and Nanping, Ganzhou and Nandan (6 years). Precise locations and trial designs were described by Gao et al. (1991). The collections comprised:

- six-year trials — 68 bark samples from provenances from Australia (New South Wales (11 provenances) and Victoria (5)), South Africa-Brazil (3), and China (5);
- five-year trial — 25 samples from provenances from Australia (New South Wales (10), Victoria (5), Tasmania (5) and South Australia (1)), South Africa and Brazil (3), and China (1) (see Table 1).

Bark collection

One average tree per provenance was selected for sampling in each replicate; thus 5–6 trees were sampled per provenance at each individual site, depending on the number of replicates present. Height and diameter of average trees were recorded (see Table 1). Ten discs were removed with a wad

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Table 1. Characteristics of *Acacia mearnsii* provenances across four trial sites (Nanping (A), Ganzhou (B) and Nandan (C) aged 6 years, Changtai (D) aged 5 years).

Seedlot No.	Location	Lat@ (S) (° ')	Long. (E) (° ')	Alt. (m)	Bark thickness (mm)				Diameter (Dbhob)(cm)				Height (m)			
					A*	B	C	D	A	B	C	D	A	B	C	D
14394	Candelo, NSW	36 45	149 40	80	3.4	3.3	3.6	3.3	9.6	5.3	5.7	4.1	8.1	5.9	8.0	4.2
14395	Lake George, NSW	35 15	149 20	700	2.9	4.1	—	—	12.8	6.3	—	—	10.0	5.7	—	—
14397	Bodalla, NSW	36 08	150 05	75	1.8	3.8	3.3	3.4	8.5	6.0	6.8	4.7	8.5	6.5	9.6	5.0
14398	Batemans Bay, NSW	35 42	147 15	40	2.8	3.3	3.5	3.4	11.0	5.1	6.8	4.7	10.6	5.5	9.1	4.8
14416	Dargo, Vic	37 28	147 15	200	2.8	3.8	3.5	3.6	9.7	5.7	6.2	4.2	8.6	6.1	8.7	4.6
14725	Bungendore, NSW	35 12	149 32	760	4.0	3.8	—	3.3	11.3	5.4	—	4.9	9.3	5.8	—	5.2
14769	Googong, NSW	35 29	149 16	670	2.8	3.6	3.7	3.1	9.5	5.1	5.4	3.5	8.5	5.6	6.9	3.8
14770	Polacks, NSW	36 39	149 35	260	2.3	3.3	3.5	3.1	10.0	4.8	6.9	4.4	8.8	5.4	8.4	4.6
14771	Cooma, NSW	36 28	149 01	940	2.7	4.0	4.2	3.6	9.6	6.0	7.9	4.9	9.2	6.2	9.7	5.0
14922	Braidwood, NSW	35 15	149 38	720	2.8	4.7	4.0	3.8	12.1	5.9	7.9	5.0	9.4	6.0	6.0	4.9
14923	Bombala, NSW	37 09	149 20	500	2.6	4.1	3.5	3.5	10.6	5.7	6.3	4.3	9.6	5.9	8.0	4.7
14924	Merimbula, NSW	36 55	149 54	20	2.6	4.0	3.9	3.2	9.9	5.4	6.8	3.7	9.4	5.5	9.1	4.1
14925	Blackhill Reserve, Vic	37 12	144 28	500	3.5	5.0	4.3	3.9	10.1	6.6	7.1	4.9	9.2	6.3	8.9	5.2
14926	Omeo Hwy, Vic	37 10	147 45	300	4.0	4.5	3.7	3.9	10.4	6.2	7.6	4.5	9.2	6.3	9.7	4.8
14927	Sth.Gippsland, Vic	37 44	146 51	100	2.8	3.8	3.5	3.6	9.7	5.7	6.2	4.2	8.6	6.1	8.7	4.6
14928	Cann River & Orbost, Vic	37 34	148 28	100	2.6	4.0	3.6	3.3	11.6	5.7	7.6	6.3	10.3	6.3	8.4	6.0
15326	Georgetown,Tas	41 07	146 52	60	—	—	—	3.2	—	—	—	2.9	—	—	—	3.4
15327	Bicheno,Tas	41 54	148 18	30	—	—	—	3.8	—	—	—	4.2	—	—	—	4.4
15328	Avoca,Tas	41 49	147 35	220	—	—	—	3.2	—	—	—	3.6	—	—	—	4.1
15330	Boyer,Tas	42 46	147 08	60	—	—	—	3.7	—	—	—	4.0	—	—	—	3.8
15331	Hobart,Tas	42 50	147 31	10	—	—	—	3.1	—	—	—	3.6	—	—	—	4.2
15458	Mt Gambier, SA	37 50	140 47	65	—	—	—	3.9	—	—	—	4.7	—	—	—	4.6
15087	Harding, S.Africa	30 35	29 51	932	3.3	5.2	—	4.1	8.8	5.8	—	5.3	7.4	5.7	—	5.0
15088	Natal, S.Africa	29 32	30 28	838	3.8	4.8	—	4.0	9.9	6.5	—	5.2	8.9	6.1	—	5.1
C20	Brazil	—	—	—	3.9	4.3	4.8	4.4	12.9	6.3	9.0	7.0	10.5	6.3	10.6	5.7
C21	Wenzhou, China	28 01	120 40	50	4.1	4.9	4.3	—	11.0	6.7	6.8	—	9.4	6.3	8.7	—
C22	Guangnan, China	24 02	105 02	1540	3.2	4.9	4.4	4.2	11.8	5.6	5.7	4.9	9.7	5.1	6.7	4.7
C23	Ganzhou , China	25 51	114 50	124	3.7	5.1	3.5	—	10.4	5.9	6.0	—	8.9	5.8	7.9	—
C24	Tongjiang, China	31 56	107 14	690	3.1	5.6	4.6	—	10.8	6.7	7.9	—	9.2	6.3	9.5	—
C25	Jiangbian,China	24 20	103 20	1600	3.0	5.0	4.1	—	9.9	6.2	5.7	—	9.2	6.0	6.5	—
Mean		—	—	—	3.1	4.3	3.9	3.6	10.6	5.9	6.8	4.6	9.2	6.0	8.6	4.7

NSW: New South Wales, Vic: Victoria, SA: South Australia, Tas: Tasmania, @: North latitude (N) for Chinese seedlots, * Bark thickness under air-dry conditions; others fresh weight punch (33.3 mm diameter) in a vertical line ranging from 1.1–1.5 m above ground on the south side of the bole. Thus 50–60 discs (ca 300–400 g in fresh weight) were gathered per provenance on each site and mixed to form a sample for the provenance at each site. Bark thickness on the disc was measured with a vernier caliper, and then the discs were placed in a labelled cloth bag and air-dried. Bark was collected on four trial sites and the samples sent for analysis of bark quality to the Research Institute of Chemical Processing and Utilization of Forest Products in Nanjing.

Analysis of bark quality

Bark quality analyses were undertaken in accordance with the methods described by Gu and Yazaki in Appendix 1. The small extractor used was designed by Professor Gu Renxia, who also contributed to development of the determination methods (see Yazaki et al. in these proceedings, and Yazaki et al. 1993). Means of the five measured indexes for each site are given in Table 2.

Results and Discussions

Total solids

Total solids of 93 bark samples varied between 41.2% (Cooma, NSW grown at Nanping) and 65.2% (Wenzhou grown at Ganzhou). The average yield of 68 samples collected from 24 provenances at 6 years of age was 54%, slightly higher than that of native mature stands (53%) in Australia (Yazaki et al. 1990) and of provenances (52%) at 5 years of age in China. Of the bark samples collected from 6-year-old provenances, 19% contained more than 60% extractive (Fig.1).

Figure 1 also indicates that yields from Tasmanian, Victorian, South African and Brazilian seedlots were less variable than those from New South Wales and China. In the South Africa-Brazil group, 71% of bark samples had extractive yields higher than 60%, while in the Chinese and Victorian groups 40 and 13% of samples respectively yielded more than 60%.

In the New South Wales and Tasmanian groups, no provenance sample showed yield higher than 60%. The yield of Tasmanian provenances aged 5 years was higher than that of other native mature stands in Australia (Yazaki et al. 1990).

