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Agroforestry with High Value Trees

by Dr David Lamb, University of Queensland and
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RIRDC/LWRRDC/FWPRDC Joint Venture Agroforestry Program
Supported by the Natural Heritage Trust and the Murray Darling
Basin Commission

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ISBN 0 642 57833 8
ISSN 1440-6845

Agroforestry with High Value Trees
Publication no 98/142
Project no. UQ-18A

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Published in December 1998
Printed on environmentally friendly paper by Union Offset

Foreword

Until recently the local supply of high-quality tropical rainforest timbers came almost entirely from state forests in Queensland's wet tropics. Logging in these forests ceased in 1988 at the time of listing of the World Heritage Area, causing a substantial decline in the supply of these timbers to the market. An obvious question to ask is whether some of these high-value species might be grown in plantations?

This report describes the early results of two trials undertaken to examine the growth of several high-value rainforest tree species when grown in farm plantations in southeast Queensland.

The first trial was established to examine the potential for growing trees in a farm woodlot where the landowner was prepared to devote the land exclusively to this purpose. The second trial was established to examine the potential for combining pasture production and tree growing on the same land.

This report, the latest addition to RIRDC's diverse range of over 250 research publications, forms part of the Joint Venture Agroforestry Program, which is jointly funded by RIRDC, the Land and Water Resources Research and Development Corporation, and the Forest and Wood Products Research and Development Corporation. Additional funding also comes from the Natural Heritage Trust and the Murray Darling Basin Commission. The JVAP aims to integrate sustainable and productive agroforestry within Australian farming systems.

Peter Core

Managing Director

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Acknowledgements

This project has been carried out with the assistance of a large number of people. Geoff Borschmann, now with Greening Australia, has been involved in all aspects of the work from the earliest stages and has been responsible for most of the day to day operations. He has also collaborated in the preparation of this report and should be seen as a co-author. David Cameron was also involved in the early stages and made a critical contribution to designing the original trials. Without his efforts it is unlikely the project would have been established. Others who have helped in a variety of ways include Jim Johnson, Peter Lawrence, Alex Hajkowicz, Lindsay Hutley, Oliver Woldring, Steve Howell and a number of volunteers from Greening Australia and students from the University of Queensland.

We would also like to particularly acknowledge the contribution made by Don and Audry Pickering on whose land the trials have been established. The early constraints imposed by the trial on grazing, especially in the dry weather of 1991, were greater than any of us expected but Don and Audrey were magnificent in helping us manage during a difficult stage. They have also been generous in allowing access to their land for a large number of student workers over the years.

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Executive Summary

This report describes the early results of two trials undertaken to examine the growth of several high-value rainforest tree species when grown in farm plantations in SE Queensland.

The first trial was established to examine the potential for growing trees in a farm woodlot where the landowner was prepared to devote the land exclusively to this purpose. In this case the study compared the growth of 16 rainforest tree species grown in a mixed species plantation established at 3 m spacings.

The second trial was established to examine the potential for combining pasture production and tree growing on the same land. In this case the trial compared the growth of several trees (*Araucaria cunninghamii* and *Flindersia brayleyana*) grown at a range of tree spacings and also monitored the effect of tree density on pasture production.

In the woodlot study there was, as expected, a large variation in the growth rates of the 16 species but, overall, the rates achieved were often higher than measured with many of these species before. At six years of age the most promising species (in terms of height growth and form) were *Elaeocarpus grandis* and *Grevillea robusta*, with *Acacia melanoxylon* and *Cedrela odorata* also achieving rapid growth but suffering from poorer form or some insect problems. Other promising species included *Flindersia brayleyana* and *Khaya nyassica*. There was evidence of scope for improved tree form and vigour in most species by better seed selection.

In the spacing trial, both tree species had faster initial tree height growth at higher tree densities although signs of a competitive inhibition of tree height growth at higher densities were becoming evident after six years. By contrast *Araucaria cunninghamii* diameter growth was reduced by high tree density from an early age. This inhibitory effect did not occur in the case of *Flindersia brayleyana*.

Pasture growth was unaffected by tree growth until the trees were in their fourth year. From that stage on there was evidence of a reduction in pasture growth at tree stockings of more than several hundred trees per hectare. For several years there appeared to be some evidence of an improvement in pasture production at intermediate tree stockings (100-300 trees per hectare) under *Araucaria cunninghamii* over the production found at wider spacings. There was no evidence of the same effect under *Flindersia brayleyana*. However, this effect has disappeared in more recent years. Currently (at age 6.5 years) pasture growth appears to be only reduced at tree stockings of 150 trees per hectare or more.

Background to the Research

Until recently the local supply of high-quality tropical rainforest timbers came almost entirely from state forests in Queensland's wet tropics. Logging in these forests ceased in 1988 at the time of listing of the World Heritage Area, causing a substantial decline in the supply of these timbers to the market. This decline comes before an anticipated decrease in the supply of high-quality cabinet timbers imported from the SE Asian region caused by unsustainable logging practices, the clearing of land for agriculture or because of the exclusion of logging in these rainforests for other reasons. This means the overall availability of high-value rainforest timbers is likely to decline substantially in future years.

An obvious question to ask is whether some of these high-value species might be grown in plantations? In fact, trials to test the growth of some of these species were first carried out over 60 years ago in various parts of Queensland by the Queensland Forest Service (now DPI Forestry) and a recent review of some of these trials is given in Cameron and Jermyn (1991). Although the growth of many species was promising, only one rainforest tree - hoop pine (*Araucaria cunninghamii*) - was ever subsequently used in commercial plantations. There were probably several reasons for this. One was that the necessarily smaller diameter plantation-grown trees were never going to be as attractive to industry as the larger logs then still available from natural forest. A second reason was that most of these trees grew comparatively slowly, especially compared with fast growing exotics such as *Pinus* species. And finally, the real value of these timbers was underpriced in the marketplace such that the disadvantage of this slower growth rate could not be overcome by price, despite the much higher timber quality.

The cessation of logging in natural forests has changed these circumstances and means that it is now worth reconsidering growing some of these rainforest species in plantations. The early trials provide some guidance in assessing which species might be used but, unfortunately, not much else. As noted above, many of these trials were established over 60 years ago when nursery techniques, establishment methods and the need for rigorous weed control were less well developed or appreciated than they are today. This suggests that the growth rates achieved then are rather less than could be achieved now if the methods established for present-day commercial pine or eucalypt plantations were used.

Notwithstanding these changed circumstances, commercial tree growing by private landowners is still a risky business. Plantation establishment methods can be expensive, rotations are long and there is a substantial delay before any financial return is made. And the nature of the future timber market, and thus the magnitude of the financial returns, is very unclear, even allowing for the expectation that there will always be a premium paid for quality timbers.

There are three possible ways in which a landowner might act to reduce these negative factors.

(i) *by using species that have above-average market value but which also grow quickly.*

While past experience suggests many commercially valuable rainforest species are always slow-growing in plantations, this might not be the case if trees are given good site preparation, weed control and fertilizer treatments. Perhaps a more careful examination of a wider variety of species grown under more favourable conditions might suggest other rainforest species suitable for commercial plantations in addition to just *Araucaria cunninghamii*.

(ii) *by combining tree growing with some other land use to obtain additional, non-timber market benefits.*

Production synergies involving tree growing and other agricultural pursuits, such as pastoralism, are well documented (e.g. Daly 1984, Sun and Dickenson 1994, Bird et al. 1991). The design of these agroforestry systems requires an understanding of the interactions between the design components, and

to some extent, quantification of these relationships. The interactions between many potentially useful agroforestry tree and pasture components have not been the subject of much research effort in the sub-tropical Australian environment. Such research would enable a greater deal of certainty in predicting the production outcomes of agroforestry system designs [for example using software such as FARMTREE (Loan 1994) and the Agroforestry Estate Model (Knowles and Middlemiss 1994)].

(iii) *by growing trees in such a way as to create other, non-market benefits such as wildlife habitats or other “conservation” benefits over the period before harvesting takes place.*

Tree plantations confer benefits to landowners beyond just the timber they contain. Such benefits may be less easily achieved, however, using the plantation monocultures that are the most common plantation design currently planted. For example, monocultures are probably less attractive as wildlife habitats than mixed species plantations. There are also various theoretical reasons why mixtures might have some ecological and production benefits over monocultures as well. These include reduced insect and disease problems, nutritional advantages and a more efficient use of site resources (Kelty 1992).

Field situations where the merits or disadvantages of these several options might be examined are limited and those that do exist are poorly documented. The present studies were therefore undertaken to examine the first two options in some detail. The work was carried out in such a way as to enable the third “conservation” option to be also examined at a later date when the trees have matured.

Objectives of the Project

- (1) To assess the growth potential of 16 high value cabinet timber trees growing in a plantation polyculture and to identify species worthy of use in timber plantations.
- (2) To assess tree and pasture production under a range of tree stocking rates and to assist the development of tree/pasture systems in which both trees and pasture maintain viable productivity.

Introductory Information about the Problem

There appear to be two alternative approaches that might be adopted by landowners interested in growing trees.

- (a) devote part of their land exclusively to tree growing, or
- (b) combine tree growing with another prior land use such as grazing.

For this reason two trials were established. The first was to compare the performance of a range of commercially attractive rainforest species when grown in a plantation under favourable conditions. Prior commercial harvesting operations in natural forests have defined those species having recognised market values. Little is known about how well these might grow in plantations. With the exception of *Araucaria cunninghamii*, none of these species have been subject to tree improvement programs and the plantation form and apical dominance of most species is poorly known. Likewise, little is known about their nutrition, spacing requirements or other silviculture needs.

Most timber plantations in Australia have used even-aged plantations of single species. The growing conditions in even-aged monocultural plantations are necessarily different to those in uneven aged natural forests and the consequences of such differences on growth rates and insect attack in most species are unknown. One well-known species which appears to do poorly in such even-aged monocultures is the well-known red cedar (*Toona ciliata*). This species is heavily attacked by the tip moth borer (*Hypsiphila robusta*) when grown in the open in monocultures but appears to be less heavily attacked when grown in mixed species plantings under some shade (Keenan *et al.* 1995). Little is known about the early requirements of other rainforest species but some have argued that many of these also require early shade.

For these reasons the first trial was designed as a mixed species planting. This had the advantage of allowing the early growth of a variety of species to be compared while also allowing those species that may require some early shading to achieve this from faster growing surrounding trees. At the same time, such a design also creates a forest that might be attractive to those landholders interested in combining production with some non-market values such as conservation or land protection (i.e. the third option referred to earlier).

There are few guidelines for designing species mixtures. Little is known, for example, about which species might be planted together and which species should not be combined. One criteria might be to use species with complimentary phenologies. That is, to plant together species that have their periods of growth out of phase. This would mean that competition for resources would be reduced and the overall efficiency in the use of the site's resources by the plantation could be maximised. For this reason a study of growth phenology was carried out using the species in this first trial

The second trial was an agroforestry study. The objective of this trial was to determine the tree spacing that could allow trees to be grown at a site while still maintaining pasture production. The closer the tree spacing the more likely it will be that any pasture will be shaded out. However, wide tree spacings that foster better pasture production also allow large lateral branches to develop on the trees. Such branches can give rise to knots in timber which is of major concern when the purpose of using rainforest trees is

to produce high-value timbers. The trial was therefore also used to study the effect of tree spacing on tree growth rate and tree form.

Research Methodology and Justification

Study Sites

The two studies were established at the property of D and M Pickering at Mt. Mee, about 70 km north of Brisbane (lat. 25 ° 05', longitude 152° 45') at an altitude of about 400 m. The sites were formerly occupied by rainforest but were probably cleared for dairying some 100 years ago. At the time of tree planting they contained pastures dominated by Kikuyu grass (*Penisetum clandaetinum*). The site used for the mixed species trial has a south western aspect and a slope of about 5°. It is exposed to sometimes strong south easterly and westerly winds. The site used for the agroforestry trial is about 1000 m away and faces east. It, too, has a slope of about 5°.

The area has a sub-tropical climate with a long-term average annual rainfall of 1514 mm, most of which falls in the summer months (records from Mt. Mee forestry station about 3 km distant). The average rainfall in the driest month of the year (August) is 41 mm. The rainfall during the period of the study included some of the driest years on record in the south east Queensland region and rainfall received over the period of the study is shown in Figure 1.

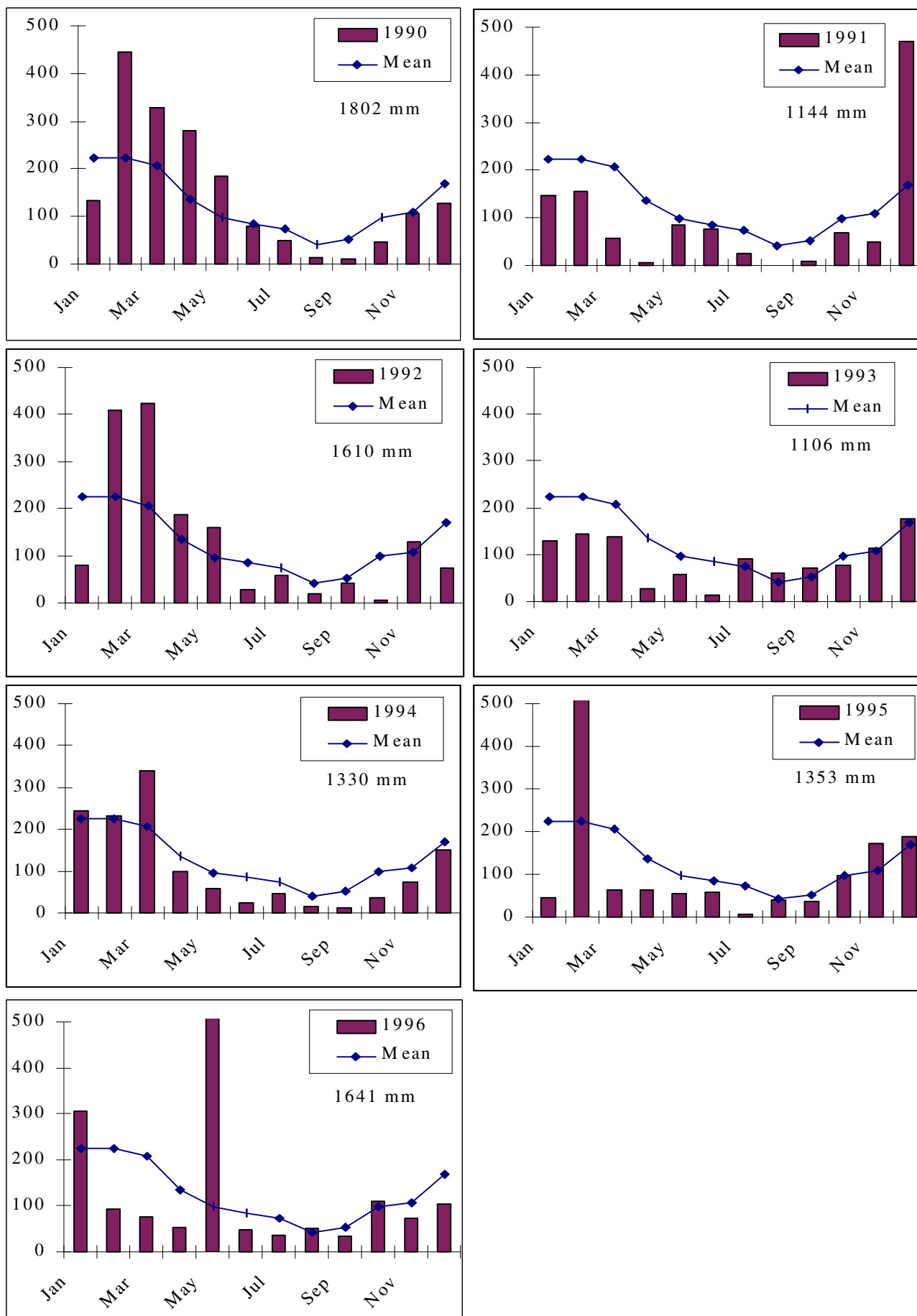
The soils of the area are kraznozems derived from basalts and are deep and well structured. Table 1 shows the fertility levels at the site are adequate for plant growth and there are no obvious major nutrient deficiencies.

Table 1: Soil Analyses at Mt. Mee field site

<i>Soil depth</i>	<i>pH</i>	<i>N</i> <i>mg/kg</i>	<i>P</i> <i>%</i>	<i>C</i> <i>%</i>	<i>Na</i> <i>meq/100g</i>	<i>Ca</i> <i>meq/100g</i>	<i>K meq/100g</i>	<i>Mg</i> <i>meq/100g</i>
0-8cm	5.3	6500	60	4.50	0.14	10.60	0.73	3.18
8-13cm	5.3	4700	25	4.00	0.11	9.02	0.27	2.40
50cm	6.0	1600	56	1.10	0.08	6.76	0.09	1.56

Notes: pH in a 1:5 water suspension; P using Colwell (bicarbonate) method.

Figure 1 Rainfall at Mt Mee during period of study (average = 1514mm)



The Species Trial

Species Used

Sixteen high-value rainforest species were chosen for the trial (Table 2). These varied in their timber properties and include species with a wide range of colours and densities. The group also included deciduous and evergreen species, hardwoods and softwoods, species with simple and compound leaves, species varying considerably in their crown architectures and two potential nitrogen fixers (*Acacia melanoxylon*, *Castanospermum australe*). The species are representative of early, mid and late successional stages of rainforest growth. Most species are native to SE Queensland (and most are present in natural rainforest within several kilometers from the study site). Of the non-indigenous species, *Flindersia brayleyana* is a well known cabinet timber species from north Queensland, *Cedrela odorata* is from central America and *Khaya nyasica* is from Africa.

Araucaria cunninghamii (hoop pine), a conifer, has been widely planted in tropical and sub-tropical Australia and New Guinea and was included in the trial as a reference species. At medium quality sites it is capable of developing stands with a mean annual increment (MAI) of about 9m³/ha/yr (Dale and Johnson 1991). The seed for this species came from the Imbil seed orchard (Batch M104,0) of the Queensland Forest Service. The seed of all other species came from unspecialised collections in natural forests or field trials in south east Queensland or northern NSW. The seed of the two exotic species (*Cedrela* and *Khaya*) came from field trials of these species at Imbil. In both cases the original provenance was unrecorded.

Table 2. Species used in trials and their attributes

Species	Family	Timber Density ¹ (kg m ⁻³)	Successional Status ²
<i>Acacia melanoxylon</i>	Mimosaceae	640	1
<i>Araucaria cunninghamii</i>	Araucariaceae	560	3
<i>Argyrodendron trifoliolatum</i>	Sterculiaceae	925	4
<i>Castanospermum australe</i>	Fabaceae	755	4
<i>Cedrela odorata</i>	Meliaceae	415	2
<i>Cryptocarya erythroxylon</i>	Lauraceae	720	4
<i>Dysoxylum fraserianum</i>	Meliaceae	705	3
<i>Dysoxylum mollissimum</i>	Meliaceae	640	2
<i>Elaeocarpus grandis</i>	Elaeocarpaceae	495	2
<i>Flindersia brayleyana</i>	Rutaceae	575	2
<i>Flindersia schottiana</i>	Rutaceae	675	2
<i>Gmelina leichhardtii</i>	Verbenaceae	545	2-3
<i>Grevillea robusta</i>	Proteaceae	625	2-3
<i>Khaya nyasica</i>	Meliaceae	560	?
<i>Rhodospaera rhodanthema</i>	Anacardiaceae	690	3
<i>Toona ciliata</i>	Meliaceae	450	2

¹ Timber Density: Cause *et al.* (1989)

² Successional Status: Pioneer (1), Early Secondary (2), Late Secondary (3), Mature (4) (M. Olsen, *pers. comm.*)

Figure 2 Layout of the Species Trial

[illegible]

LEGEND

- 1 *Acacia melanoxylon* 9 *Elaeocarpus angustifolius* 13 *Crevillea robusta*
2 *Arbutus cuneifolia* 10 *Findera brachyanta* 14 *Rhus myrica*
3 *Arbutus cuneifolia* 11 *Flindersia schottiana* 15 *Rhus myrica*
4 *Argemone trifoliata* 12 *Gmelina leichardtii* 16 *Tronox australis*

Trial Layout and Establishment

Each species was represented by a single individual in a plot of 16 trees (four rows of four trees) planted at 3 m spacings (equivalent to a stocking of 1100 trees per ha). The trial contained 28 of these plots (i.e. there were 28 individuals of each species). The whole trial was surrounded by a buffer row of *Araucaria cunninghamii* (Figure 2).

The trees were planted in June 1990 following a late wet season. At the time of establishment the planting holes for each tree were prepared using a special auger which loosened the soil but left a roughened surface on the edge of the soil. Despite the apparently favourable soil conditions, all seedlings were given 150 gm of diammonium phosphate at the time of planting and a further 80 gm per tree every year thereafter for the next four years (i.e. total 433 kg per ha).

Once planted the trees were surrounded by triangular plastic shelters about 100 cm tall and 25 cm diameter with an internal collar about 5cm deep at ground level (Trade name Growtubes[®]). These cylinders had been previously shown to provide some early growth advantages to rainforest seedlings, possibly by maintaining a high atmospheric water content in the vicinity of the seedling leaves (Applegate and Bragg 1989). The plastic shelters were maintained until the trees emerged from the open tops after which they were removed. A few of the seedlings died not long after planting. These were replaced within a month but were not used in the subsequent analyses. Weed control was maintained by regular applications of glyphosate in a radius of 90 cm around each tree and by mowing between rows. This weed control was maintained until canopy closure effectively shaded out the original ground cover.

Rainfall in the planting year was 1802 mm and well above average (average rainfall being 1514 mm) but only reached 1144 mm in 1991. Several seedlings showed signs of drought stress so that some trees were watered once in late August 1991. No further irrigation has been provided although rainfall has often been erratic or below-average over the study period (Fig 1).

Growth Measurements

Growth measurements have been made on all trees every six months for the first four years and annually since then. Measurements included height and diameter at 10cm above ground and subsequently at 130cm when the trees had grown taller. Tree volume was measured in two ways. Conical volume at age five years was calculated using an estimate of the stem cross sectional area at ground level based on measures at 30cm, the height and an empirical form factor of 0.33. In subsequent analyses an index of volume was calculated using simply height x basal area. Crown radii (average of four directions) were measured at each measurement occasion.

The form of the various species was rated using a scale of 1 (poor) to 10 (good) based primarily on stem straightness, branch size and branchiness and a count was made of the number of leading shoots.

Growth Phenology

A study was made of the phenology of growth to observe whether there were differences between the species in their seasonal growth patterns. Any such differences could be used to develop plantation mixtures which minimise the extent of inter-species competition. Such arrangements could result in a more equitable distribution of the resources of a site amongst the several plantation species, thereby delivering greater overall site productivity. The study commenced in December 1992 when monthly measures of tree height growth were made on a subsample of 10 of the faster growing individual trees of each species. This monitoring was maintained on the same trees for a further 31 months.

Foliar Analyses

Leaf samples were collected from each species on an annual basis for foliar analysis to monitor nutritional status. Sampling usually took place in the late winter months or just before the new growing season (September -October) and involved collecting the youngest, fully developed, exposed sun-leaves from the outer parts of branches in the upper third of the crown. A total of 10 trees of each species were selected at random for sampling (the same ten being sampled on each occasion). The leaves of each species were pooled, mixed, dried and ground for analysis. Analyses were carried out each year between 1992 and 1996 for nitrogen and from 1992 to 1995 for phosphorus, potassium, calcium and magnesium.

Tree Spacing and Pasture Growth Trial

Species Used

The two species used in this study were *Araucaria cunninghamii* and *Flindersia brayleyana*. The seed sources were as described above.

Trial Layout and Establishment

The trial was established using a Nelder design (Nelder 1962) in which trees are planted along spokes in a series of eight concentric rings (Fig 3). Because the space available per tree varies at each ring, the design provides for a range of nominal tree densities varying from 3580 trees per ha in the center of the trial to 42 trees per ha in the outer ring (which is effectively a buffer). Each of the two species were planted along a particular row and adjoining rows were either of the same species or the alternative. The intent of this design feature was to provide for intra-specific tree competition (when the adjoining rows contained the same species) or inter-specific competition (when the rows had the alternative species). Establishment methods were as before. Weed control was carried out using glyphosate only. Note that the planting layout means that the fertiliser application rates per ha. were necessarily higher in the center of the trial than at the outer circles.

Grazing animals were excluded from the trial for the first few years. Thereafter a system of "crash" grazing was used whereby animals were introduced and allowed to graze on the trial for a short concentrated period (usually only one day) before being removed. By six years grazing was effectively uncontrolled except for the seven week pasture measurement periods.

Growth Measurements

Tree growth measures were carried out using the techniques described earlier.

Pasture was assessed using the Botanal technique of Tothill *et al.* (1978) at 600 positions over the range of tree densities in the trial (42 to 3580 trees per hectare). Records were made at each position for: above ground biomass, species present and the proportion of each species in the above-ground biomass. These measurements were made during both the wet and dry seasons, covering annual periods of maximum and minimum pasture production.

Pasture Chemical Analyses

Samples of pasture were collected from beneath both species of tree at various densities in March 1995 when the trees were nearly five years old. These were dried and analysed as before.

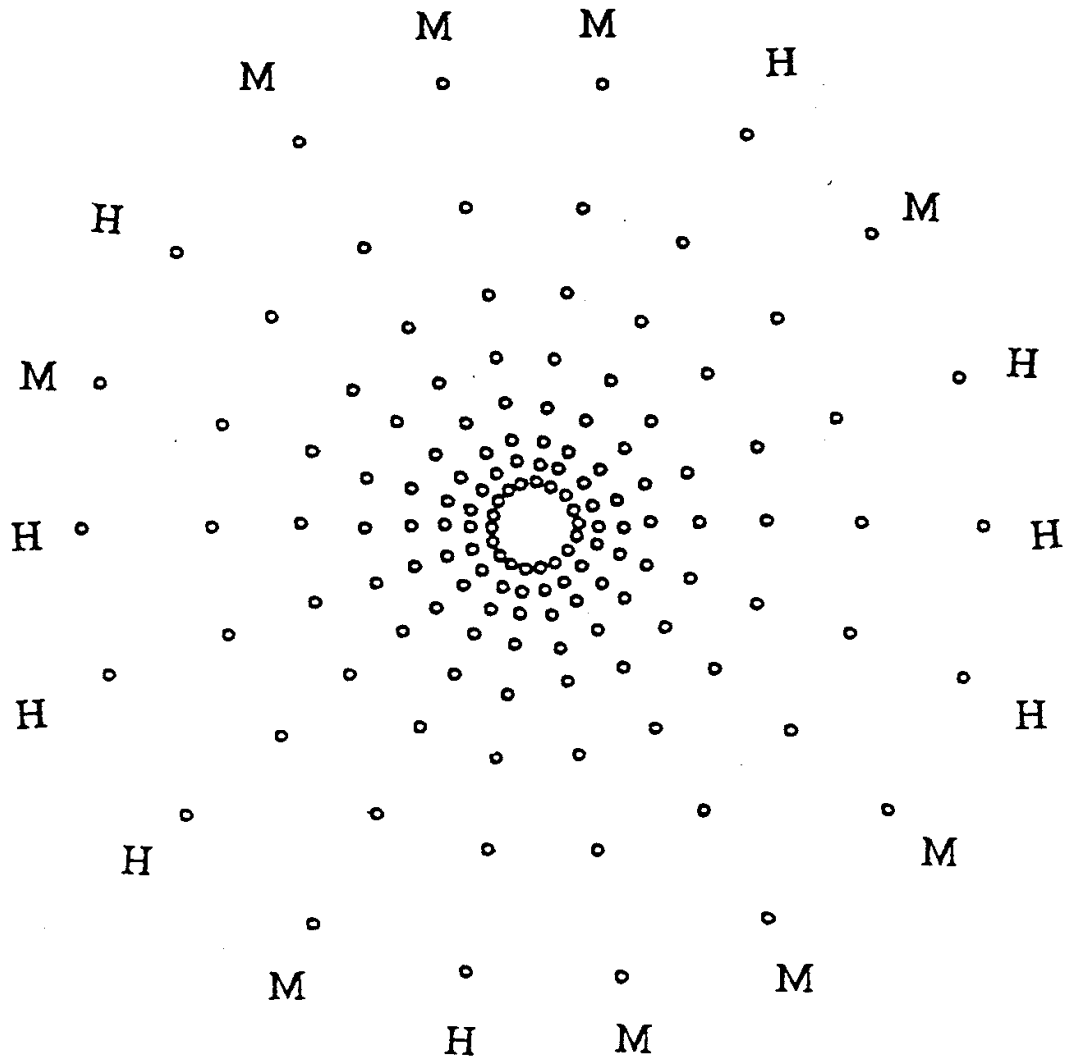
Figure 3 The 'Nelder wheel' tree/pasture trial at Mt Mee

o = tree position

H = a 'spoke' of Hoop pine (*Araucaria cunninghamii*) in the wheel

M = a 'spoke' of Queensland maple (*Flindersia brayleyana*) in the wheel

The tree stocking rate extends from 3580 trees per hectare in the centre circles, to less than 42 trees per hectare in the outer circle.



0 10 20 30 40 50

Distance (Metres)

Detailed Results

The Species Trial

Growth Rates

The tallest trees after six years were *Acacia melanoxylon* which averaged 10 m in height. Other fast growing species included *Elaeocarpus grandis*, *Cedrela odorata*, *Grevillea robusta*, *Rhodosphaera rhodanthema* and *Flindersia brayleyana* all of which reached 7 m or more (Table 3). These species were also amongst the fastest growing when growth was expressed in terms of diameters or volumes.

Cryptocarya erythroxylon was the slowest growing species and a number of individuals died during the study period. Interestingly, there is some evidence that the surviving seedlings of this species are now beginning to show an improvement in vigour and in growth rate. This poor early performance may have been due to photo-inhibition which is now being reduced by the shading provided by the surrounding trees of other species. Another one of the poorer performing species was *Toona ciliata* but in this case the cause was insect damage. Like many members of the Meliaceae, *Toona* is attacked by shoot borers. The insect responsible was *Hypsipyla robusta* which appeared in the first summer after planting and has reappeared every summer since then. Until that time *Toona* was growing very strongly but subsequently it has lost most of its leading shoots each summer. Only a few trees have died but the overall growth has been poor. Interestingly, *Cedrela odorata* (another member of the Meliaceae but from Central America) was also damaged by insects in the second growing season of the study. In this case the damage stimulated axillary growth development and many individuals developed multi-leaders. Subsequent insect problems have been slight. Other members of the Meliaceae in this trial (*Dysoxylum* and *Khaya*) appear to be unaffected by *Hypsipyla* or other insect problems.

The remaining species were intermediate in growth. This group included *Araucaria cunninghamii*, the only native rainforest species currently used in commercial plantations. Most of these slower growing species showed no obvious signs of ill-health. The main exception was *Gmelina leichhardtii*. Many trees of this species have significant levels of herbivory and suffer premature leaf drop from the upper crown. The growth rate of *Gmelina* was initially rapid but has declined in more recent years as this premature leaf drop problem has worsened. No other major insect problems were found except that some unidentified borers were noted in several *Acacia* stems.

The height growth rates of most species were generally constant throughout the period of study suggesting that interspecific competitive interactions had not adversely influenced the growth of shorter species within the period of study (Fig 4). The exceptions to this observation are *Toona* and *Gmelina* for the reasons given above.