The means for South Africa-Brazil and the China group were 59 and 58% respectively, compared with 55% for Victoria and 51% for New South Wales. In terms of yields, 12 outstanding provenances are: Australia (Lake George, Sth Gippsland, Cann River and Orbost, Blackhill Reserve, Dargo), South Africa (two seedlots), Brazil, and China (Guangnan, Tongjiang, Wenzhou and Ganzhou), all of which had yields of more than 55%; Australian provenances from Bungendore, Polacks Flat Ck and Cooma had yields of less than 50%.

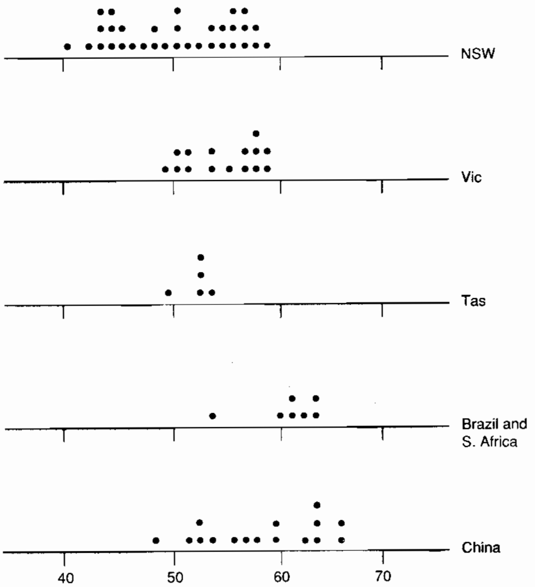

Fig. 1. Dot plot showing the distribution of total solids (%) at state level.

The results of analysis of variance on the yields for 24 provenances aged 6 years at individual sites or across the three 6-year-old sites showed that the yield means at a state level or a provenance level are highly significantly different ($p < 0.01$) — (see Tables 3 and 5), while for the 5-year-old provenances, no differences in yields were found between the three Australian states (Table 4).

Two patterns of geographical variation in the yields were found in Australian provenances on a drier site and on three more humid sites across southern China. On the Ganzhou site (1434 mm in annual rainfall) southern mainland provenances contained higher yields than northern ones. At more humid Nanping (1679 mm), Changtai (1658 mm) and Nandan (1559 mm) sites, inland Australian provenances showed higher yields than coastal ones (Table 6).

Table 6 also reveals that the yields are strongly related to bark thickness but the relationship between the yields and diameter varied with trial sites. The correlation is strongest at Ganzhou and Changtai, but weaker at the other two sites.

Table 2. Means of the five bark tannin characteristics for *A. mearnsii* provenance bark samples across four trial sites: at 6 years, Nanping (A), Ganzhou (B), Nandan (C); at 5 years, Changtai (D).

Seedlot No.	Total solids (%)				Tannin content (%)				Polyflavanoid content (%)				Stiasny value (%)				UV value			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
14394	50.8	55.6	46.6	47.2	34.2	39.7	34.2	31.2	43.7	49.8	44.5	40.9	86	89.5	95.5	86.3	79.5	83.3	89.8	79.8
14395	54.6	58.9	—	—	37.4	42.8	—	—	46.9	53.1	—	—	85.9	90.1	—	—	79.3	83.9	—	—
14397	44.2	57.9	50.9	49.8	30.5	43.1	34.2	33	40.4	53.8	43.6	42.4	91.4	92.8	85.7	85.1	85.4	86.9	79.1	78.5
14398	50.5	54.7	45.2	54	33.6	39.5	33.2	37.7	43	49.7	43.4	47.5	85.2	90.8	95.9	87.9	78.6	84.7	90.1	81.5
14416	60.3	58.3	50.2	51.4	43.4	42.5	34.7	34.6	53.4	52.8	44.5	44	88.6	90.4	88.7	84.9	82.3	84.3	82.4	78.3
14725	46.1	53.5	—	49.7	29.4	38.8	—	32.6	38.9	49.1	—	41.9	84.3	91.8	—	84.4	77.6	85.8	—	77.7
14769	46.3	49.4	47.8	48.5	31.8	33.9	31.3	27.5	41.6	43.7	40.7	37	89.9	88.5	85.3	85	83.7	82.2	78.7	78.4
14770	43.6	55.9	45.2	52	28.1	40.9	31	34.6	37.9	51.4	40.8	43.9	89.9	92	90.3	84.4	81.5	86	84.2	77.7
14771	41.2	57.8	45.2	50.8	24.7	41.5	31.5	33.8	34.2	51.5	41.4	43.2	83.1	89.2	91.5	85.1	76.3	83	85.5	78.5
14922	56	53.6	52.1	51.2	40.9	38	35.3	34.5	51.3	48	44.7	44	91.7	89.3	85.9	85.9	85.7	83.1	79.3	79.3
14923	56.2	56.7	43.6	52.6	39.8	40.1	30.2	35.1	49.7	50	40.1	44.3	88.4	88.1	91.9	84.2	82.1	81.7	85.9	77.5
14924	50.1	56.6	47.8	52.6	34.5	41.2	34.1	35.2	44.2	51.5	44.3	44.5	88.4	91	92.7	84.7	82.1	85.1	86.8	78
14925	58.9	60.2	54.2	52.3	41.9	43.8	37.3	35.9	51.6	54.1	46.9	45.4	87.6	89.9	86.5	85.7	81.7	83.7	80	79.1
14926	51.3	58.8	49.3	54.3	36.3	43.1	34.5	36.9	46.4	53.6	44.5	46.2	90.2	91.1	89.5	84.8	84	85	—	78.1
14927	59.1	59	51.1	54.9	42.9	42.4	36.3	38.3	53	52.4	46.3	47.9	89.9	88.8	90.7	87.2	83.7	82.5	84.6	80.8
14928	53.6	55.9	49.9	51.1	38.2	40	34.7	34	48.2	50.1	44.6	43.3	90	89.6	89.5	86	83.8	83.4	83.3	79.5
15326	—	—	—	52.3	—	—	—	34.2	—	—	—	43.4	—	—	—	82.7	—	—	—	75.9
15327	—	—	—	54	—	—	—	37.5	—	—	—	47.1	—	—	—	87.4	—	—	—	81
15328	—	—	—	48.8	—	—	—	31.3	—	—	—	40.5	—	—	—	83	—	—	—	76.2
15330	—	—	—	51.8	—	—	—	34.2	—	—	—	43.3	—	—	—	83.7	—	—	—	76.9
15331	—	—	—	52	—	—	—	36	—	—	—	45.7	—	—	—	88.1	—	—	—	81.7
15458	—	—	—	54.9	—	—	—	38.5	—	—	—	48.3	—	—	—	87.9	—	—	—	81.5
15087	—	61.1	—	55.9	44.2	44.6	—	38.6	54.8	54.9	—	48	91.9	89.9	—	86	85.9	83.7	—	79.5
15088	60.8	63.1	—	60.8	44.2	46	—	42.9	54.3	56	—	52.2	89.3	88.7	—	89.3	83.1	82.4	—	83.1
C20	61	62.8	53.6	58.7	44.1	45.7	38.5	41	54.1	55.7	49	50.3	88.7	88.7	90.9	85.7	82.4	82.4	84.8	79.1
C21	59.4	65.1	57.2	—	43.1	48	40.7	—	53.4	58.3	50.5	—	89.9	89.5	88.4	—	83.7	82.7	82.1	—
C22	52.4	62.7	55.4	56.6	36.5	45.3	38.6	38.5	46.2	55.3	48.2	47.6	88.1	88	87	84.2	81.7	81.6	80.5	77.5
C23	62.3	62.9	51.1	—	44.2	45	35.5	—	53.7	54.5	45.4	—	85.9	86.7	88.9	—	79.3	82.4	82.6	—
C24	56.2	65.2	53.1	—	40	47.6	37.3	—	49.9	57.5	47.2	—	88.9	88.2	88.9	—	82.6	81.9	82.6	—
C25	47.1	62.9	51.7	—	32.4	46	36.8	—	42.3	56.2	46.8	—	89.8	89.4	90.5	—	83.6	83.2	84.8	—
Mean	53.4	50.3	58.7	54.6	37.4	42.5	35	37.4	47.2	52.6	44.9	46.7	88.5	89.7	89.7	85.3	83.2	82.1	82.6	78.7

Table 3. Results of analysis of variance on bark quality of *Acacia mearnsii* geographic regions at 6 years of age (means of three trials).