Table 3. Mean values of tree growth parameters after 6 years
(Values in brackets are standard deviations)

Species	Height (cm)	Dbh (cm)	Conical Volume ¹ (m ³)	Form Rating ²	Leaders ³	n ⁴
<i>Acacia melanoxylon</i>	1001 (154)	19.1 (3.8)	0.1300 (0.0489)	6.9	1.2	22
<i>Araucaria cunninghamii</i>	683 (166)	11.1 (2.2)	0.0318 (0.0129)	9.9	1.1	27
<i>Argyrodendron trifoliolatum</i>	454 (157)	6.2 (2.6)	0.0104 (0.0074)	8.7	1.2	19
<i>Castanospermum australe</i>	479 (138)	5.7 (2.2)	0.0102 (0.0072)	7.5	1.2	26
<i>Cedrela odorata</i>	858 (217)	17.2 (3.3)	0.1295 (0.0581)	6.9	1.3	25
<i>Cryptocarya erythroxylon</i>	359 (101)	3.1 (2.2)	0.0028 (0.0009)	9.9	1.0	6
<i>Dysoxylum fraserianum</i>	374 (88)	5.3 (2.1)	0.0069 (0.0036)	6.2	1.5	24
<i>Dysoxylum mollissimum</i>	526 (78)	8.4 (1.3)	0.0168 (0.0043)	7.7	1.1	28
<i>Elaeocarpus grandis</i>	995 (214)	18.5 (2.6)	0.1251 (0.0506)	10.0	1.0	25
<i>Flindersia brayleyana</i>	769 (91)	12.1 (1.6)	0.0380 (0.0114)	8.3	1.1	27
<i>Flindersia schottiana</i>	498 (185)	6.1 (2.1)	0.0088 (0.0072)	9.0	1.0	27
<i>Gmelina leichhardtii</i>	474 (87)	8.2 (2.1)	0.0157 (0.0079)	9.4	1.2	26
<i>Grevillea robusta</i>	896 (196)	16.7 (4.1)	0.1046 (0.0422)	8.6	1.0	27
<i>Khaya nyasica</i>	697 (148)	9.8 (2.2)	0.0381 (0.0202)	9.0	1.1	26
<i>Rhodosphaera rhodanthema</i>	761 (102)	16.3 (2.0)	0.0739 (0.0260)	7.2	1.7	28
<i>Toona ciliata</i>	401 (133)	6.9 (3.2)	0.0152 (0.0111)	6.2	1.8	22

¹ Estimated stem conical volume using stem cross-sectional area at 30 cm, height and an empirical form factor of 0.33.

² Form rating based on stem straightness and branchiness ranging from 10 (good) to 1 (poor)

³ Numbers of leading dominants

⁴ Trees surviving from 28 originally planted

These growth data were based on measurements of all surviving trees [survival rates being high for all species except *Argyrodendron trifoliolatum* (19 trees remaining or 68 percent) and *Cryptocarya erythroxylon* (6 trees remaining or 21 percent)]. The performance of the best five trees of each tree species is also given in Table 3 and shows that these averaged 1-2 m faster growth than the overall average over the measurement period. Given that all species except *Araucaria cunninghamii* were from unimproved stock, there is considerable scope for productivity increases through tree selection in all species.

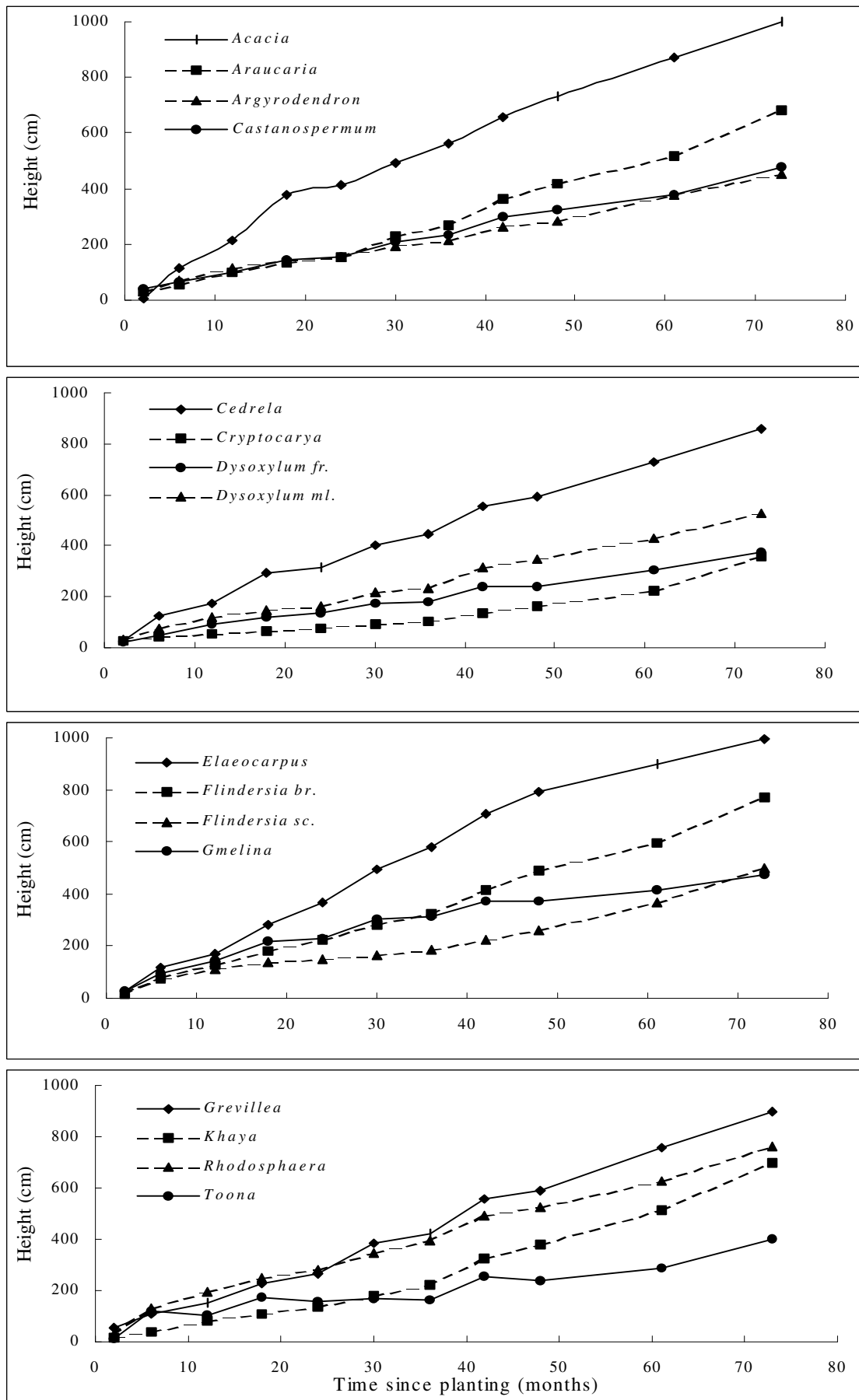
Rapid tree height growth was correlated with lower timber density (height at 5 years = $11.62 - 0.01$ (wood density), $n = 15$, $r^2 = 0.351$) and with earlier successional status (height at 5 years = $3.83 - 0.239$ (successional rank), $n = 14$, $r^2 = 0.331$).

Further notes on the performance of individual species are given in Appendix 1

Tree Form

The tree form and the number of leading shoots for each species is shown in Table 3. Of the faster growing trees, *Elaeocarpus grandis* was clearly superior on both counts with a form ranking of 9.9 (out of 10) and an average of only 1.1 leaders per tree. *Grevillea robusta* also ranked highly. Several of the remaining fast growing species had form ratings of 7 or less and a tendency for multiple leaders indicating the need for improvement through some kind of selection programme or different silvicultural treatments. *Araucaria cunninghamii* had very high form rating reflecting both the good natural habit of this species plus the fact that selected seed originating from a Queensland Forest Service seed orchard were used for this trial.

Figure 4 Tree height growth over study period at Mt. Mee.



Growth Patterns and Seasonality

The seasonal patterns of growth of the various species over two years is shown in Fig 5. The period of maximum growth for most species was during the wetter summer months, particularly January and February, and most produced little growth in the drier winter months. (Occasional negative values are a result of tip damage or dieback). These data suggest there may be limited scope for reducing competition in plantations by combining species with contrasting growth phenologies.

New growth appeared to be triggered, at least in part, by the timing of the onset of the rainy season. In late 1991 and 1992 the new growing season began around December or later for most species. In these years the rainfall in the second half of the year was below-average and the rains started abruptly in December and November respectively. In 1993 the rainfall in the second half of the year was closer to average and there was a more gradual commencement to the wet season. This was reflected in the more gradual increase in new growth by many species in that year. Despite this broad correspondence between the onset of rain and the commencement of new growth there were differences between species suggesting that rainfall alone was not the only trigger.

The various species differed substantially in terms of monthly height growth but four broad categories can be recognised (Table 4).

Group 1 : were species able to grow very rapidly during favourable conditions (e.g. more than 0.6 cm/day) and rarely had periods of slow growth (e.g. less than 0.2 cm/day). These species included *Elaeocarpus*, *Acacia*, *Cedrela* and *Grevillea*. All of these species are representative of early rather than late successional stages.

Group 2: were species such as *Araucaria*, *Khaya*, *Rhodosphaera* and *Flindersia brayleyana* which were not able to match the overall vigour of the Group 1 species but which maintained steady growth throughout the period and, like Group 1, seldom grew slower than 0.2 cm/day.

Group 3: were species such as *Dysoxylum mollisimum*, *Gmelina*, *Castanospermum* and *Toona* which were mostly slow-growing (less than 0.2 cm/day) but which were capable of occasional periods of faster growth. In the case of *Toona* this pattern was largely a consequence of the insect damage referred to above. Without this damage *Toona* would have almost certainly been classed in the first group.

Group 4: included the species *F. schottiana*, *Cryptocarya* and *Dysoxylum fraserianum* which had few growth spurts and rarely grew faster than 0.2 cm/day, irrespective of season. *Cryptocarya* and *D. fraserianum* are late successional species but *Flindersia schottiana* is from an earlier successional stage.

Figure 5 Seasonality of height growth at Mt. Mee between 1991-1994 (based on sample of 10 trees per species).

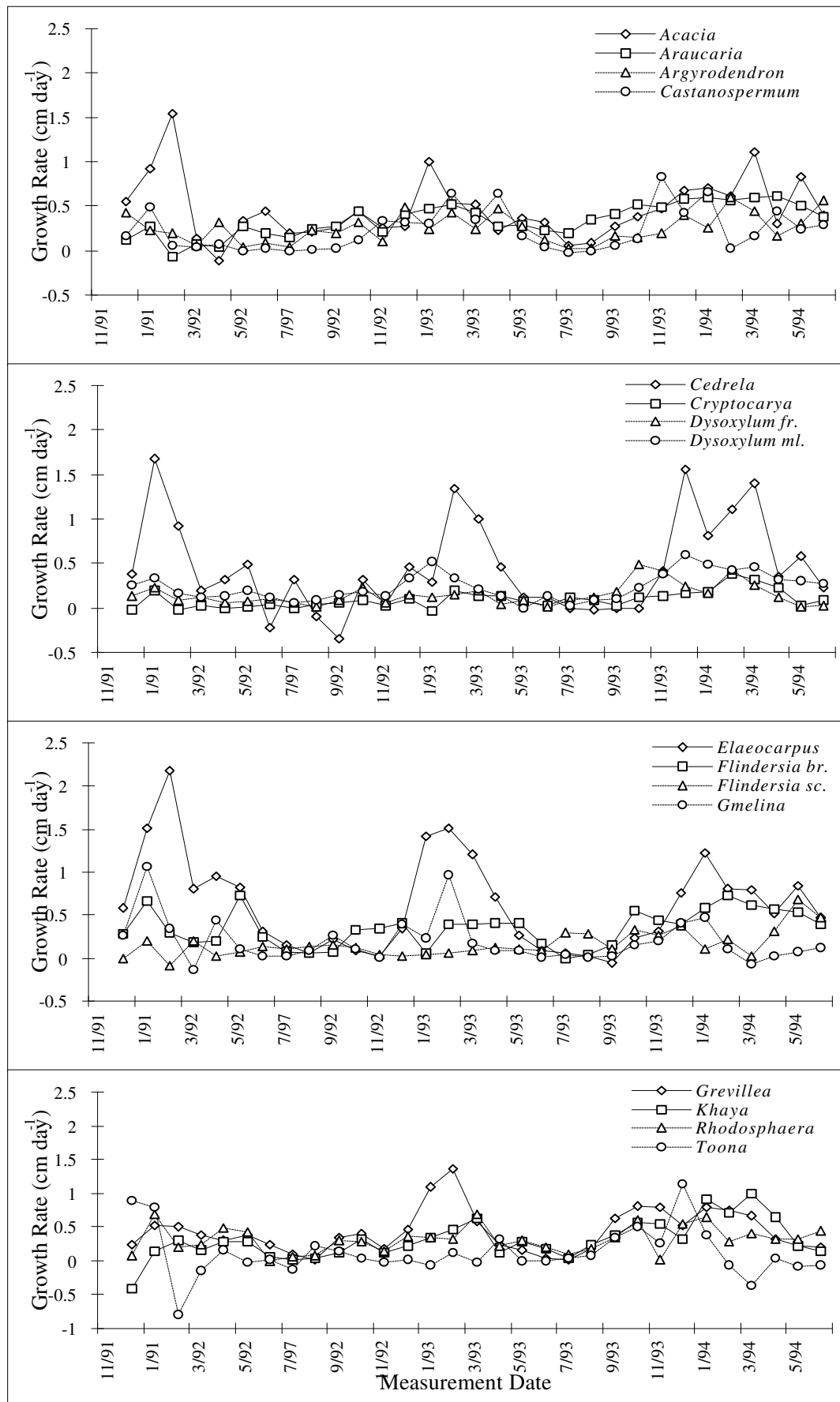


Table 4 Phenology groupings

Species groupings according to rates of monthly height growth between ages 17 and 48 months. Data are the number of months (out of 31) in which a species achieved a particular growth rate (cm day⁻¹)

Groupings	Height Growth Categories (cm day ⁻¹)			
	<0.2	>0.2	>0.4	>0.6
Group 1				
<i>Acacia melanoxylon</i>	5	26	15	8
<i>Cedrela odorata</i>	10	21	13	8
<i>Elaeocarpus grandis</i>	8	23	17	14
<i>Grevillea robusta</i>	8	23	14	8
Group 2				
<i>Araucaria cunninghamii</i>	5	26	13	3
<i>Flindersia brayleyana</i>	9	22	14	4
<i>Argyrodendron trifoliolatum</i>	12	19	8	0
<i>Khaya nyasica</i>	9	22	7	4
<i>Rhodosphaera rhodanthema</i>	8	23	8	4
Group 3				
<i>Castanospermum australe</i>	18	13	7	4
<i>Dysoxylum mollissimum</i>	16	15	5	1
<i>Gmelina leichhardtii</i>	20	11	5	2
<i>Toona ciliata</i>	22	9	4	3
Group 4				
<i>Cryptocarya erythroxylon</i>	26	5	0	0
<i>Dysoxylum fraserianum</i>	23	8	2	0
<i>Flindersia schottiana</i>	20	11	1	0

Foliar Nutrient Levels

The foliar nutrient levels are given in Figure 6.

Nitrogen (Fig. 6a)

The nitrogen concentration of most species were around 1.5-2.0 percent with *Acacia*, *Castanospermum*, *Cedrela*, *Dysoxylum fraserianum*, *D. mollissimum* and *Toona* having slightly greater concentrations. By contrast, *Araucaria* was well below the concentration of most other species at around 1.2 percent nitrogen.

Samples were first taken when the trees were only two years old and for many species the concentration increased during the next few years to a maximum in 1994 (the last year in which nitrogen and phosphorus fertilizer was applied) but then began to decrease with time. Excluding *Toona*, for which there were incomplete samples, the majority of the species had successively lower concentrations in these last two years of sampling than at this earlier maximum.

Phosphorus (Fig. 6b)

Most species had foliage concentrations mostly well in excess of 0.1 percent phosphorus. Apart from single results for *Cryptocarya* and *Toona*, the species with the highest consistent concentrations were the two *Dysoxylum* species with around 0.2 percent. Several species with lower concentrations, especially in the most recent samples, included *Flindersia brayleyana*, *Flindersia schottiana* and *Grevillea robusta* all of which had values at or below 0.1 percent. In a clear majority of species the most recent (1995) concentrations were less than the 1994 concentrations.

Calcium (Fig. 6c)

The concentration of foliar calcium was mostly in excess of 1.0 percent and was consistently high for both *Dysoxylum* species and *Khaya* (generally more than 2.0 percent). *Acacia* had amongst the lowest concentrations (declining to 0.6 percent in the most recent 1995 sample). For the majority of species the most recent sample contained the lowest concentration measured over the four sample times.

Potassium (Fig. 6d)

The concentration of potassium was mostly in excess of about 0.75 percent in all species sampled. The species having a low concentration at most of the sampling occasions included *Khaya* and *Castanospermum*. Unlike nitrogen, phosphorus or calcium there was no evidence in most species that foliar concentrations were declining in the most recent samples.

Magnesium (Fig. 6e)

The concentration of magnesium was generally above 0.18 percent in most species with the two *Dysoxylum* species again being above-average in their foliar concentrations. By contrast, *Elaeocarpus* always had less than 0.13 percent magnesium on each of the four sample occasions. The most recent samples did not have consistently lower concentrations than earlier samples and there was no consistent pattern of decline in foliar magnesium over the four sample periods among the various species.