Origin	Means# (percentages transformed to arcs in degrees)			
	Yields	Tannin	Polyflavanoid	Stiasny
S.A. & Brazil	50.3a	41.0a	46.9a	71.6
China	49.5ab	39.9ab	45.6ab	70.3
Vic	48.1b	38.9ab	44.7b	71.1
NSW	45.4c	36.4c	42.2c	71.2
F-test	14.34**	11.33**	11.64**	1.23ns
$LSD_{0.05}$	2.1	2.1	2.1	—

** ($p<0.01$), ns (not significant).
# Means having the same letter are not significantly different (5%).

Table 4. Results of analysis of variance on bark quality of *Acacia mearnsii* provenances at 5 years of age at Changtai County, Fujian Province.

Origin	Means# (%)			
	Yields	Tannin	Polyflavanoid	Stiasny
S.A & Brazil	58.5a	40.8a	50.2a	85.9
Vic	52.8b	35.9ab	45.4b	86.0
NSW	50.3b	33.5b	43.0b	85.3
Tas	51.8b	34.6b	44.1b	85.0
Mean	53.4	36.2	45.7	85.5
F-test	8.01**	7.61**	6.81**	0.47ns
$SD_{0.05}$	3.8	5.9	3.7	—

** ($p<0.01$), ns (not significant).
# Means having the same letter are not significantly different (5%).

Tannin content

Tannin contents in all 93 bark samples varied between 24.7% (Cooma, NSW, grown at Nanping) and 48.0% (Wenzhou grown at Ganzhou). The average content in 68 bark samples from 24 provenances at 6 years of age was 38.5%, which was 10.9% less than that in barks from Australian natural mature stands of unknown age (Zheng et al.1991). The highest means of 66 Australian bark samples based on bark sample and provenance at age 5-6 years were 43.8 and 41.9% respectively, which were both from Blackhill Reserve. In the three even-aged trial stands at 6 years of age, 86, 60 and 53% of bark samples in South Africa-Brazil, China and Victoria groups had more than 40% tannin, while 32.3% of samples showed higher than 40.0% tannin content. On Changtai site (5 yr), no provenances from Tasmania contained more than 40% tannin (Fig. 2).

Analysis of variance on tannin content across three sites reveals that the mean values were highly significantly different at a provenance or a state level ($p<0.05$) (Tables 3, 4 and 5). The group means of South Africa-Brazil, China and Victoria were 43.1, 41.1 and 39.5% respectively, compared with 35.3% of provenances from New South Wales.

Table 5. Means of the four measured bark tannin characteristics for *Acacia mearnsii* provenance bark at 6 years across three sites, and results of $LSD_{0.05}$ test.

Seedlot	Means# (percentages transformed to arcs in degrees)			
	Total solids	Tannin	Polyflavanoid	Stiasny
14394, NSW	45.6ghi	36.9efgh	42.7fghi	72.3
14725, NSW	43.8i	34.8h	40.6i	70.3
14770, NSW	44.0i	35.2gh	41.2hi	72.3
14769, NSW	43.8i	34.7h	40.4i	69.7
14397, NSW	45.6ghi	36.8efgh	42.7fgh	71.8
14922, NSW	47.3cdefgh	38.1cdefg	43.9cdefgh	70.7
14398, NSW	45.1hi	36.5fgh	42.4gh	72.7
14924, NSW	45.9fghi	37.2defgh	43.0efghi	72.4
14395, NSW	47.8bcdefgh	38.4bcdef	44.1bcdefgh	70.1
14771, NSW	43.9i	34.7h	40.6i	69.9
14923, NSW	46.3fghi	37.3defgh	43.0efgh	71.2
14927, Vic	48.7abcdefg	39.6abcde	45.4abcdefg	71.4
14925, Vic	49.5abcde	39.8abcd	45.5abcdef	69.8
14416, Vic	48.6abcdefg	39.4abcdef	45.2abcdefg	70.9
14926, Vic	46.8defgh	38.0cdefg	44.0cdefgh	71.9
14928, Vic	46.8defgh	37.9cdefg	43.7defgh	71.3
15087, S. Africa	49.9abc	40.9abc	46.9abc	72.7
15088, S. Africa	50.8ab	41.3ab	47.1ab	70.9
C20, Brazil	50.3abc	40.9abc	46.7abcd	71.1
C21, Wenzhou	51.1a	41.5a	47.4ab	70.9
C22, Guangnan	49.0abcdef	39.3abcdef	45.0abcdefg	69.5
C23, Ganzhou	50.1abc	40.1abcd	45.7abcdef	69.1
C24, Tongjiang	49.8abcd	40.2abcd	45.9abcde	70.4
C25, Jiangbian	47.3cdefgh	38.3bcdef	44.1bcdefgh	71.5
Mean	47.4	38.2	44.1	71.0
F-test	4.52**	4.10**	4.03**	0.59ns
$LSD_{0.05}$	3.2	3.0	3.0	—

** ($p<0.001$)
# Means having the same letter are not significant different (5%).

Tannin content is apparently related to tree age although because of the confounding of trial site location and age of assessment conclusions must be tentative. In the stand at 5 years of age, 8% (two out of 25 sampled provenances) of bark samples gave values higher than 40%, compared with 42% (10 out of 24) in three stands at age 6 years. It was found that 72% (13 of 18) provenances contained more than 40% tannin in native mature stands in Australia (Zheng et al. 1991).

Table 2 also indicates that at the drier Ganzhou site provenances showed higher tannin content than at more humid sites.

Ten provenances are outstanding with respect to tannin content: Lake George, South Gippsland, Blackhill Reserve, South Africa (two seedlots), Brazil, and Guangnan, Tongjiang, Wenzhou and Ganzhou; all contained more than 40% tannin. There was a significant relationship between tannin content and bark thickness, but a poor correlation with diameter at Nanping and Nandan, and stronger relationships at Ganzhou and Changtai.

There was a positive association of tannin content with latitude of origin in Australia at the drier site, and a negative trend with longitude at more humid sites (Table 6).

Table 6. Correlation coefficients between bark quality and growth or locations of Australian *Acacia mearnsii* provenances.

	Yields	Tannin	Polyflavanoid
Changtai (5 years)			
BT (25)	0.75**	0.75**	0.74**
Dbh (25)	0.46*	0.47*	0.46*
Long. (16)	−0.43*	−0.43*	−0.43*
Nanping (6 years)			
BT (24)	0.46*	0.42*	0.41*
Dbh (24)	0.30	0.25	0.24
Long. (16)	−0.59*	−0.56*	−0.56*
Ganzhou (6 years)			
BT (24)	0.75**	0.70**	0.67**
Dbh (24)	0.72**	0.70**	0.69**
Lat (16)	0.61*	0.61*	0.61*
Nandan (6 years)			
BT (20)	0.54*	0.61**	0.63**
Dbh (20)	0.13	0.17	0.19
Long. (14)	−0.37	−0.53*	−0.56*

BT: Bark thickness; Dbh: diameter at breast height; Long: longitude
Figures inside the brackets indicate the sample numbers analysed.
* ($p<0.05$), ** ($p<0.01$), *** ($p<0.001$)

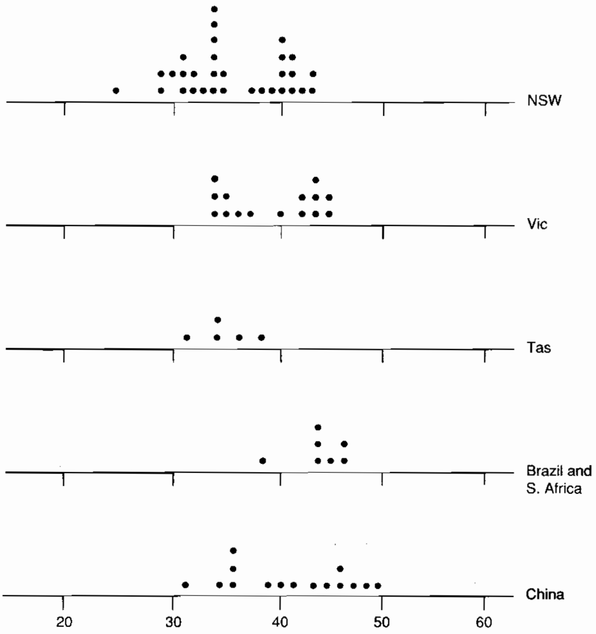

Fig. 2. Dot plot showing the distribution of tannin content (%) at state level.