No obvious signs of deficiency symptoms were observed in any species.

Figure 6 Foliar nutrient levels

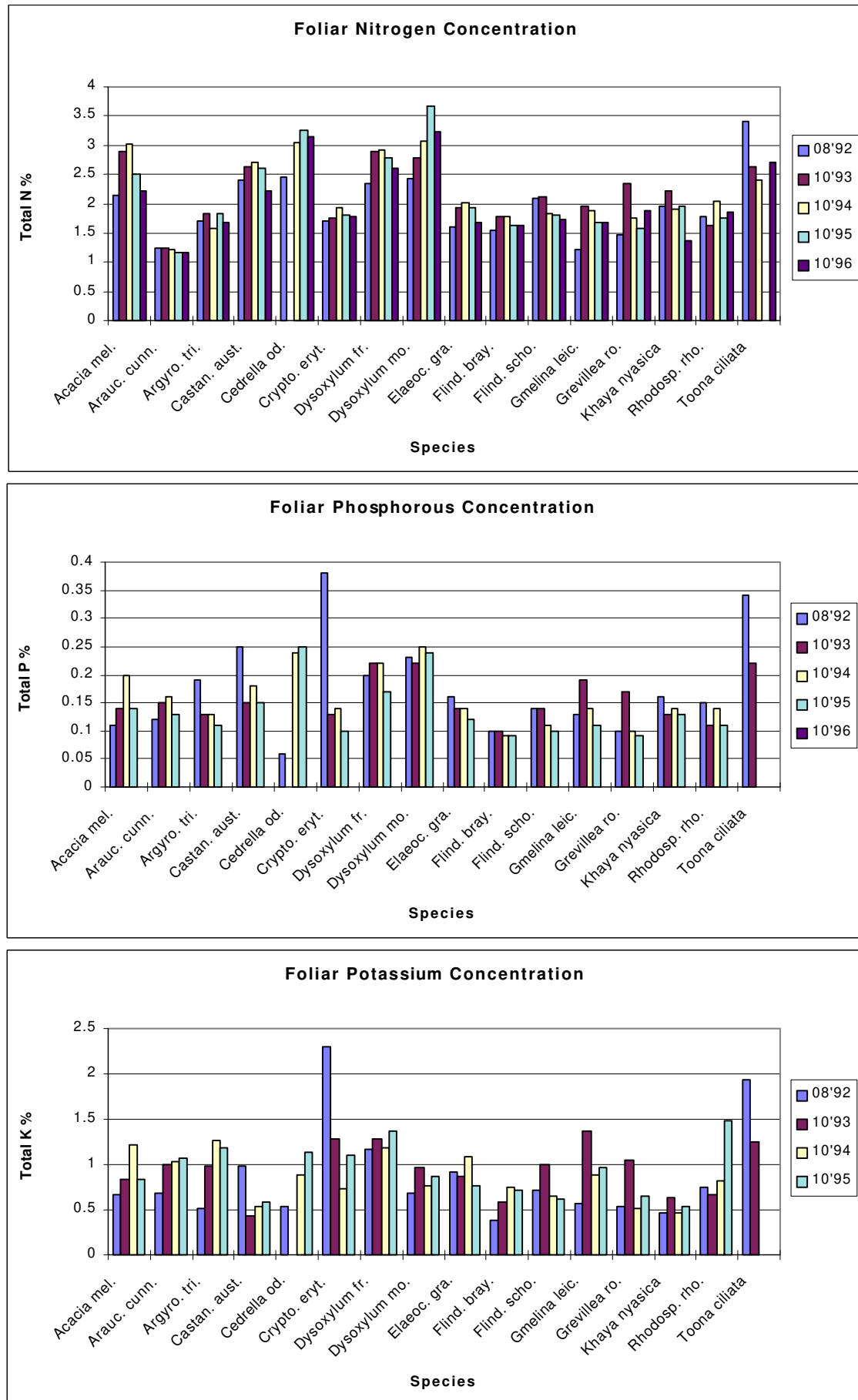
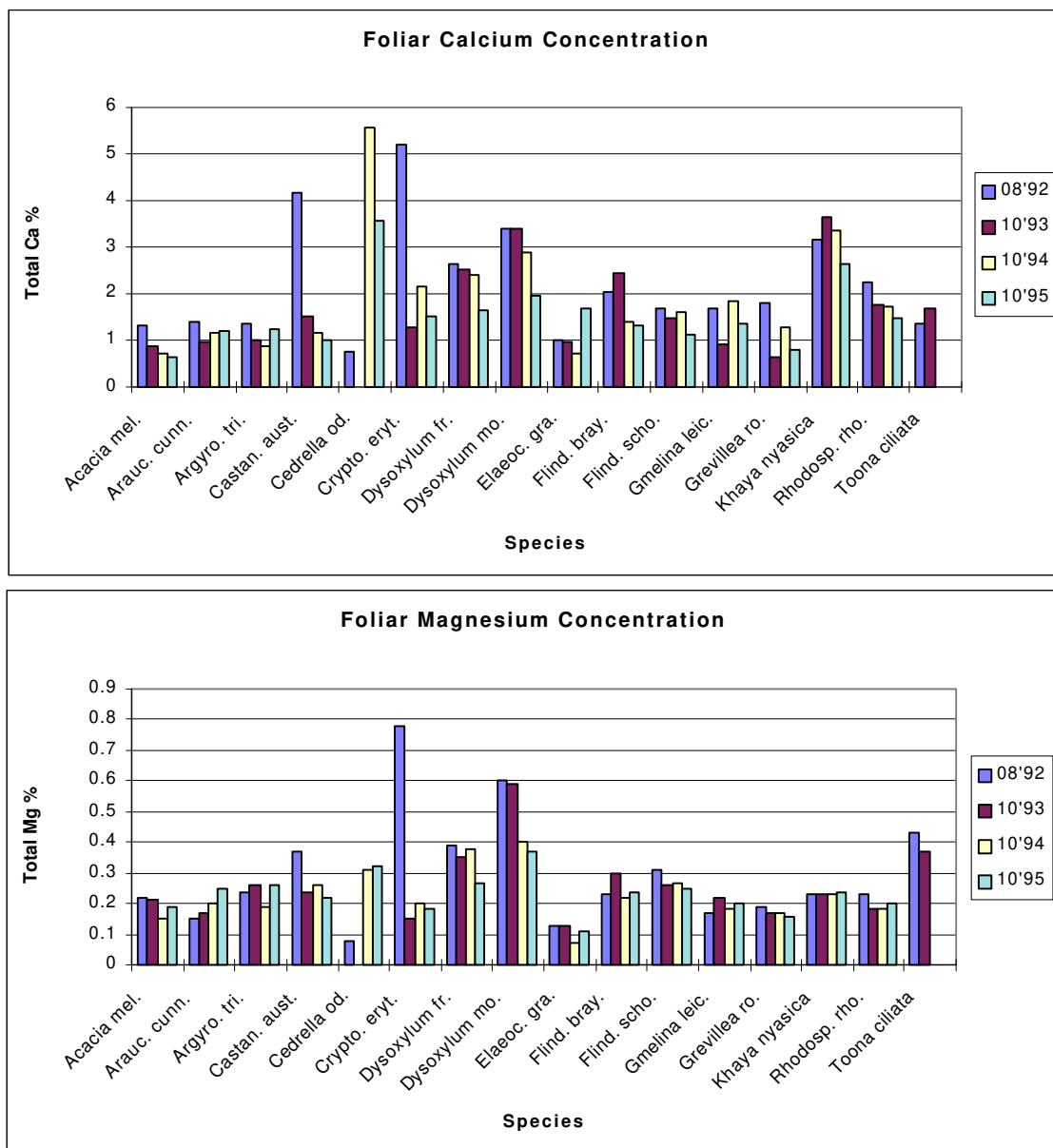


Figure 6 Continued



Discussion of Results of Species Trial

Growth Differences

Five years age is an early stage at which to assess the performance of species that might be expected to grow in a plantation for 40 years or more. However it is already clear that several groups of species can be identified. The first are those that grew most rapidly over the first five years of the trial and could be expected to rapidly outcompete grass and weeds. The phenology study showed that all were able to take advantage of favourable growing conditions. These species included *Elaeocarpus*, *Grevillea*, *Acacia* and *Cedrela* which all grew well in terms of height or volume. It is noteworthy that all these species grew generally faster than in previous trials in tropical and sub-tropical Queensland summarised by Cameron and Jermyn (1991). This suggests that the attempt in the current study to provide optimum growing conditions succeeded, notwithstanding the dry weather conditions sometimes experienced during the trial period.

Of these fast growing species, only *Elaeocarpus* and *Grevillea* had good tree form as well as rapid growth rates. The growth of *Acacia* was rapid but the poorer form and the occurrence of stem borers make the species much less attractive without a provenance or tree selection program. *Acacia melanoxylon* is distributed over a very wide latitudinal range from 16°S to 43°S (Boland *et al.* 1984) and is regarded as an important timber species at these higher latitudes. There is also evidence that the southern provenances are genetically distinct from the sub-tropical provenances from which the seed for the trees in the current trial originated (Playford *et al.* 1993). Trials in Africa have found that *Acacia melanoxylon* will grow well in many environments but will only produce quality timber in certain environments using seed of particular provenances (Harrison 1975). The results from the present study support this conclusion. The fourth species in this group, *Cedrela*, had good growth but also had poor form (the poorest, after *Dysoxylum fraserianum*, of all the species in the trial). Burley and Lamb (1971) have noted large differences in the form of *Cedrela* between various provenances and such differences would have to be explored further for *Cedrela* to become acceptable at the present site.

The second broad group that can be recognized after this initial group are those with heights exceeding six meters after six years. This group included *Araucaria*, *Flindersia brayleyana*, *Khaya* and *Rhodosphaera*. *Araucaria* is already recognized as an important plantation species and was included in the trial as a reference species. Its intermediate height ranking therefore suggests that some of the other species in this trial may be at least as attractive as future plantation species. *Araucaria* does have several important advantages, however, that go some way to compensating for this slower initial growth. One of these is its very good form (rated as 9.9 out of 10 in the present study) and strong apical dominance. The other advantage is its exceptional ability to maintain vigorous growth beyond 30 years age when many other plantation species are beginning to suffer declining current annual increments (Dale and Johnson 1991). More time is needed to determine whether the faster initial growth and higher timber prices of the other species in this trial will outweigh these considerable advantages.

Of the other species in this second ranking group, *Flindersia brayleyana* is also recognised as a promising plantation species with a highly regarded timber. It is native to north Queensland but appears to be able to grow well with reasonable form in these sub-tropical environments. Good performance has also been observed in a 50 year old trial at Amamoor in southern Queensland suggesting it deserves to be more widely tested in other locations. *Khaya* should also be regarded as a potentially useful species with very good form that deserves wider trials. The last of this group is *Rhodosphaera* which grew vigorously but its poor form, densely branched crown and multiple leading shoots tends to outweigh this height advantage.

These species all belonged to the second of the phenological groupings recognized in Table 4. The only other member of that group was *Argyrodendron trifoliolatum* but the growth of this species was slow thereby consigning it to the final group of poorly performing species. These were slow growing species or those that suffered major insect problems. Several in this group may have benefited from some form of temporary shelter. These include *Toona* because of the well known tip moth problem and the evidence suggesting the frequency of insect attack on *Toona* is reduced when the trees are shaded (see, for example, Cameron and Jermyn 1991, Keenan *et al.* 1995). Some of the remaining *Cryptocarya* trees also appear to have recently benefited from the shelter provided by neighbouring trees. Perhaps more time is needed to evaluate the performance of these species in plantation mixtures. Others in this last

group, such as *Gmelina*, *Dysoxylum fraserianum*, *D. mollissimum*, *Castanospermum* and *Flindersia schottiana* had high rates of survival under the trial conditions but had such slow growth rates or insect problems that they might be difficult to establish in routine plantations.

Reasons for These Differences

There was evidence that some of the faster growing species in this trial tended to come from earlier successional stages. Likewise, there was evidence that many of the faster growing species tended to have lower density timbers. However, neither of these two observations are explanatory. Mycorrhiza differences did not appear to be a factor. A supplementary study on mycorrhiza found all species had appropriate mycorrhizal associations similar to those in the nearby natural forest (Matthews 1995 - see Appendix 2). Likewise herbivory was not a major problem for any species, with the possible exception of *Gmelina leichhardtii* mentioned earlier (van Gestel and Kurstjens 1992 - see Appendix 2).

One of the primary reasons has to do with differences in the basic physiology of species. Studies have been made on photosynthesis and water use by eight of the 16 species in the trial (Drane 1996 - see Appendix 2). She found net maximum photosynthetic rate and maximum conductance both correlated well with tree height and stem volume. *Elaeocarpus* and *Cryptocarya* did not fit the overall trend as well as the other species and their performance may be related to the rather different total leaf areas (one much higher and one much lower) associated with these two species. There did not appear to be any consistent relationship between the growth of any species and their tissue water relationships.

Nutrition

Foliar nutrient analyses have been used for some time to aid in the diagnosis of nutrient deficiencies. Miller (1986) and Drechsel and Wolfgang (1991) have suggested concentrations that may be "critical" or limiting to plant growth (the latter authors being particularly concerned with tropical tree species). Single analyses have limited use but sequential analyses, as used here, (a form of "crop logging") can provide a better indication of trends and incipient stress.

Although all trees had mycorrhiza and no trees showed obvious signs of nutritional stress the data suggest that nitrogen and phosphorus may be becoming deficient for some species. This is at a time when canopy closure has just begun and hence nutrient stress is probably at its most acute.

Both nitrogen and phosphorus concentrations in some species were at or below the ranges suggested by Miller (1986) and Drechsel and Wolfgang (1991) as being adequate. Thus in the most recent samples many species had nitrogen concentrations around 1.50-1.80 percent while values below 1.8 percent may be limiting for many species. Likewise, for phosphorus many species had foliar concentrations of 0.10 percent while values below 0.18 percent may be limiting. These data suggest, therefore, that the modest fertilizer application rates applied in the early stages of plantation development were not enough and better growth might have been achieved if these had been increased.

The data also suggest that there may be differences between species in terms of their ability to acquire and utilise nutrients. For example, the concentration of nitrogen was especially low in *Araucaria* which, being a conifer, might be expected to have a slightly lower "critical" level than other broadleaved species (Miller 1986). Likewise, both *Dysoxylum fraserianum* and *D. mollissimum* usually had high foliar nutrient concentrations compared to most other species. The causes for these differences need further study.

Future Growth Patterns

The mostly steady and linear patterns of growth illustrated in Fig 4 suggested interspecific competition had not begun to differentially influence the performance of the various tree species during the six year period of the study. This was not because differences in growth phenology allowed species to avoid competition. In fact, most of the faster growing species all grew best in the warmer and wetter times of the year suggesting these were all utilising resources at this time. (This assumes, of course, that the seasonality of root growth and resource utilisation matches that of shoot growth). Instead competition may have limited simply by the young age or small tree size. If this is so then the effects of canopy closure and competition are likely to become more evident shortly.

The effects of canopy closure are not always negative. One consequence of the establishment of a diverse community of rainforest trees at this site has been that it is now becoming attractive to various bird species. As a result of these, seeds of several new plant species have been introduced to the understorey of the plantation (Juniper 1997 - Appendix 2). The numbers of these are still small but their presence illustrates the potential restorative capacity such small plantations may have for landowners interested in the “conservation” benefits of tree planting as well as timber production.

Plantation Monocultures and Mixtures

The primary purpose of this trial was to explore the early growth of a variety of rainforest species. A mixed species design was used because of the expectation that many landowners would like to achieve “conservation” benefits as well as timber production on their properties. It is still too early to assess whether such a plantation mixture is better or worse for these species than the monoculture design traditionally used in timber plantations in Australia. What does seem clear, however, is that 16 species is too many to successfully manage if timber production alone is the objective. In the present trial the large variation in growth rates mean many species will eventually become suppressed individuals below the main plantation canopy. They may, or may not, die but will not contribute to timber production and may have an inhibitory effect on the more dominant individuals.