Polyflavanoid content

The polyflavanoid contents of all samples ranged from 34.2% (Cooma, NSW, grown at Nanping) to 58.3% (Wenzhou, grown at Ganzhou). The average value of bark samples collected from provenances at 6 years of age was 48.4%, much more than that (35.5%) in provenances at 5 years of age and slightly higher than that (47.5%) in native stands of unknown age in Australia (Yazaki et al. 1990).

The highest means of 66 Australian samples based on a provenance and bark sample aged 5-6 years were 54.1 and 50.9 % respectively — both from Blackhill Reserve. In South Africa-Brazil and China groups, 86 and 54% of bark samples showed higher polyflavanoid content than 50%, compared with 53% in Victoria and 26% in New South Wales. Provenances from Tasmania at 5 years of age had a content of less than 50% (Fig. 3).

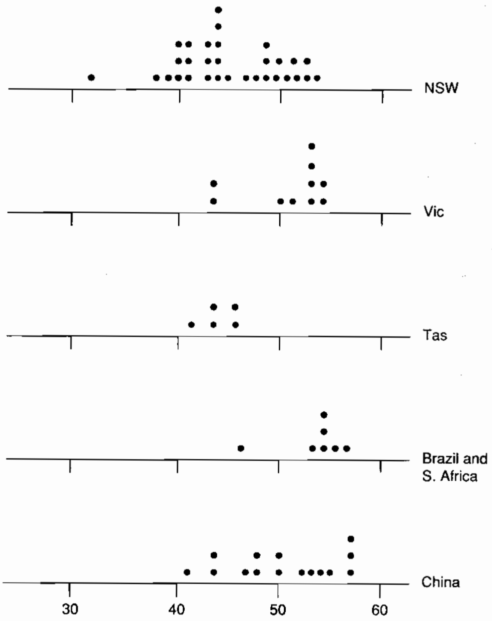

Fig. 3. Dot plot showing the distribution of polyflavanoid content (%) at state level.

The results of analysis of variance reveal that the polyflavanoid content values were considerably different at a provenance or a state level ($p<0.05$ or $p<0.001$) (Tables 3, 4 and 5). The group mean of Victoria was 49%, greater than that of New South Wales (45%). However, the means of provenances at 5 years of age from Victoria, New South Wales and Tasmania were almost at the same level (Table 4). Provenances of South Africa-Brazil and China were better than Australian ones at both ages (Tables 3 and 4).

Ten provenances had superior polyflavanoid contents — Lake George, Sth. Gippsland, Blackhill Reserve, Dargo, South Africa (2), Brazil, and Tongjiang, Wenzhou and Ganzhou; all gave polyflavanoid readings greater than 50%. A markedly positive relationship between the content and latitude of provenance in Australia was also found on the Ganzhou site ($p<0.05$) while a strongly negative correlation between the content and longitude was found on the other three sites ($p<0.05$) (Table 6).

The polyflavanoid content was significantly related to bark thickness, and weakly related to diameter at Nanping and Nandan, and more strongly at Ganzhou and Changtai (Table 6).

Stiasny values

The Stiasny values varied between 82.7% (Georgetown, Tasmania, grown at Changtai) and 95.1% (Batemans Bay, NSW, grown at Nandan). The mean of provenances at 6 years of age was 89.4%, which was slightly greater than that (85.8%) recorded by Yazaki et al. (1990) in native stands of unknown age from Australia and also higher than that (77.8%) of the commercial wattle tannin standard in South Africa. Furthermore, the means of all bark samples were higher than 80% and 24 means of 6-year-old provenances were all more than 85% while 60% (15 of 25) of bark samples showed higher than 85% Stiasny value in the stand aged 5 years (Fig.4).

Analysis of variance on Stiasny value reveals that mean values at a state level or a provenance level are not significantly different (see Tables 3, 4 and 5). There were no marked relationships between Stiasny value and locations of Australian provenances, and bark thickness or height or diameter (see Tables 1 and 2). Stiasny value was also not apparently related to stand age. The Stiasny means of stands at 5 years (25 samples), 6 years (68 samples) and mature stage were 85.5, 89.3 and 84.9% respectively.

Conclusions

Geographic variation in bark quality, particularly regarding extractive yields, tannin and polyflavanoid contents, was found in even-aged populations of *Acacia mearnsii* in China. On the driest site, the bark quality of inland provenances is superior to that of coastal ones, while on the more humid sites, southern provenances were better than northern ones. The seedlots from South Africa-Brazil were superior in bark quality to native provenances in Australia, reflecting genetic improvement of this species in these two countries. The five local (Chinese) seedlots, which were selected from commercial plantings and adapted to exotic conditions, are similar to native provenances from Victoria.

No large variations for Stiasny values were found at provenance or state levels, or age of stands.

The results indicate that provenances from Victoria, South Africa-Brazil and China contain more tannin and polyflavanoid than those from New South Wales and are more suitable for leather tanning and waterproof wood adhesives in these respects. In an overall evaluation, other factors such as growth rates and frost tolerance, reported elsewhere in these proceedings, may also be considered.

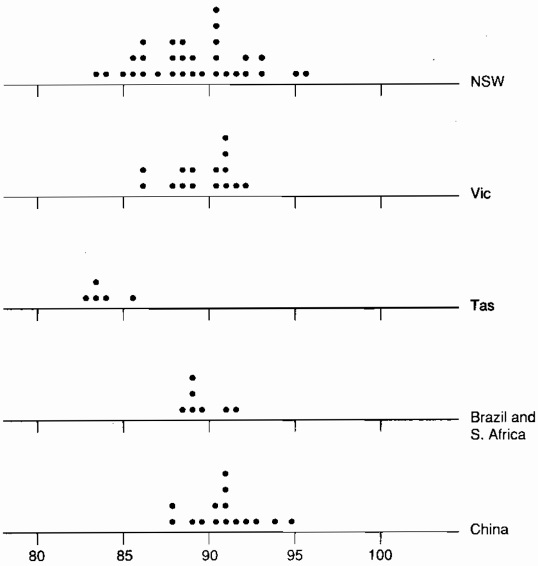

Fig. 4. Dot plot showing the distribution of Stiasny values (%) at state level.

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Appendix 1

Quality analyses of black wattle bark samples

Gu Renxia* and Y. Yazaki**

Samples

Air-dried bark samples from 93 *A. mearnsii* trees were provided by the Research Institute of Subtropical Forestry, Fuyang. Bark preparation for tannin analysis was carried out according to the Chinese Standard, in which the bark samples were ground to pass through a 3-mm retaining screen in a Wiley mill and the ground bark samples were then stored in glass jars at room temperature prior to analysis.

Extraction

A small Soxhlet-type extractor designed for extraction from small bark samples (ca 0.5 g) (Fig. 5) was used for the tannin analysis of the 93 samples. The table below demonstrates the close results obtained from the small extractor in comparison with a standard extractor (ALCA).

Sample code	Extractor type	Dry sample (g)	Time of extraction (min)	Volume of extraction (ml)	Total solids (%)	Tannin content (%)	Stiasny value (%)
A	Small-sized	0.4665	35	250	59.0	44.0	92.9
	ALCA	17.0183	210	2000	58.1	43.2	92.9
B	Small-sized	0.4711	25	250	50.9	34.2	86.2
	ALCA	18.1010	240	2000	51.2	34.7	86.5
C	Small-sized	0.4663	28	250	54.1	37.0	86.0
	ALCA	18.3175	240	2000	54.9	38.0	86.5
D	Small-sized	0.4812	25	250	63.8	46.0	87.1
	ALCA	18.1910	270	2000	64.3	46.8	88.1

The ground bark (ca 0.5 g) from each tree was extracted with hot water (250 ml) using the small extractor, and total solids and UV absorption (A) were determined.

Moisture content

Samples of ground bark (1–2 g) from each tree were oven-dried at 105 °C for 2 hours, cooled in a desiccator containing silica gel for 30 minutes, weighed, again dried at 105 °C for 1 hour, cooled in the dessicator for 30 minutes and weighed. The samples were classified dry when the weight difference between two determinations was less than 1 mg. The bark moisture content was calculated as follows:

$$\text{Moisture content (\%)} = \frac{\text{dried solids (50 ml)} \times 5}{\text{oven-dried bark weight}} \times 100$$

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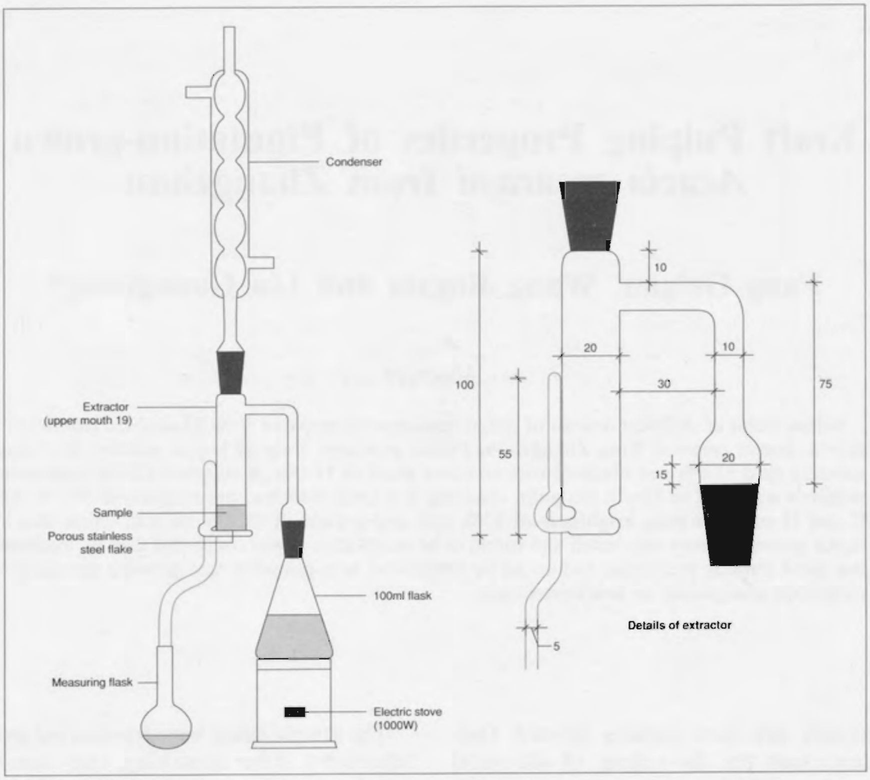

Fig. 5. Details of small Soxhlet-type extractor for use with small bark samples.

UV value

A 5.0 ml aliquot of the 250 ml extract solution was diluted to 100 ml with 0.1% $NaHSO_3$ aqueous solution and the UV absorption (A) was determined at 280 nm, using a Chinese ultra-violet spectrophotometer Model 75. The UV spectrophotometer was standardised using benzoic acid solution according to Roux (1951). The UV values were calculated according to the following equations (Yazaki et al. 1993):

$$E = \frac{A \times 2.5 \times 20}{\text{total solids}} \qquad \text{UV value} = \frac{E}{120.4} \times 100$$

E = absorptivity (total solids)
120.4 = absorptivity of standard sample

Tannin content, Stiasny value and polyflavanoid content

Tannin contents of the bark samples and Stiasny values of the corresponding extracts were estimated according to the following equations (Yazaki et al. 1993):

$$\text{Tannin content } (\%) = -38.1 + 0.871 \times \text{total solids} + 0.353 \times \text{UV value}$$
$$\text{Stiasny value } (\%) = 13.3 + 0.915 \times \text{UV value}$$

Furthermore, approximate estimates of polyflavanoid contents in the bark samples were calculated by multiplying total solids by Stiasny values and dividing by 100. The experiments were repeated four times and the mean values were taken for the analysis of bark quality.

Kraft Pulping Properties of Plantation-grown *Acacia mearnsii* from Zhangzhou

Fang Guigan, Wang Jingxia and Liu Guangliang*

Abstract

Sulfate pulps of different degrees of delignification were prepared from 13-year-old plantation-grown *Acacia mearnsii* from Zhangzhou, Fujian province. Pulp of kappa number 20.8 and screened yield 52.6% was obtained with an active alkali of 11.0%. A standard CEHD bleaching sequence was used to bleach the pulp, resulting in a total chlorine consumption of 5% in the C and H stages, a pulp brightness of 82% ISO and a yield of 49.2% on o.d. chips. Black liquor properties were also tested and found to be acceptable. It was concluded that *A. mearnsii* has good pulping properties and could be considered as a potential fast-growing species for pulpwood plantations in southern China.

MANY countries are now turning toward fast-growing plantations for the supply of industrial wood. If the plantations are to be grown to supply pulpwood, it is necessary to assess pulpwood quality when choosing suitable species.

Many acacia species have been tested in China during the joint ACIAR/CAF projects. Some of these are growing well and have been identified as having good potential for tropical and subtropical plantations (Brown 1990). Several acacias are reported to have good pulping properties (Logan and Balodis 1982; Logan 1987; Fang et al. 1991a; Clark et al. 1991). The aim of Project 8849, sub-project D, is to assess the wood and pulpwood properties of acacias from Chinese plantation trials.

This paper reports results for a sample of *Acacia mearnsii*, to be used as a standard for comparisons with wood from the ACIAR trials.

Materials and Methods

Five 13-year-old trees were sampled by the Forestry Bureau of Zhangzhou. The trees ranged in breast height diameter from 32 to 47 cm and in merchantable height from 8.0 to 10.8 m.

The sample stems were transported to the Nanjing laboratory. After debarking, each stem was divided into butt, middle and top logs, and several 25 mm disks were cut from each log. The disks were chipped in a laboratory chipper and the chips mixed to form separate composite samples representing the three parts of the trees. The composites were air-dried for one month, then stored in sealed plastic bags.

The basic densities of the composite woodchip samples were determined using Australian Standard AS 1301.1s-79. For kraft pulping, chips were mixed in a volume ratio of 4:3:2 for the butt, middle and top logs respectively. Sub-samples of the chip mixture were separately pulped in stainless steel vessels of 3-litre capacity in an air bath with active alkali levels ranging from 10 to 13% (as Na_2O on o.d. chips). The pulping conditions were: 500 g o.d. wood, 3.5:1 liquor to wood ratio, 25% sulfidity (as Na_2O), 75 minutes to bring to temperature, then 2 hours at 170 °C. The Kappa numbers of the screened pulps were measured according to Appita standard method P201m-86.

To bleach the pulp of Kappa number about 20, a standard CEHD sequence was used. The conditions are listed in Table 1. Pulp brightness was measured with a SBD brightness tester according to China National Standard GB8940.2-88.

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Black liquor swelling volume, which is an indication of the likely burning properties of the black liquor, was measured according to the method developed by Baklien (1960). To determine flow characteristics, black liquor viscosity at 40% total solids was interpolated from viscosity measurements at 40 °C over a range of black liquor concentrations.

Results and Discussion

The wood and pulping properties are given in Table 2. Basic density is an important factor in the assessment of pulpwood quality. It affects transport costs, the pulp production capacity of the digester, and the relationship between wood volume and pulp production rate (i.e. pulpwood productivity). The basic density of the Chinese *A. mearnsii* was within the range of commercial pulpwoods and similar to those of native-grown trees from the south coast of NSW and plantation-grown trees from South Africa. The Chinese *A. mearnsii* was significantly denser than *A. mangium* from Sabah, Malaysia, and slightly denser than *Mytilaoria laosensis*, a very fast-growing hardwood species native to China. The results for this species are based on five-tree samples from Guangxi Province (Fang et al. 1991b).

To reach a Kappa number of 20.8, the Chinese *A. mearnsii* required 11% active alkali (as Na_2O on o.d. wood). This was lower than the alkali requirements of the NSW and South African trees, and lower than that required for *A. mangium* and *M. laosensis*.

Table 1. Conditions used for standard CEHD bleaching sequence.

Bleaching stage	Reagent	Concentration of reagent (% on o.d.pulp)	Stock concentration (% o.d.)	Temp. (°C)	Time (hr)
C	Cl_2/H_2O	*	3	20	1
E	NaOh	1.5	12	60	1
H	NaOCl	1.5	10	40	2
	NaOH	0.5			
D	ClO_2	0.5	6	70	2
	NaOH	0.25			

* Concentration based on chlorine demand of unbleached pulp is given in Table 3.