Further monitoring will be carried out to explore this process. It should be possible to resolve several important questions. For example, will slower growing species be simply shaded out and eventually die (as would occur in a plantation monoculture) or will these species persist (or even eventually flourish?) in some shade? Will trees growing adjacent to *Acacia melanoxylon* (a potential nitrogen fixer) benefit from their position or not? And finally, will the competitive influence of neighbours on a particular tree depend on their taxonomic identity or merely on their relative sizes?

The Tree Spacing and Pasture Growth Trial

Trees

Araucaria cunninghamii

The overall growth of *Araucaria cunninghamii* in the spacing trial matched that of this species in the species trial described above. However, the growth appeared to vary with variations in overall tree density (Fig 7a). After 1993 (when trees were three years old) there was evidence of improved height growth in the more densely planted trees at the centre of the trial compared to those in the outer circles. This difference increased with time and in 1997 the trees at high densities were about 8 m tall compared with those at low densities which were 6 m tall (i.e. they were 33 per cent taller).

By contrast, a high tree density reduced stem diameter growth (Fig 7b). The effect became evident perhaps a year later than effect of density on height but, again, the effect was substantial. In 1997 trees planted at high densities had around 66 percent of the diameter growth of those planted at wider spacings.

The effect of tree spacing on mean tree volume is given Fig 8a. In the early years of the trial tree density had no effect on mean tree volume. However, recent measures suggest the volume of trees has become inhibited at higher tree densities and perhaps also at the lowest tree densities. That is, best volume production was occurring at intermediate spacings.

Calculations of timber volume per ha show that such mean tree differences are overwhelmed by tree stocking and the highest timber volume per ha is found at the highest tree density (Fig 8b).

Flindersia brayleyana

The height growth of *F. brayleyana* was also affected by tree density with better growth being found in trees grown at high planting densities (Fig 9a). The effect became evident by three years age and increased with time. By age six years the trees at the highest stocking were more than 9 m tall while those in the lower densities were less than 7 m. However, at this age the first signs appeared of tree growth being inhibited by high tree density.

Unlike *Araucaria*, Fig 9b shows the diameter growth of *Flindersia* was not reduced by higher tree density. (Although there was some apparent reduction in diameter growth in some of the trees growing at wider spacings).

As a result of these two responses the largest mean tree volume of *Flindersia brayleyana* trees tended to be found at higher planting densities although the effect of tree density was not particularly strong (Fig 10a). And, as was the case with *Araucaria cunninghamii*, the largest timber volume per ha at this early age was also found at the highest tree densities (Fig 10b).

Figure 7a Hoop pine height growth over time at different tree stocking rates (planted June 1990).

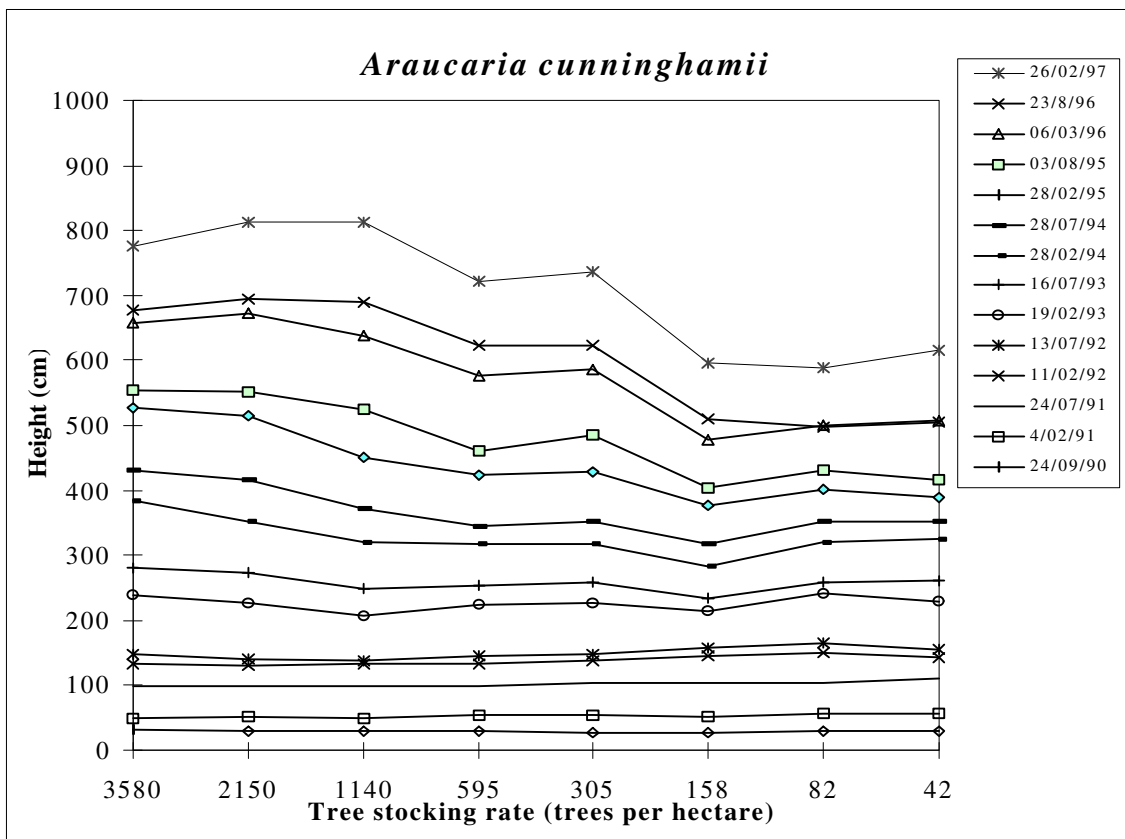


Figure 7b Hoop pine diameter (dbh) growth over time at different stocking rates.

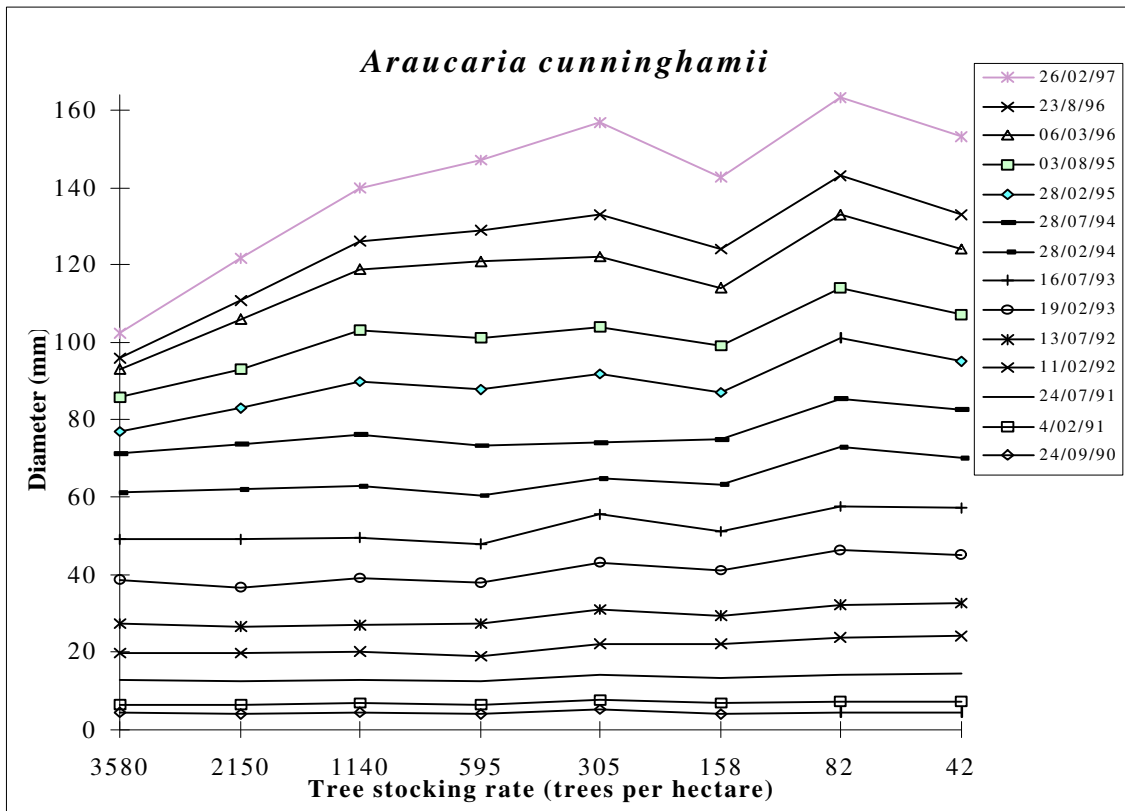


Figure 8a **Hoop pine tree volume (cu.m) over time at different stocking rates.**

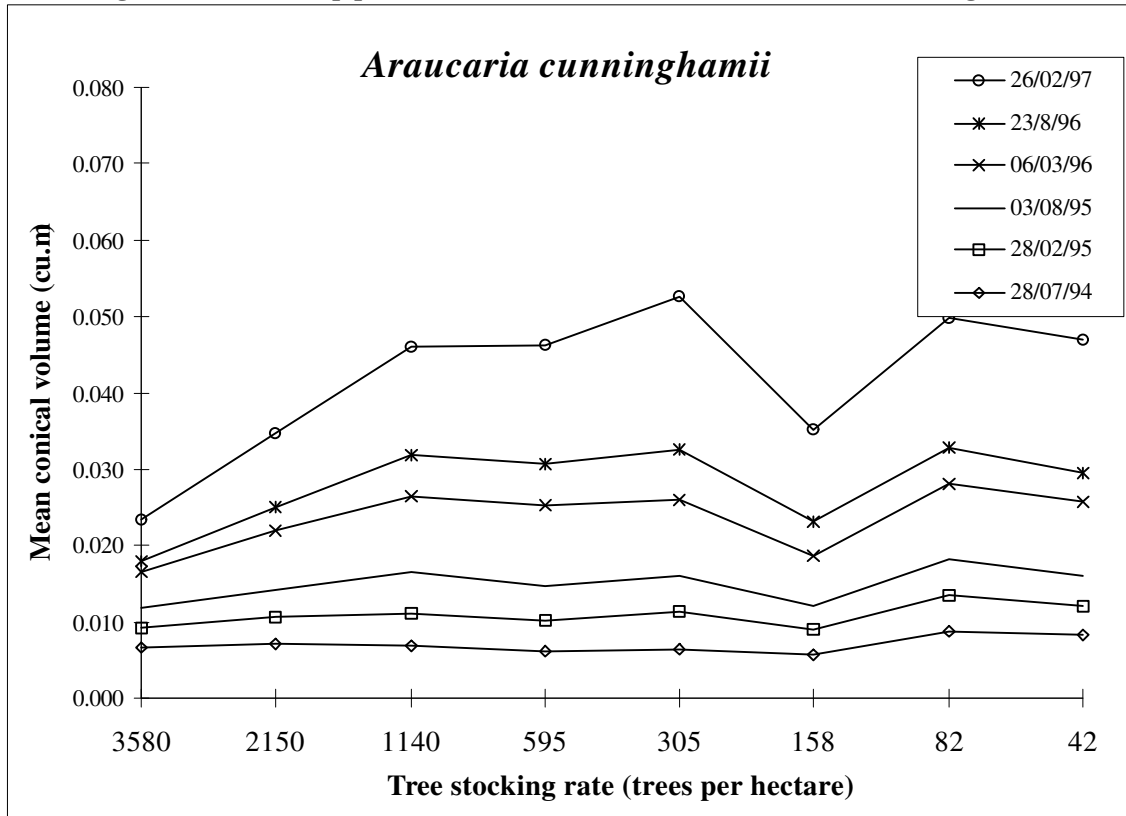
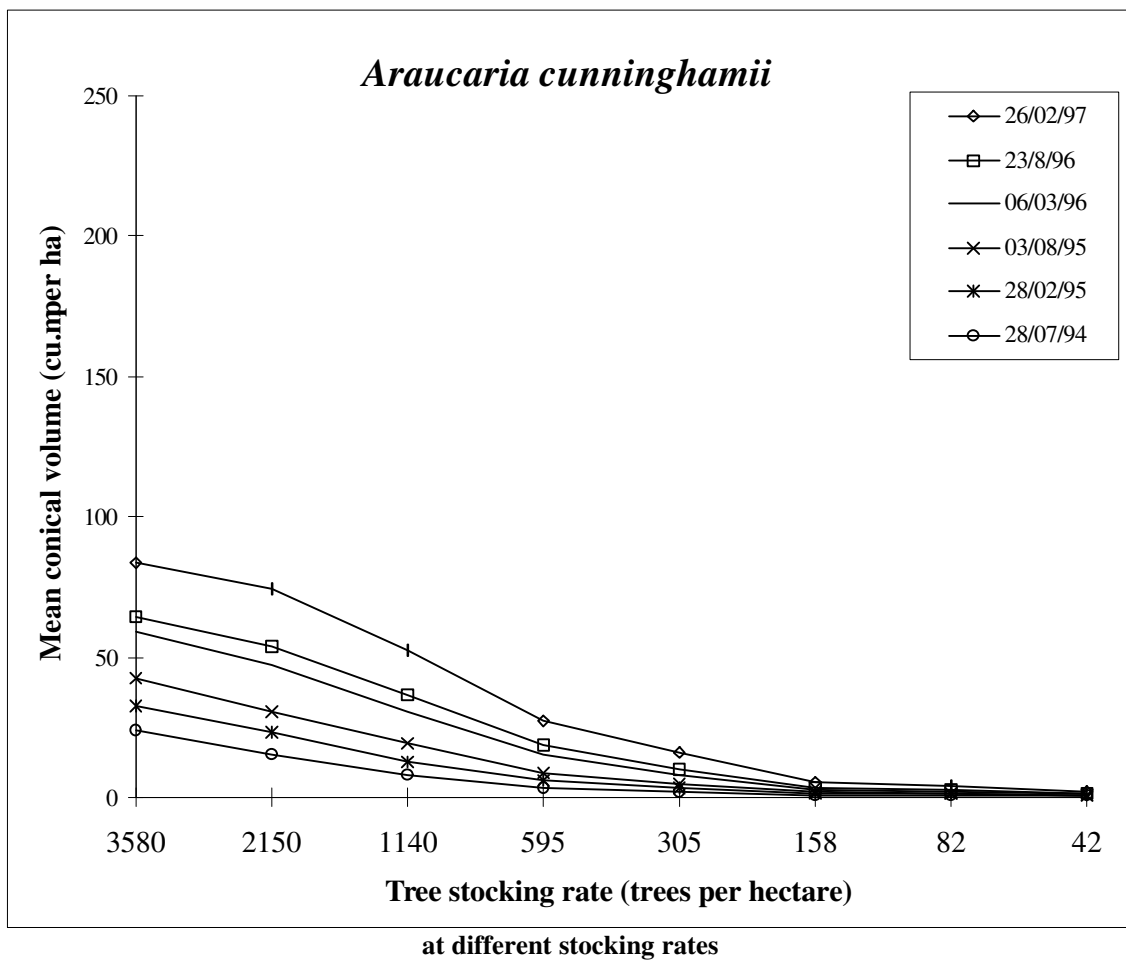


Figure 8b **Hoop pine stand volume (cu.m per ha) over time at different stocking rates**
Figure 9a **Queensland maple height growth over time**



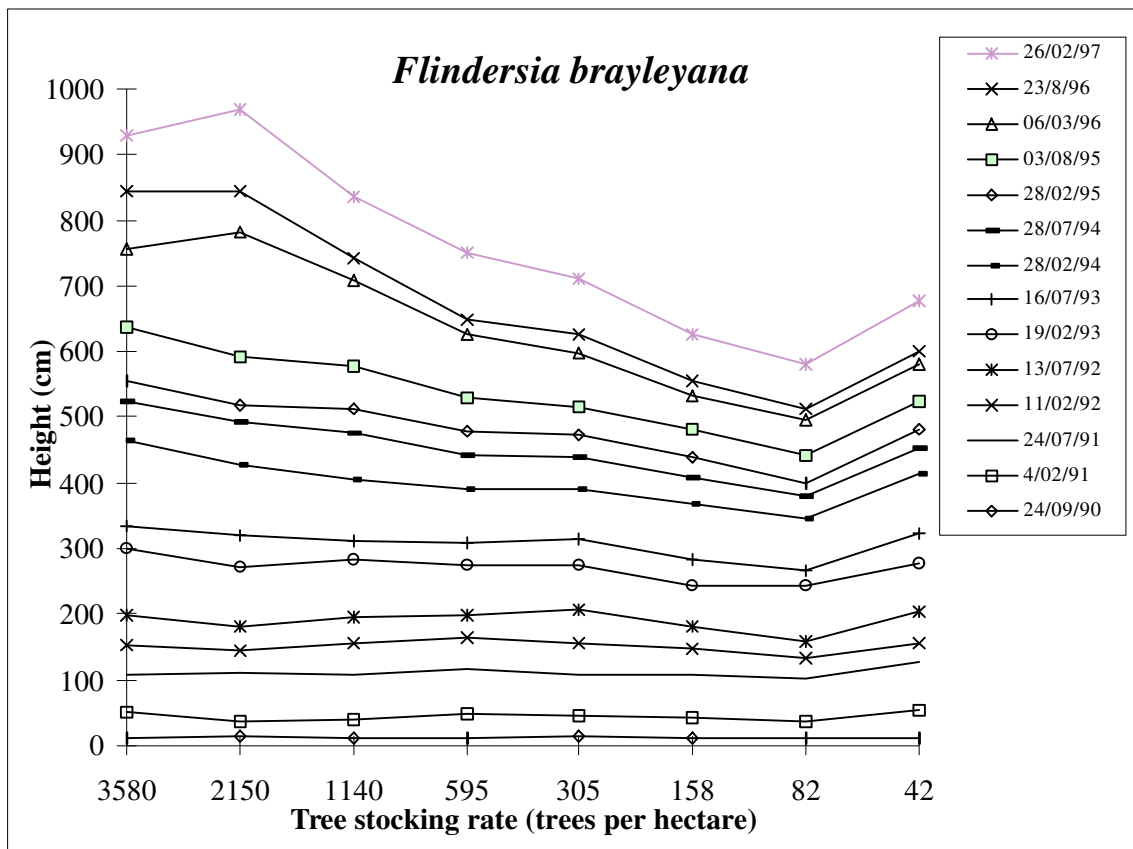


Figure 9b Queensland maple diameter growth (dbh) over time at different stocking rates.