Table 2. Wood and kraft pulping properties of acacias.

Species and origin of sample	Tree age (yr)	Basic density (kg/m^3)	Active alkali (%Na_2O)	Screened yield (%)	Screen rejects (%)	Kappa no.	PP# (kg/m^3)
A.mearnsii	13	595	10.0	51.0	5.8	35.7	
Zhangzhou, China			10.5	52.0	2.5	24.5	
			11.0	52.6	1.1	20.8*	313
			12.0	50.8	0.6	16.6	
			13.0	51.0	0.2	15.3	
Batemans Bay, NSW[1]	—	608	13.0	52.8	1.6	20.0	321
South Africa[2]	10	598	13.0	52.4	1.7	21.0	313
Acacia mangium[3]	9	420	14.0	52.3	0.1	21.0	220
Sabah, Malaysia							
Mytilaoria laosensis[4]	6	524	12.5	44.6	—	19.0	231
Guangxi, China	15	540	13.0	45.0	—	18.5	243

\# Pulpwood productivity = Basic density × screened yield / 100
* This pulp used later for bleaching
[1] Fang et al. 1991a
[2] Logan 1987
[3] Logan and Balodis 1982
[4] 4 Fang et al. 1991b

Screened pulp yield was almost identical to the yields from all the other samples except *M. laosensis*, which was significantly lower. Pulpwood productivity was similar to those of the other *A. mearnsii* samples but significantly higher than those of both *A. mangium* and *M. laosensis*.

The bleaching results are given in Table 3. For the Chinese *A. mearnsii* pulp, chlorine demand and total chlorine consumption in the C and H stages was lower than for the pulps from the other samples, and, except for *A. mangium*, pulp brightness was higher. Bleached pulp yield on o.d. unbleached fibre basis was a little lower than the other samples, but on o.d. wood basis, comparable or higher.

The black liquor properties are detailed in Table 4. Both swelling volume and viscosity were good, indicating few problems in the recovery process.

Conclusions

The basic density of the Chinese plantation-grown *A. mearnsii* woodchips was 595 kg/m^3. The wood could be pulped with the kraft process to a Kappa number of 20.8 with only 11.0% active alkali and gave a screened yield of 52.6%. The kraft pulp could be bleached to a brightness of more than 82% ISO with a CEHD sequence, consuming just over 5% total chlorine at a bleached pulp yield of 49.2% on o.d. wood. The black liquor properties were good and should not cause problems for chemical recovery operations.

Acknowledgements

The sample was supplied by Mr Fang Yulin from the Forestry Bureau of Zhangzhou. The work was

Table 3. Results for bleached kraft pulps.

Property	*Acacia mearnsii* Zhangzhou	 Batemans Bay[1]	*Acacia mangium* Sabah[2]	*Mytilaoria laosensis* Guangxi[3]
Chlorine demand (%)	4.5	5.1	4.6	5.1
Total chlorine used in C and H stages (%)	5.0	6.2	6.1	5.2
Pulp yield (%)				
on unbleached pulp	93.6	94.5	95.6	
on o.d. wood	49.2	49.9	50.9	42.5
Pulp brightness (%ISO)	82.5	81.2	86.8	—
Handsheet brightness (%ISO)	81.0	77.1	—	78.1

[1] Fang et al. 1991a
[2] Logan and Balodis 1982
[3] Fang et al. 1991b

Table 4. Properties of kraft black liquors from acacias.

Property	*Acacia mearnsii* Zhangzhou	 Batemans Bay[1]	*Acacia mangium* Sabah[2]	*Mytilaoria laosensis* Guangxi[3]
Active alkali (%Na_2O)	11.0	13.0	13.5	13.0
Kappa number	20.8	20.0	20.9	18.5
Total solids (TS) of unevaporated black liquor (%)	16.6	14.4	14.1	17.8
Swelling volume (ml/g TS)	41	25	45	83
Viscosity at 40% TS (mPa.s)	17	43	21	54

[1] Fang et al. 1991a
[2] Logan and Balodis 1982
[3] Yang et al. 1991

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A Rapid Analysis Method for Tannin Content of Black Wattle (*Acacia mearnsii*) Bark

Y. Yazaki*, R. Gu**, Y. Lin** and W. Chen**

Abstract

A rapid and reliable method for tannin analysis is vitally important for the ACIAR projects on black wattle silviculture in China. Principles, advantages and disadvantages of the hide-powder, the Stiasny and the ultra-violet (UV) methods for tannin analysis are outlined. Results obtained from the ACIAR project research are briefly reviewed, particularly with a view to developing a simple and rapid analysis method. Based on the analyses of black wattle tannins by these three methods and statistical analyses, it is concluded that tannin contents for leather tanning can be predicted from a combination of total solids and UV absorptivity, and Stiasny values for wood adhesives from the UV absorptivity. Thus, the laborious and time consuming hide-powder and the Stiasny methods can now be replaced with the simple UV method.

BLACK wattle (*Acacia mearnsii* de Wild.) grows naturally on the mainland of south-eastern Australia and in Tasmania. The bark of black wattle contains significant amounts of water-soluble components, known as *wattle tannins*. The major components of the wattle tannins are polyflavanoid (C_6-C_3-C_6 compounds) in nature (Roux and Maihs 1960), and the condensation products of such polyflavanoids with formaldehyde have been used as a basis for *wattle tannin adhesives* used in particleboard, plywood, laminated timber and other reconstituted wood products (Plomley 1966).

Black wattle plantations have been established in South Africa, eastern Africa and South America, where wattle tannins are commercially produced for leather tanning, wood adhesives and some other uses. The largest black wattle plantations have been established in South Africa and cover 160 000 ha (Boucher 1980), the original seed having been introduced from Australia. Natural stands of black wattle were stripped for bark in Australia and today tannin needs in Australia are met by imports mainly from South Africa.

Black wattle was introduced into China in the 1950s, but was only recently identified by the Chinese government as a promising species for tannin production.

In 1985, ACIAR collaborated with the Chinese Academy of Forestry on research into 'Wattle silviculture and the utilization of tannin extracts' and this project has been extended to 'Wattle silviculture and pulping studies' since 1989. The Chinese Academy of Forestry, Research Institute of Chemical Processing and Utilization of Forest Products, Nanjing, has been involved in research on analysis of tannins and utilisation of tannins as wood adhesives. Development of a rapid and reliable method for tannin analysis is vitally important for the ACIAR project on wattle silviculture in China, where new genetic resources of black wattle have been introduced from Australia through the establishment of provenance trials and progeny trials/seed orchards.

Tannin Analysis Methods

Hide-powder method

The term *tannin* has been used to denote those substances responsible for leather formation and found to be of a polyflavanoid nature. However only some of the phenolic compounds in tannin extracts can form leather. The smaller molecular weight polyflavanoids do not tan; a minimum molecular weight

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of about 500 appears to be essential. True affinity effects of polyflavanoids for collagen develop at the triflavanoid level (m.w. 800) and thereafter increase rapidly with increasing mass (Roux 1955). However, when molecular weight exceeds 3000, penetration of the polyflavanoids into collagen fibrils in hide is poor so that inadequate tanning occurs.

In order to assess the quality of a tannin extract for manufacture of leather, the most direct method, called the hide-powder method, is to mix a tannin extract with pulverised hide of known activity and to determine the amount of reactive material removed from the extract. The method requires a predetermined amount of ground bark sample to be extracted in a specified type of extractor. The 2 litres of extract obtained must contain tannin within certain limits (8.0 ± 0.5 g). Aliquots of this extract are used to determine total solids, total solubles and tannin materials. The determination of tannin materials involves shaking the aliquot with a specified amount of an approved hide-powder that has been freshly moistened and reacted with a chrome alum solution of specified strength. After mixing for a specified period, the mixture is filtered and the weight of evaporated aliquot is defined as non-tannin. The tannin matter absorbed by hide-powder is defined as the difference between the percentages of total solubles and non-tannins in the extract.

According to the Chinese Standard GB 2615-81, this method requires 15–20 g of powdered bark or approximately 4 g of dried extract for a single tannin determination and takes several days to complete an analysis.