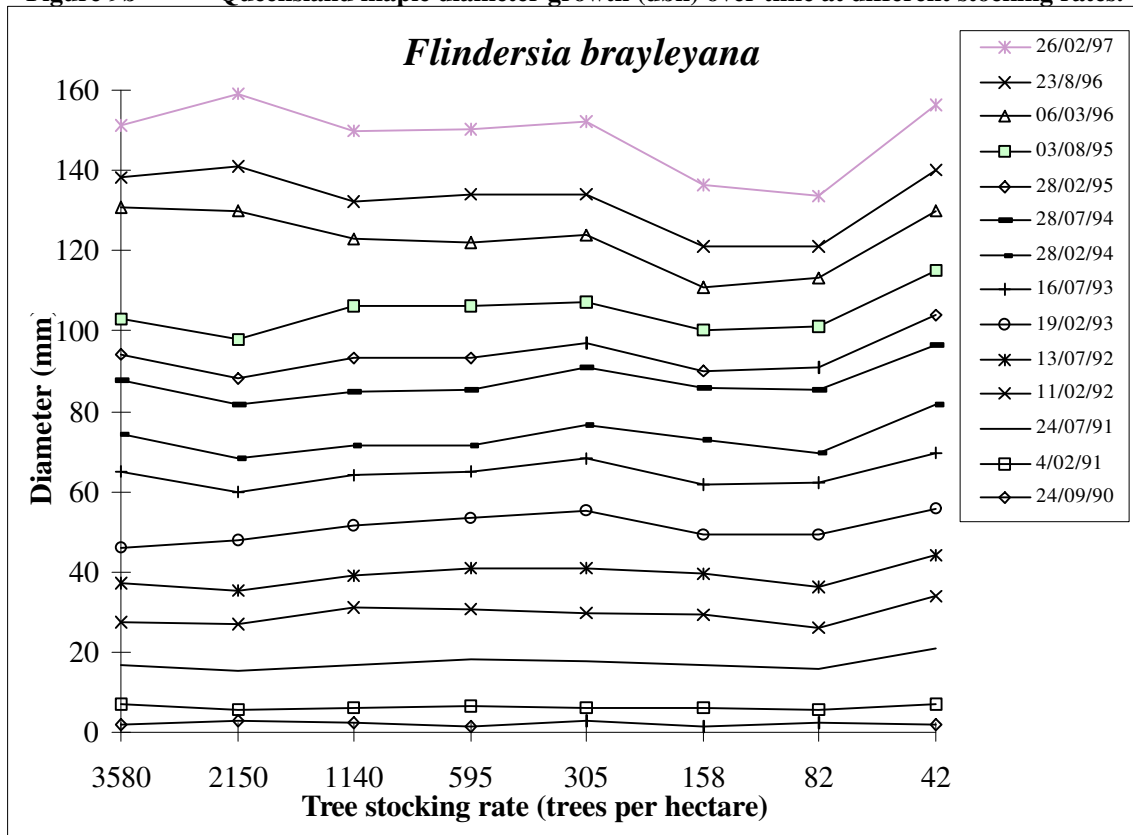


Figure 10a Queensland maple tree volume (cu. m) growth over time at different stocking rates

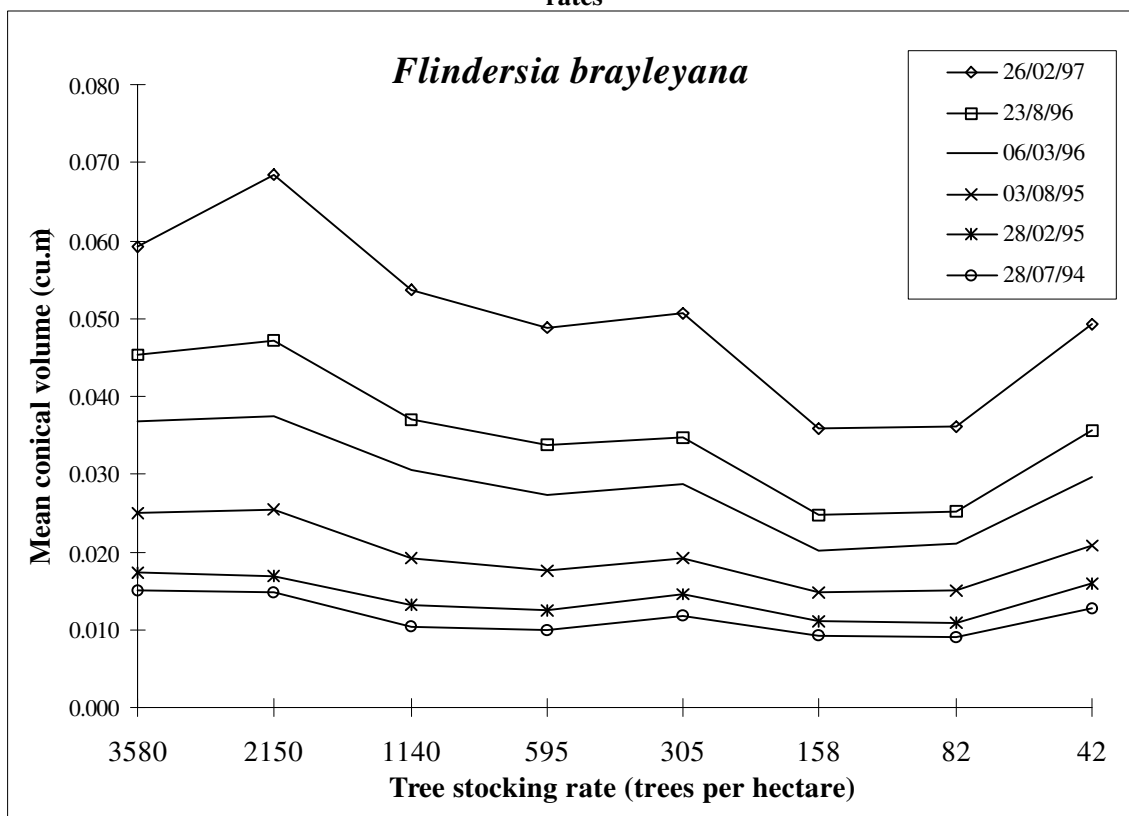
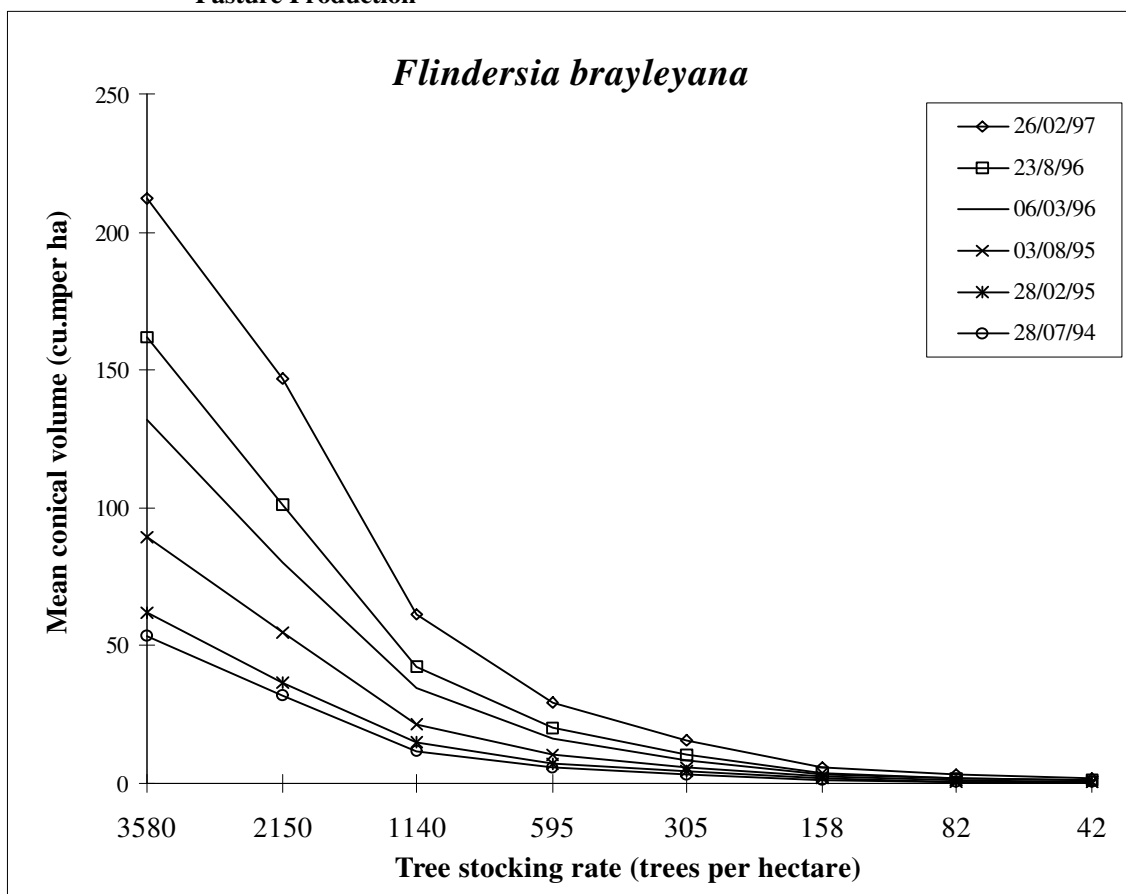


Figure 10b Queensland maple stand volume (cu.m per ha) growth over time at different stocking rates
Pasture Production



Pasture production (primarily Kikuyu grass, *Penisetum clandaetinum*) varied between 50-170 kg ha⁻¹ day⁻¹ at the site over the six years of this study as a consequence of variations in rainfall. Pasture production was not affected by trees until the trees were four years old (i.e. in 1994). In the wet season of that year, however, there was evidence of a striking decline in pasture production at the higher tree densities (Fig 11). This decline was most apparent in pasture beneath *Flindersia* trees and occurred at tree stockings in excess of around 80 trees per ha. A more complex pattern was observed beneath *Araucaria*. In this case pasture production was also reduced at the higher tree stockings but apparent improvements in pasture production were found at intermediate tree stockings (around 100-300 trees per ha) over that found at the very lowest tree densities. Signs of this apparent boost to pasture production beneath *Araucaria* trees (but not *Flindersia*) lasted until late 1995 but had disappeared by 1996. At the time of pasture assessment in that year, rainfall had been below average and it seemed that pasture production was reduced by both tree species at tree densities greater than 150-300 trees per ha. A similar pattern was found in 1997.

At the time the study commenced the dominant pasture grass in the area was Kikuyu grass. This continued to dominate the site although some broadleaved weeds became more prevalent at higher tree densities.

The nutrient concentration of pasture growing beneath trees planted at various tree densities is given in Fig 12. This shows that pasture nitrogen concentrations were highest (greater than 2.5 percent) at the highest tree densities but less than 1.8 percent when growing below trees planted at wider spacings; the improvement in nitrogen status was generally present at tree densities greater than 600 trees per ha. A similar trend was found for potassium although the difference was not as striking. However, the reverse pattern was found in the case of pasture phosphorus where lower concentrations were present in pasture where the trees were most densely planted (around 0.28 percent) and higher concentrations were found at lower tree densities (more than 0.40 percent). That is, the nitrogen to phosphorus ratio declined from a value of 11.6 at high tree densities to a value of around 4 at wider tree spacings. Pasture calcium and magnesium concentrations were similar at all tree densities.

Figure 11 Pasture production beneath hoop pine and Queensland maple grown at various tree densities after planting in June 1990.

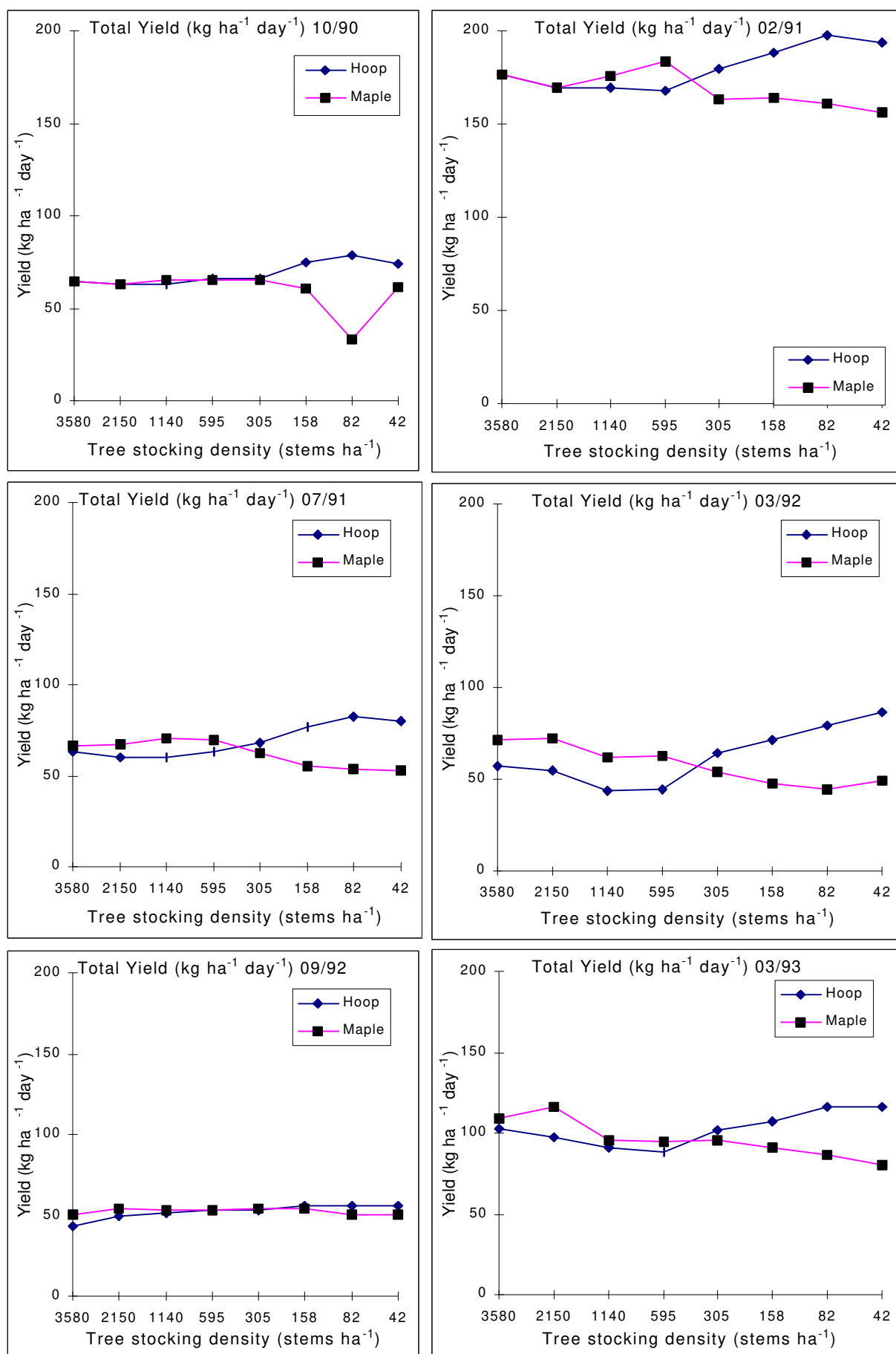
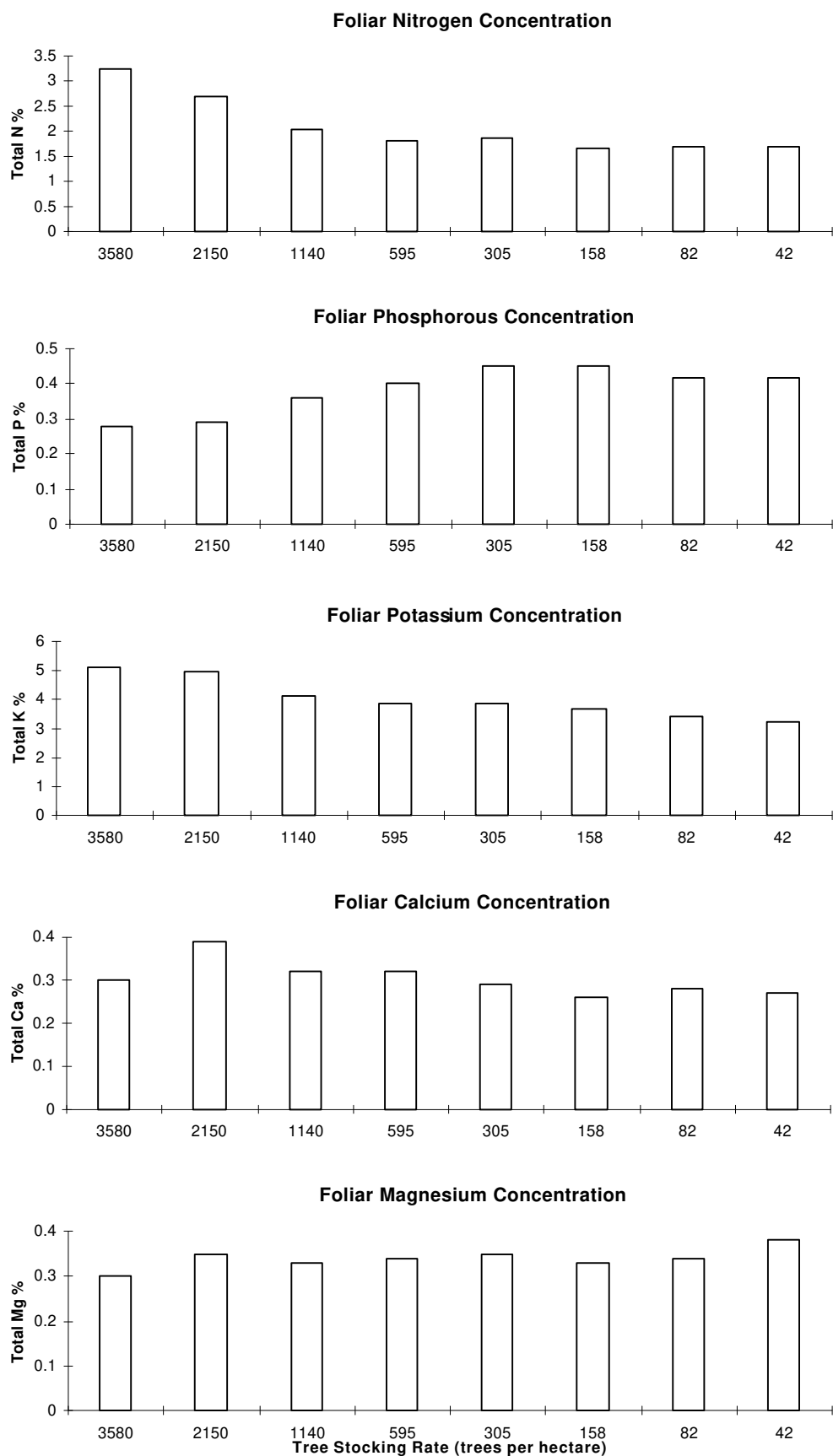


Figure 11 Continued

*

Figure 12 Nutrient concentrations in pasture grown beneath Queensland maple and hoop pine grown at various tree densities at five years after tree planting.



Discussion of Results of Tree Spacing and Pasture Growth Trial

Tree Growth at Various Planting Densities

The results from this spacing trial clearly demonstrate the beneficial influence of high tree stocking on height growth. However the difference between the two species in terms of their diameter growth at different spacings means that the shape of *Araucaria* trees is changed more by differences in tree stocking than is the shape of *Flindersia*. These differences may have implications for the ways in which plantations of these trees are managed. For example, it suggests that *Araucaria* may need earlier thinning than *Flindersia* to maintain optimum growth and form. More remains to be learned from this experiment as it ages about how to manage these species in plantations.

At close tree spacings there was an early canopy closure meaning that branches became shaded and did not develop beyond a centimeter or two in diameter. At wider spacings the lower branches were able to flourish and increase beyond this size. This has two consequences. One is that resources are channeled into branch growth rather than height or diameter growth. Another is that the potential quality of any log arising from these trees will be degraded by the knots arising from these branches. In managing this trial we were caught in a dilemma of needing to prune the trees to minimise this problem and leaving the trees unpruned to evaluate the extent to which plant resources are diverted to lower branch growth. We resolved this by pruning only the lower 2m of stem. In practice it would be preferable to carry out early and frequent pruning of all side branches once trees have reached, say 2 m tall, to ensure tree form is maintained and timber quality is maximised.

The need to prune is particularly acute in plantations using species such as *Flindersia brayleyana* where the seed is coming from mostly “bush” collections and where the market is peeler logs. Early and frequent pruning is likely to maximise quality but this is obviously expensive to carry out if the frequency is high. An unresolved dilemma, therefore, is whether less frequent but heavier prunings can be carried out (for example, up to 75 percent of the crown) without sacrificing growth increment. Further work is needed to resolve this issue.

A previous tree spacing trial using a Nelder wheel design found evidence of a “ripple” effect in which tree growth was eventually inhibited at the highest tree stockings by competition for water (Cameron *et al.* 1989, Eastham *et al.* 1988). In time the optimum growth was found at progressively wider tree spacings in the same way that a ripple spreads in a pond. In this case the tree used was *Eucalyptus grandis* and the commencement of the “ripple” was evident after 2.5 years. In the present trial the first signs of height growth inhibition have just appeared but the evidence of a diameter “ripple” is less clear and more time is needed to quantify the effect.

Pasture Production

Pasture production at the site prior to the trees developing was high compared with the values of 20 kg of dry matter per ha per day that are common at drier sites in the region (Cameron *et al.* 1989). This is largely a consequence of the good soils at the study site. Not surprisingly, the rapid tree growth had consequences for pasture production and little pasture production was found at the highest tree stockings because of canopy shade. What was surprising, however, was the evidence of the apparent boost to pasture production at intermediate tree stocking rates beyond the production achieved in more open plantings. This first became evident in 1994 when pasture production at wide tree spacings exceeded 100 kg per ha per day.

Such an effect has been observed before in C4 grasses and referred to as the “shade effect” (e.g. Wilson *et al.* 1986, Wild 1995). Wild (1995) presented evidence that the reason for this was that shade could stimulate the uptake of nitrogen by tropical grasses when their growth in full sunlight was limited by nitrogen deficiency and Wilson *et al.* (1986) suggest the mechanism for the “shade effect” is that shading alters soil moisture and the balance of nitrogen mineralisation and immobilisation in the soil allowing an increase in the amount of nitrogen available for pasture plants. Measurements of pasture nitrogen concentrations indicated a higher level was found at the highest tree stockings. A similar trend was observed by Cameron *et al.* (1989). However, there was no increase in pasture nitrogen concentration at the tree stockings at which the “shade” effect was most evident at the time.

This higher nitrogen concentration at high tree stockings might have been a consequence of the higher effective fertilisation rates (because trees were originally fertilised on a per tree basis). But if so, this should have also affected the pasture phosphorus concentrations and, paradoxically, these showed an opposite trend. Given this suggestion, it is interesting that the effect had disappeared in the assessment of late March 1996 when the rainfall in February and March was well below average and pasture production at the lowest tree stockings was less than 50 kg per ha per day.

While the work done on the “shade effect” elsewhere makes the suggestion of a soil nitrogen mineralisation explanation seem plausible, the observation that the effect was temporary and only found beneath *Araucaria* and not *Flindersia* is difficult to explain and must await further study. Likewise, further study is needed to explain the changes in pasture nitrogen and phosphorus concentration at the different tree stockings.

Whatever the final outcome of the “shade” effect it is clear that pasture production is usually inhibited beyond a certain tree density. In 5-6 year old agroforestry plantings using *Araucaria* and *Flindersia* that density is probably around 150 trees per ha or less. At these tree stocking levels heavy branch development is likely in most species and early as well as frequent pruning will be necessary to optimise timber value.

Implications and Recommendations

- (a) There are several high-value rainforest tree species that appear promising as plantation species for Australian farms with the appropriate soils and climates. These include *Flindersia brayleyana*, *Elaeocarpus grandis*, *Grevillea robusta* and the exotic species *Khaya nyassica*. The form of these species varies from moderate to good and improvements are likely to follow if further work is carried out to explore provenance differences within the species. A number of other species such as *Acacia melanoxylon* and *Rhodospaera rhodanthema* could be suitable if their form could be improved.
- (b) For best growth these require good site preparation and weed control. Early tree height growth (and reduced weed growth) is encouraged by high planting densities but initial tree spacings of at least 3 m (1100 trees per hectare) are probably most appropriate. High tree stockings would also have the advantage of allowing greater selection during thinning to compensate for the generally poorer tree form found as a consequence of using unimproved seed but would also cost more.
- (c) While no specialised work was carried out on the nutrition of these rainforest trees there is evidence that nutritional problems can develop in the early stages of growth before canopy closure on sites with soils that are regarded as “good” by Australian agricultural standards. This means fertilising is probably necessary at early stages and the nutritional requirements of these species deserves further study.
- (d) Early and frequent pruning is necessary to ensure knots are confined to the smallest possible size and do not develop to a size likely to affect timber quality. This pruning should begin when the trees are about 2 m tall. This need for pruning is particularly acute using the unspecialised seed collections available at present. Again, further work is needed to resolve the trade-off between pruning intensity and frequency.
- (e) Most of these rainforest trees can be grown in the open without the need for a shade or nurse crop to protect them. Mixed species plantings may have some benefits over single species monocultures but these benefits are difficult to quantify at present and may only develop over time. If timber production is a primary objective the numbers of species in mixtures should probably be kept to only around two or three species to simplify management.
- (f) High-value rainforest trees can also be grown at low planting densities in a manner that permits pasture production to be maintained. When trees are young a planting density of around 150 trees per ha should be suitable. However, some thinning may be needed to reduce tree stockings as the trees develop. Because wide tree spacings encourage lower branch development there is a need to ensure frequent and early branch pruning in these widely spaced trees to optimise timber quality.

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Appendix 1

Species Notes

Acacia melanoxylon (blackwood)

In terms of both height and volume, this species outperformed all other species in the trial. Many individuals were of poor form and were also badly affected by stem borers. However there was considerable variation in form and susceptibility to borers and some outstanding trees served as testament to the considerable potential of a selection program. The seed-stock for this (and most other spp) did not come from parent trees selected for timber production characteristics.

Araucaria cunninghamii (hoop pine)

As is consistent with the Queensland plantation experience with this species, growth rates for hoop pine were relatively slow during the first two years after planting. Growth rates have increased since then and are expected to continue this trend until age 40-50 years. The overall form rating for the species is high as is to be expected from stock which is the result of an intensive improvement program.

Argyrodendron trifoliolatum (white booyong)

A slow species in this trial, with a large variation in the performance of individuals. Trees tend to have many small branches forming a tight bushy crown. Apical dominance is strong with most individuals maintaining one leader.

Castanospermum australe (black bean)

Black bean was amongst the slowest of species in the trial. Insect damage to new growth has been significant during most but not all summers. Trees have been prone to producing epicormic side branches low on the bole which have had to be removed during pruning operations. Form pruning has left most trees with single leaders, although most pruned trees have been left with the legacy of crooked boles resulting from the selection of one of a number of high branch angled co-dominant leaders.

Cedrela odorata (cigar-box cedar)

This species has demonstrated impressive growth. However, form is generally quite poor with many trees having large multiple leaders arising from low down on the bole. Many of the form problems of this species have resulted from tip moth attack (most likely *Hypsiphyla robusta*) which occurred during the second summer after planting. The damage was unlike that which occurs to *Toona ciliata* in that little structural damage was caused. Instead, the effect appeared to have stimulated the development of axillary shoots resulting in multi-stemmed crowns. This phenomenon is not universal to the region. A number of nearby plantings have not developed the problem. Wind damage has been more common in this species than any other in the trial. Seven of a total of 28 trees have had major branches or leaders blown off.

***Cryptocarya erythroxylon* (pigeonberry ash)**

A poor performer. Last in height and volume rankings and with the highest mortality of all species with a total of 6 of the original 28 trees surviving. Post-graduate research at Queensland University has shown that young plants of this species experience photoinhibition in unshaded conditions. Growth rates for this species have improved as the plantation canopy has developed. As one of the few representatives of the later successional stages in rainforest development, it will be of great interest to follow the response of this species to the changing environment of the maturing plantation.

***Dysoxylum fraserianum* (rosewood)**

Heavily branched, multi leadered and slow growth. Very few individuals offer sawlog potential.

***Dysoxylum mollissimum* (red bean)**

A mid-range performer after six years with height and volume rankings falling within the lower half of the 16 spp. Most individuals hold large high angled branches and on some trees these large branches compete with the leader for dominance.

***Elaeocarpus grandis* (blue quandong)**

In terms of all-round performance, *E. grandis* has been the best of the sixteen species in the trial. Almost all individuals exhibited excellent form, height and volume growth, and there have been no insect or disease problems. Pruning is an easy operation with large lengths of clear bole between whorls of branches. A small number of trees produce some very low angled branches which are difficult to prune in a way which will not cause some defect.

***Flindersia brayleyana* (Queensland maple)**

A mid-range performer in terms of height, volume and other attributes including form.

***Flindersia schottiana* (bumpy ash)**

This species has not performed to expectations. Plantings on similar sites in the region have produced much better results. Measures from years five and six have revealed an increase in growth rate which may result in more promising future growth. Poor planting stock may be a reason for this unexpected result.

***Gmelina leichhardtii* (white beech)**

Growth of this species has been hindered by substantial annual defoliation by insects. Considerable variation is evident between individuals in resistance to insect attack. Form is generally good, with small branch diameters and straight boles being typical.

***Grevillea robusta* (southern silky oak)**

This species has performed very well in almost all respects. Form problems in some individuals due to wind damage has lowered the average form rating. The prevalence of wind damage to this species has been second only to *Cedrela odorata* in this trial.

***Khaya nyasica* (Nyasland mahogany)**

After a disappointing slow and diseased start (2 years) this African exotic now looks promising. Form is generally very good and stem volume at 6 years is 16% better than the tried and proven hoop pine. Branch development has been modest meaning that pruning is not difficult.

***Rhodosphaera rhodanthema* (deep yellowwood)**

Despite good stem volume production, the extremely heavy branching of this species presents problems for utilisation. Improvements could result from selection, frequent pruning and higher initial stocking rates.

***Toona ciliata* (red cedar)**

The cedar tip moth *Hypsiphyla robusta* has severely hampered growth of all trees. Initial hopes that the polyculture arrangement of the plantation may reduce the level of attack have not been realised. Many trees are mal-formed and multi-leadered as a result of the insect. A few individuals have retained the potential to produce a mill log. Despite the insect damage, most trees remain alive (78 percent survival).