Stiasny method

The major components of wattle tannin belong to a group described as *condensed tannin* which consists of flavanoid units (mainly flavan-3-ols) and which has been condensed to varying degrees. The distinctive flavan-3-ol units of wattle tannin are (-)-fisetinidol and (-)-robinetinidol, which consist of resorcinol for the A ring and catechol and pyrogallol respectively for the B ring. Formaldehyde reacts with these flavanoids to produce insoluble polymers through methylene linkages to reactive positions of mainly the A rings of the polyflavanoid molecules. This is the fundamental reaction for wattle tannin adhesives.

A direct method for determining these polyflavanoids including monomers and polymers in the extract is the reaction with formaldehyde. The Stiasny formaldehyde-hydrochloric acid test for the tannin was originally developed by Stiasny in 1905. Later Wissing (1955) studied a similar method using tannin aqueous solutions as starting materials and found that comparable results were obtained only when the reaction was carried out on solutions of the same concentration of tannin material and within a narrow pH range in the acid region. In order to overcome these problems, Yazaki and Hillis (1980) further developed the Stiasny method, using dried tannin extracts as starting materials and obtaining more reliable results. Dried samples (100 mg) dissolved in water (10 mL) and heated under reflux with 37% formaldehyde (2 mL) and 10 N hydrochloric acid (1 mL) for 30 minutes yielded a precipitate which could be filtered, washed and dried. The procedure enables 10 samples of dried tannin extract to be analysed by one person daily to give reproducible results.

This Stiasny method therefore has been regarded as a rapid and reliable method for estimating the amount of polyflavanoid components in tannin extracts which are used for wood adhesives.

Ultra-violet (UV) method

Organic compounds containing resonating structures such as phenyl, naphthyl, carbonyl and nitro groups absorb radiant energy in the ultra-violet (UV) and visible regions of the spectrum. Thus, phenolic compounds show strong absorption in the UV region, particularly 250–280 nm, whilst non-resonating structures such as most carbohydrates are completely transparent.

Since deviations from Beer's Law are less frequently encountered in the UV region and the absorption is a function of the phenolic content of the tannin solution, the UV method could be very suitable for quantitative analyses. Roux (1951) developed the UV method for tannin analysis which has been shown to be highly reproducible. However, since polyflavanoid monomeric and dimeric components were not adsorbed on to protein, the results from the UV method did not agree with those from the hide-powder method (Roux 1957; Gordon-Gray 1957). Furthermore, tannin extract from black wattle bark contains polyphenols which do not react with formaldehyde. Therefore, results from the UV method would not be expected to agree with those from the Stiasny method.

However, the UV method requires only small amounts of tannin material (normally 10 mg) and the speed and simplicity of this method are extremely attractive.

Details of chemical structures of components contained in wattle tannin extract are shown in Figures 1–5, and the components and their responses to collagen, formaldehyde and UV at 280 nm are summarised in Table 1.

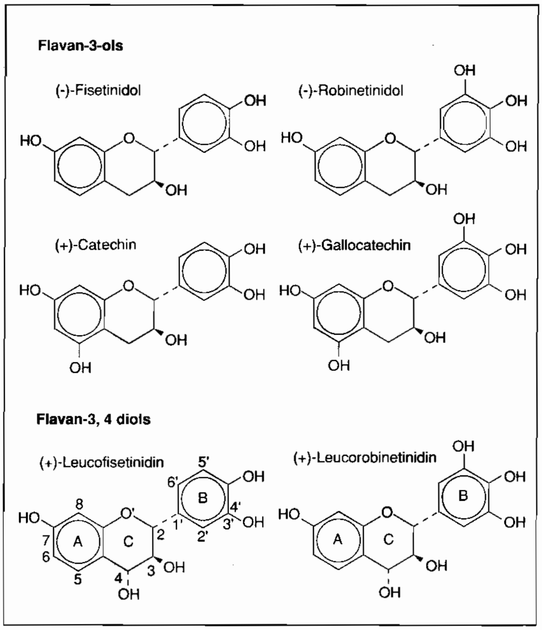
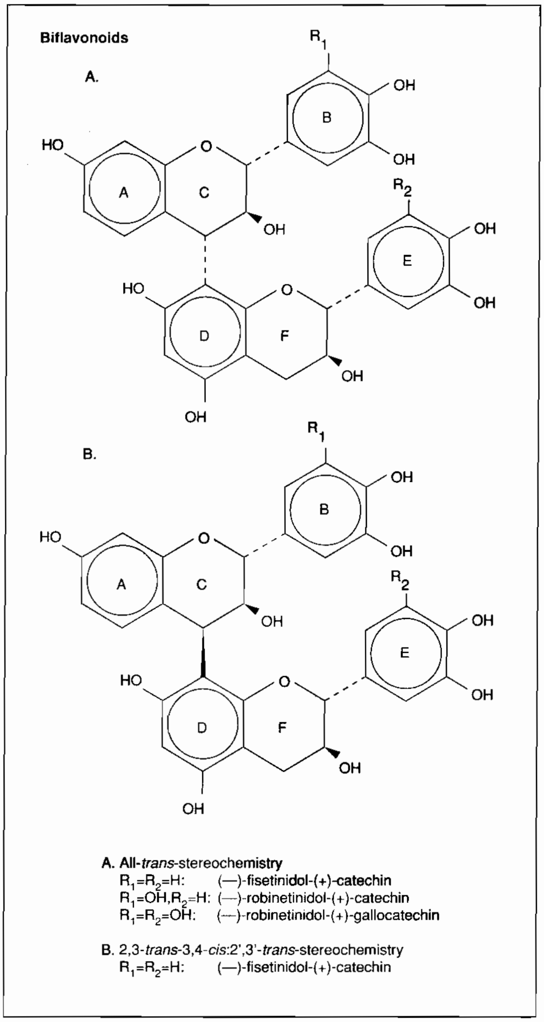


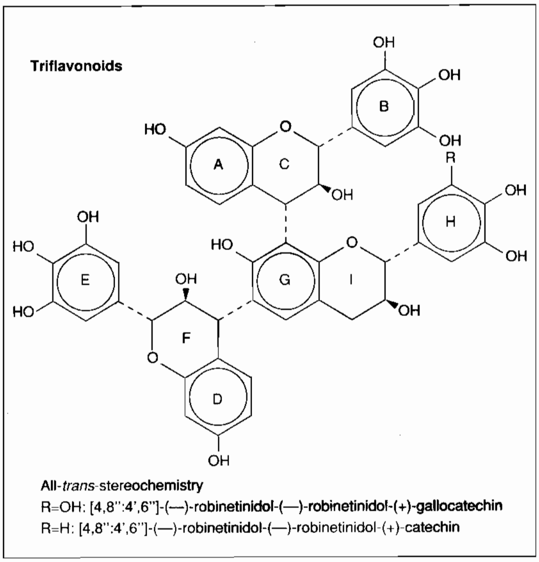
Fig. 1. Flavan-3-ols and flavan-3,4 diols contained in wattle tannin extract.



A. All-*trans*-stereochemistry
R_1=R_2=H: (—)-fisetinidol-(+)-catechin
R_1=OH,R_2=H: (—)-robinetinidol-(+)-catechin
R_1=R_2=OH: (—)-robinetinidol-(+)-gallocatechin

B. 2,3-*trans*-3,4-*cis*:2',3'-*trans*-stereochemistry
R_1=R_2=H: (—)-fisetinidol-(+)-catechin

Fig. 2. Dimers of flavan-3-ols contained in watle tannin extract.



All-*trans*-stereochemistry
R=OH: [4,8":4',6"]-(—)-robinetinidol-(—)-robinetinidol-(+)-gallocatechin
R=H: [4,8":4',6"]-(—)-robinetinidol-(—)-robinetinidol-(+)-catechin

Fig. 3. Trimers of flavan-3-ols contained in wattle tannin extract.

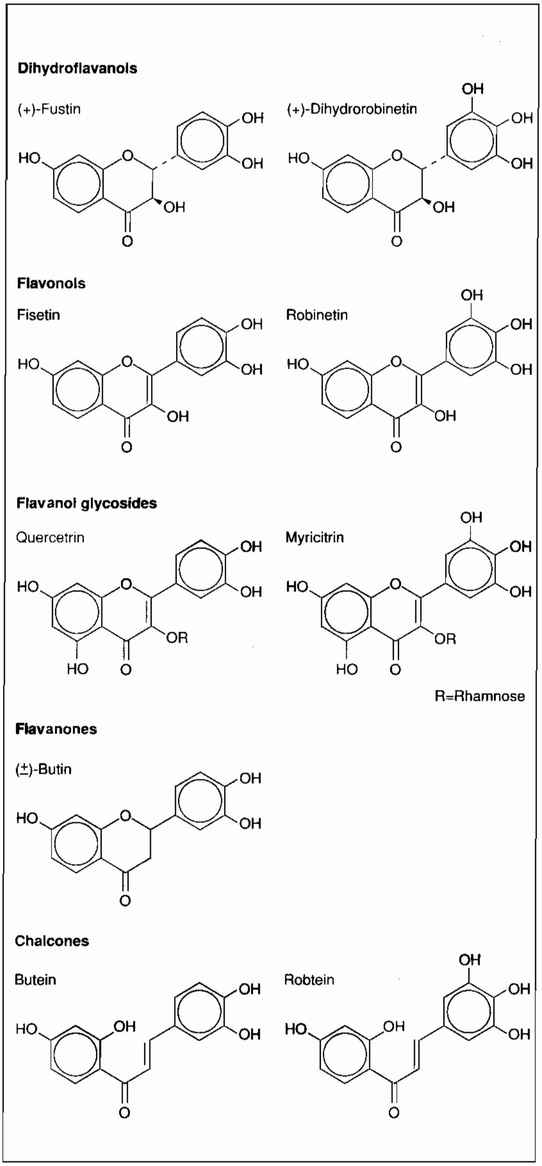


Fig. 4. Other flavonoid compounds contained in wattle tannin extract.

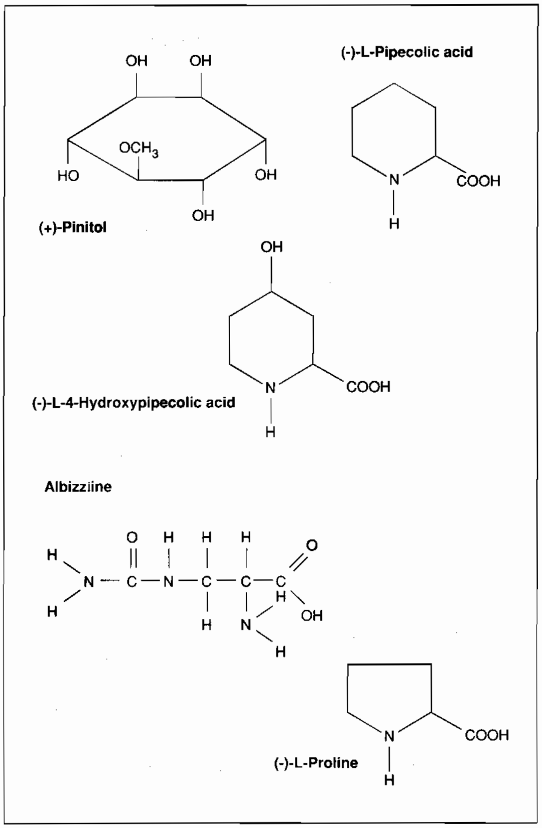


Fig. 5. A carbohydrate and some nitrogenous compounds contained in wattle tannin extract.

Table 1. Components of wattle tannin extract and their responses to collagen, formaldehyde and UV at 280 nm.

Component	Collagen	Formaldehyde	UV at 280 nm
Flavan-3-ols and flavan-3,4-diols	–	+	+
Dimers of flavan-3-ols	–	+	+
Trimers, polymers of flavan-3-ols	+	+	+
Other flavonoid compounds	–	–	+
Carbohydrates and N compounds	–	–	–

'Standard' Wattle Tannin

There is no pure wattle tannin which satisfies both hide-powder and Stiasny analyses. Furthermore, since the above three methods are based on three different principles, it was necessary to find how various fractions of a wattle tannin responded to these three methods. A Chinese laboratory-prepared wattle tannin (Zheng et al. 1988) was fractionated into six fractions using centrifugation, solvent extraction and ultrafiltration. The experimental details have been described elsewhere (Yazaki et al. 1992). These six fractions and the original wattle tannin were analysed by the three methods. The hide-powder method was carried out according to the Chinese Standard and the Stiasny method was based on the dried samples. For the UV method, the UV spectrophotometer was standardisd according to Roux (1951). Based on the absorbance at 280 nm, absorptivity (a) values of tannin solutions were obtained according to the equation $a = A/bc$ where a is absorptivity, A is absorbance, b is sample pathlength (cm) and c is concentration of the substance (mg/cm^3). Details of results have been published by Yazaki et al.(1992). Since the ethyl acetate soluble fraction gave the highest values in the Stiasny and the hide-powder methods, this was regarded as the standard tannin fraction. Consequently, these values (i.e. 108.9, 120.4 (10a) and 93.0 for the Stiasny, the UV and the hide-powder methods, respectively) were used as standards for the three methods. Based on this, the percentage of wattle tannin in each fraction was calculated.

These results revealed that for more than 94% by weight of the wattle tannin, comprising ethyl acetate solubles, retentate $>10^4$, retentate $<10^4$ and filtrate fractions, the amounts of tannin content were extremely similar and correlated significantly for the three methods. However, for the insolubles and ether soluble fractions, amounting to less than 6% by weight, the tannin contents obtained by the three methods were significantly different. Consequently, the overall tannin contents of the original wattle tannin were expected to be very similar and proved to be almost the same (87.6, 87.5 and 87.2%) for the Stiasny, the UV and the hide-powder methods respectively (Yazaki et al. 1992).

The above results indicate that the UV method may be very useful for predicting values for the Stiasny and the hide-powder methods when the ethyl acetate soluble fraction is used as a standard.

Analyses of Bark Samples

Bark samples of 94 individual black wattle trees were collected from 20 provenances across the species' natural distribution in Australia. These 94 bark samples were analysed by the Stiasny method with a view to providing estimates of the polyflavanoid compounds reactive with formaldehyde in adhesive formation. Details of selection of provenances, sampling of barks and analytical results have been published previously (Yazaki et al. 1990).

After bark samples of trees from the same provenances were combined, the tannin content of bark from 18 of the 20 provenances was determined by both the hide-powder and Stiasny methods. The remaining two samples could not be analysed because insufficient bark was available for the hide-powder method which required more than 40 g of bark for each analysis. The results were analysed statistically to test the correlation between these two methods. The statistical analysis revealed that the Stiasny values cannot be used to predict tannin content for the treatment of leather, although the correlation between tannin content in the total solids from the hide-powder and Stiasny values was marginally significant (Zheng et al. 1992).

In the meantime, the Chinese Academy of Forestry, Research Institute of Chemical Processing and Utilization of Forest Products, Nanjing established the UV method for tannin analysis as described above. This UV method was used to determine tannin content of the 18 tannin extracts, which had been analysed previously by the hide-powder and the Stiasny method, and the tannin analysis by the Stiasny method was repeated. The results obtained by these three methods were analysed statistically to find any relationships among the results with a desire to replace the hide-powder and the Stiasny methods with the UV method. Details of this experiment and results have been published elsewhere (Yazaki et al. 1992).

The correlation between tannin content and total solids is highly significant and this correlation can be further improved by including UV data in the regression equation. The regression equation is as follows:

$$\text{Tannin content} = -38.1 + 0.871 \text{ total solids} + 0.353 \text{ UV}$$

During the determination of Stiasny values the filtration procedure for Stiasny precipitates using some batches of glass filters was found to affect subsequent Stiasny values. This was due to the damage of the surface of a glass filter by scraping, because it required frequent stirring of the suspension before vacuum filtration. Therefore, Stiasny value determination was carried out without scraping the surface of the glass filter and at the same time another set of UV determinations was carried out.

A highly significant correlation has been found between the Stiasny value and UV results and the following regression equation has been obtained:

$$\text{Stiasny value} = 13.3 + 0.915 \text{ UV}$$

Conclusions

The tannin content for leather tanning can be predicted with high accuracy by obtaining total solids, using the hide-powder method and UV absorptivity by the UV method. Furthermore, the UV method can be used to predict the Stiasny value of the wattle tannin extract for wood adhesives.

Thus, the UV method is a rapid and simple procedure which can be used to estimate both tannin content and Stiasny values. It could prove to be particularly useful in selection for high tannin content of provenances or progenies where a large number of tannin analyses are required.

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