Appendix 2

Summary of Post-Graduate Research Carried out on the Mt Mee Site

The following University of Queensland student projects were undertaken partially or wholly at Mt. Mee between 1990 and 1996. Although these used the Mt Mee trials for study, all were funded by the University of Queensland and no RIRDC funds were utilised. The project undertaken jointly by the two Dutch students was done while they were visiting the University. The abstracts have been taken from the respective theses or reports.

Abstracts

1. Ecophysiological characteristics of eight rainforest species established in mixed-species plantings – Catherine Drane (PhD submitted 1995)
2. Physiological aspects of growing cabinet timber species in plantations – Amanda Snell (PhD submitted 1996)
3. Pasture productivity below rainforest trees : an agroforestry trial – Oliver Woldring (BSc Honours 1995)
4. Mycorrhizae of tropical rainforest trees – Veronica Matthews (BSc Honours 1995)
5. Leaf herbivory in mixed species plantations and natural rainforests in south-east Queensland - Jorn Van Gestel and Gijs Kurstjens (Research Report, University of Nijmegen, Netherlands, 1992)
6. Colonisation of a rainforest plantation - Martin Juniper (Third Year Undergraduate student project, 1996)

ECOPHYSIOLOGICAL CHARACTERISTICS OF EIGHT RAINFOREST SPECIES ESTABLISHED IN MIXED-SPECIES PLANTINGS

Catherine Mary Drane

Due to the rapidly declining availability and production of rainforest cabinet timber in Australia and elsewhere, it has become necessary to obtain a means of rapid appraisal of species performance in plantation trials. Physiological assays were utilised to investigate establishment strategies and species/site selection for the plantation growth of rainforest timbers on ex-rainforest land. Two trials have been established in sub-tropical south east Queensland to assess the relative performance of a number of high value rainforest cabinetwoods when grown in mixed species plantations. To this end a physiological survey of eight species was undertaken:- *Acacia melanoxylon*, *Argyrodendron trifoliolatum*, *Castanospermum australe*, *Cryptocarya erythroxylon*, *Elaeocarpus grandis*, *Gmelina leichhardtii*, *Grevillea robusta* and *Rhodosphaera rhodanthema*. These species represent components of the successional sequence found in the remnant rainforests extant in the environs of the study sites.

Information on the growth rates and the general performance of these species in cultivation was recorded. Quantitative information on the physiological attributes of each of the species was gathered through periodic studies of photosynthesis and leaf water relations under different climatic conditions. Glasshouse studies yielded additional information on growth and other responses to incident light flux density.

Species that displayed some early successional attributes i.e. *Acacia melanoxylon*, *Elaeocarpus grandis*, *Grevillea robusta* and *Rhodosphaera rhodanthema*, exhibited the highest growth rates in the Mt. Mee plantation during the first four years of establishment. The other species were able to survive and grow, albeit at lesser rates. *Cryptocarya erythroxylon* performed poorly under open grown conditions such as those experienced in newly established plantation configurations. This reflects this species' generally accepted position as a mature phase species. Field data in combination with glasshouse trials indicate that the slow growth of *Cryptocarya erythroxylon* may be the result of photoinhibitory or photorespiratory effects.

For six of the eight species, net maximum photosynthetic rate and maximum conductance were found to correlate well with height growth and stem volume growth. Plants representing the early secondary successional stage displayed the highest rates of photosynthesis and conductance, and the greatest growth in the plantation environment. The remaining two species, *Cryptocarya erythroxylon* and *Elaeocarpus grandis* conformed to the postulated successional sequence, but it was necessary to utilise other parameters for their respective assays. Mature phase physiological characteristics in the case of *Cryptocarya erythroxylon* and leaf area compensatory mechanisms for *Elaeocarpus grandis* proved the most reliable indicators for these species. It was determined that the modelling the growth of species in such plantation configurations can be achieved via the assay of diagnostic physiological attributes and simple morphological features. Thereby, it will be feasible to achieve a dramatic reduction in the time-frame for assessing species performance across the spectrum of environmental conditions encountered in the field.

PHYSIOLOGICAL ASPECTS OF GROWING CABINET TIMBER SPECIES IN PLANTATIONS

Amanda Jane Snell

Australia's forests have provided the community with timber and other wood products in the past, but presently, there is no sustainable production of cabinet timber species coming from either Crown or private forests, and there is a serious trade deficit in forest products. One solution to this dilemma involves the incorporation of cabinet timber trees into farming systems. However the ecophysiology of species-environment relations is poorly understood. This thesis explores some physiological aspects associated with growing cabinet timber species in plantations.

A physiological survey of seven *Flindersia* species was undertaken in the first year of establishment at two adjacent mixed species plantations at Canungra in south-east Queensland. One plantation consisted of species endemic to the mesic climate of north Queensland (*F. brayleyana* F. Muell., *F. pimenteliana* F. Muell. and *F. iffaiiana* F. Muell.); whilst the other consisted of species naturally occurring in the more xeric climate of south-eastern Queensland (*F. australis* R. Br., *F. bennettiana* F. Muell., *F. schottiana* F. Muell., and *F. xanthoxyla* (Cunn. ex Hook.) Domin). The site was subjected to frosts and low rainfall during winter. All individuals endemic to north Queensland (mesic) died during winter, yet most individuals naturally occurring in south-east Queensland (xeric) survived. Maximum rates of assimilation declined in all species during winter, and there was little recovery in the xeric species during spring, with only *F. australis* making a slight increase in gas exchange rate. The xeric species tended to have greater maximum rates of assimilation than the mesic species during the dry winter months, although only *F. brayleyana* (mesic) showed a significantly lower rate during summer, when water supplies were adequate. The xeric species also tended to have higher stomatal conductances and transpiration rates than the mesic species during the dry winter months.

When three *Flindersia* species were subjected to a glasshouse drying cycle, the water use efficiency in all species increased with drought. The xeric species (*F. australis* and *F. schottiana*) tended to have greater water use efficiencies than did the mesic species (*F. brayleyana*) in each treatment. Leaf water potentials remained relatively high in the three *Flindersia* species studied when compared with the more xeric *F. collina* (Yates *et al.*, 1988). Gas exchange rates decreased significantly in all species in response to drought.

The physiology of *Araucaria cunninghamii* Aiton ex D. Don and *F. brayleyana* at eight different planting densities in a Nelder Wheel at Mt Mee in south-east Queensland were monitored between August 1992 and December 1994. Planting density effects on maximum photosynthetic rates were most apparent in *F. brayleyana*, with greater rates occurring in trees planted at low densities (42 - 158 stems ha⁻¹) than those planted at high densities (2150 - 3580 stems ha⁻¹). *A. cunninghamii* had higher rates of photosynthesis at intermediate densities (305 - 1140 stems ha⁻¹) than at either high or low planting densities. *A. cunninghamii* maintained high water potentials when surrounding individuals of *F. brayleyana* displayed low potentials. This was attributed to the deeper rooting system in *A. cunninghamii*, which, when coupled with the low stomatal conductance in this species, would contribute to increased drought resistance. Growth rates were affected less by planting density in *A. cunninghamii* than in *F. brayleyana*. The sensitivity of *F. brayleyana* to seasonal water deficits may be more pronounced in south-east Queensland than its natural environment. The ability of *F. brayleyana* to compete for soil moisture either between individuals of the same species or with individuals of deeper rooted species is diminished when planted at high density at sites where seasonal droughts may occur.

Growtube®s reduced transpirational water loss from seedlings, but increased stomatal conductance when compared with control leaves at similar photosynthetic rates in three

Flindersia species (*F. australis*, *F. brayleyana*, and *F. schottiana*). Relative humidity and CO₂ concentrations were greater and leaf-to-air vapour pressure deficits were lower inside the enclosures than in ambient air. Photosynthetic rates of leaves of all species inside the tubes, were greater than for control plants at all light levels. Growtube®s should be a useful silvicultural aid for the establishment of seedlings where water loss is limiting to growth and survival, but where water supplies are sufficient to produce overnight condensation within the tube, and high relative humidities during the day.

The results of this thesis are relevant to species selection criteria in areas where establishment of cabinet timber species can be limited. *A. cunninghamii* is relatively more drought resistant than any of the *Flindersia* species studied, but may be limited by other factors such as light availability. *Flindersia* seedlings grown on plantation sites under drought conditions would have diminished canopy assimilation. Evidence suggests that biomass production is correlated with water use, therefore any plan towards intensive management of *Flindersia* species in plantations should incorporate a selection of sites, species and silvicultural practices which enhance water availability and reduced leaf-to-air vapour pressure deficit. The high cost of plantation establishment can then be justified by increasing the sustainable yield beyond that previously attainable with natural forests.

Abstract 3

PASTURE PRODUCTIVITY BELOW RAINFOREST TREES : AN AGROFORESTRY TRIAL

Oliver Woldring

The relationship between the stocking density of two rainforest trees and pasture productivity, with particular emphasis on the role of the light microclimate, was assessed in a Nelder wheel plantation. Queensland Maple (*Flindersia brayleyana*) and Hoop Pine (*Araucaria cunninghamii*) were planted in the winter of 1990 in densities ranging from 3580 to 42 stems per hectare (sph). The study spanned from spring 1994 to autumn 1995 when trees were 4 to 5 years old.

Yield of the pasture, dominated by the C₄ grass Kikuyu (*Pennisetum clandestinum*), was found to be very closely related to transmitted PAR at densities greater than about 595 sph where shading was significant. The light quantity was found to vary between species, depending on tree density. The tree species were also shown to have differing affects on light quality with the greatest reductions in red/far-red ratio values below dense Hoop Pine canopies. At densities where light quality was reduced, considerable increases in internodal length and blade length were found in Kikuyu.

At densities less than about 595 sph where the levels of shade were negligible, pasture yield was primarily determined by the trees affect on soil moisture. When influenced by Queensland Maple in high rainfall years pasture yield was reduced, probably as a result of root competition, at densities as low as 82 sph. In contrast, below Hoop Pine pasture yield increased with increasing densities (up to 595 sph). It is speculated that this was a result of the increased protection afforded by the denser, lower canopy of Hoop Pine. At low tree densities, where protection is minimal, pasture yield was lower when influenced by Hoop Pine compared to Queensland Maple, suggesting greater root competition.

Pasture nutrient concentrations generally increased with higher tree densities and nutrient yield reflected total pasture yield. As a generalisation, however, nutrient levels do not appear to be important in determining pasture productivity although the level of soil nutrients and the affects are not known.

This report is one of few that have shown increases in pasture production below shade of non-leguminous trees, and the first to discuss the effects of rainforest trees species on productivity. Whilst this work raises many questions, it suggests that current thinking regarding the negative effects of trees on pasture may be wrong and more detailed research is required.

Abstract 4

MYCORRHIZAE OF TROPICAL RAINFOREST TREES

Veronica Matthews

Most knowledge on mycorrhizal associations has been derived from studies in temperate areas and from controlled glasshouse experiments. This investigation, therefore, addressed two current needs by examining the mycorrhizae of tropical rainforest trees in the field.

The sites of investigation comprised a mixed species plantation trial composed of sixteen high-value timber species; the pasture surrounding this plantation; and adjacent areas of natural rainforest. These sites were studied over two seasons to examine seasonal variation in mycorrhizal infection.

Two approaches were employed to monitor the mycorrhizal status of the rainforest trees. Roots were examined for infection and soils were examined for mycorrhizal spores. For the two data sets collected, all species formed vesicular-arbuscular mycorrhizal associations including *Grevillea robusta* which had proteoid roots. The extent of infection varied considerably between species both in space and time. The only species to exhibit consistent high infection was *Rhodosphaera rhodanthema*.

Since the mycorrhizal association is essentially a three-way interaction between the host, the mycorrhizal fungus and the environment, numerous factors may exert some effect over the extent of infection. Considered in this report are various host features, such as their rooting morphologies and growth rates, as well as different environmental parameters such as rainfall, soil pH and soil nutrient content. VAM infection generally decreased as the pH and the moisture and nutrient contents of the soil increased.

The distribution of sporulating mycorrhizal species, as indicated by spore type and abundance, was also dependent on environmental influences such as soil moisture and nutrient content. Although there was an insignificant difference in spore abundance between sites there was a general trend of larger spore populations in the plantation and pasture soils which had higher nutrient contents. The average spore numbers sampled in the plantation, pasture and rainforest were 176, 293 and 97 respectively. Mycorrhizal species diversity was low at all sites with only four species found. However, the relative effect with a two-fold decrease in spore numbers in summer, when there was greater rainfall and therefore increased soil moisture.

Judging from the results obtained, the total variation in mycorrhizal infection cannot be explained by one factor alone. The multitude of factors influencing mycorrhizal systems is likely to explain their apparent complexity. Understanding the ecological role of tropical mycorrhizae will require more extensive studies than the one performed here. Knowledge of the favourable distributions of effective mycorrhizal species has important implications for forestry and horticulture.

LEAF HERBIVORY IN MIXED SPECIES PLANTATIONS AND NATURAL RAINFORESTS IN SOUTH-EAST QUEENSLAND

Jorn Van Gestel & Gijs Kurstjens

There is widespread concern at the rate of conversion of tropical forest to other forms of land use. As in many other (sub-)tropical regions, the rainforests in Queensland, Australia, are vanishing at an alarming rate: up to 75% of the original forest has already been cleared.

Increasing popular concern has resulted in the transfer of much of the Australian rainforest estate to land tenures that preclude commercial timber production. But, because of the continuing demand for rainforest timbers, one of the consequences was a rapid escalation of timber prices.

At first sight, an ideal solution could be the establishment of the desirable timber species in plantations, in this way protecting the still unlogged, natural rainforests. However, most monoculture plantings of rainforest species were reported to have been disappointing, with the exception of Hoop Pine (*Araucaria cunninghamii*).

Polycultures of tree species are difficult to manage and their successful establishment and regeneration require understanding of the physiological characteristics and ecological requirements of the species. The same constraints apply to the management of natural areas. Still, much is unknown about the ecology of tropical rainforests.

Within this framework, we were given the opportunity to initiate a new research project, dealing with herbivory in subtropical rainforests. This manuscript is the report of a nine months research period, as it has been carried out under supervision of Dr. D. Lamb, Senior Lecturer of the Department of Botany, in the period from October 1 99 1 till July 1 992.

Research on leaf herbivory and leaf turnover has been carried out on two mixed species plantations and several sites (on different altitudes) in subtropical rainforests of South-East Queensland, Australia. For ten species, herbivory was measured over a period of five months. Values obtained in this relatively long-term experiment were higher than estimations from one-time measurements (the current methodology), as totally damaged leaves could be included and more categories than eating were used.

Levels of herbivory did not vary between the trees grown in the polyculture and nearby natural rainforests. However, on higher altitudes insect damage on leaves was far less than in lowland rainforests.

There was a strong correlation between leaf longevity and the level of herbivory which suggested that long-living leaves are better defended against herbivores than short-living leaves. Our results gave support to the current theories concerning plant herbivore interactions.

COLONISATION OF A RAINFOREST PLANTATION

Martin Juniper

The purpose of this investigation is to document and examine the seedling dispersal within a rainforest plantation. The plantation was planted in 1990 on a farm at Mt Mee. The species that were found included: the *Solanum mauritianum*, *S. capsicoides*, *Clerodendrum floribundum*, *S. stelligerum*, a species from the family Euphorbiaceae, *Acacia melanoxylon* and the *Trema aspera*. The species were found to be early successional weedy species, growing in different levels of light, from areas other than the plantation, probably as a result of dispersion by birds and most were affected by root competition and nutrient availability.

PRINTERS INSTRUCTIONS

Back cover blurb:

Until recently the local supply of high-quality tropical rainforest timbers came almost entirely from state forests in Queensland's wet tropics. Logging in these forests ceased in 1988 at the time of listing of the World Heritage Area, causing a substantial decline in the supply of these timbers to the market.

An obvious question to ask is whether some of these high-value species might be grown in plantations?

This report describes the early results of two trials undertaken to examine the growth of several high-value rainforest tree species when grown in farm plantations in southeast Queensland.

The first trial examined the potential for growing trees in a farm woodlot devoted exclusively to this purpose, while the second trial examined the potential for combining pasture production and tree growing on the same land.

This report, the latest addition to RIRDC's diverse range of over 250 research publications, forms part of the Joint Venture Agroforestry Program, which aims to integrate sustainable and productive agroforestry within Australian farming systems.