ANATOMICAL AND PHYSIOLOGICAL VARIATIONS IN CERTAIN SELECTED SPECIES AND PROVENANCES OF *Acacia*

By

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THESIS

Submitted in partial fulfilment of the requirement for the degree of

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COLLEGE OF FORESTRY

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2001

DECLARATION

I hereby declare that the thesis entitled '**Anatomical and physiological variations in certain selected species and provenances of *Acacia***' is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or any other similar title of any other University or Society.

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We, the undersigned members of the Advisory Committee of Mr. Santhosh Jacob, a candidate for the degree of Master of Science in Forestry, agree that the thesis entitled **'Anatomical and physiological variations in certain selected species and provenances of *Acacia*'** may be submitted by Mr. Santhosh Jacob in partial fulfillment of the requirement for the degree.

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Dedicated to the loving memory of my dear father
For
what I have today and hope to be in future

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For
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INTRODUCTION

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Determination of the geographic sources within a species that should be used in a given area is known to be the first logical step in the genetic improvement programme of any forest tree species. Provenance trial, a study of the available variations in the entire range of any species and determination of population capable of providing the best tree, will help to identify the most suitable geographic source for afforestation and for further breeding programme. Provenance trials to evaluate the growth performance, stem form, wood quality, various anatomical and physiological properties, susceptibility to pest and diseases etc., is the first step in a genetic improvement programme component of plantation establishment. The primary aim of such trials is to identify the suitable provenance for large scale planting locally.

The genus *Acacia* is known to have many species, which have shown their potential as multipurpose species for good quality wood production, non-wood timber products, soil conservation etc. There are about 1100 species in this genus, of which over 850 are indigenous to Australia and neighbouring Papua New Guinea (PNG) and Indonesia. The remaining are endemic largely to Africa and tropical America. Of these tropical species, *Acacia mangium* Willd., *A. auriculiformis* Cunn. ex., Benth, *A. crassicarpa* Cunn ex., Benth and *A. aulacocarpa* Cunn. ex., Benth are the more widely planted ones. They demonstrated an ability to survive and grow rapidly in a wide range of environment with low soil nutrients.

A. mangium is one of the most widely planted acacias in the humid or sub humid tropics. It has a fragmented natural distribution, which stretches from Indonesia to Iriyan Jaya, the Western province of Papua New Guinea (PNG) and northeast Queensland in Australia. The main range from just above mean sea level to about 100m with an upper limit of 780 m. Distribution is strongly influenced by rainfall patterns and soil drainage.

In Australia, the *A. auriculiformis* occurs on Cape York Peninsula, Queensland and in the north of Northern Territory in Papua New Guinea the species occur in the Western province and Central province. The distribution in Indonesia is restricted to the South Eastern region of Iriyan Jaya and Kai group of Island. In most locations the species occur on the banks of rivers and streams including areas immediately behind mangroves along saline estuaries. The latitudinal range is from $8\text{-}16^0$ S` and altitudinal range stretches from sea level to 400 metres with the main occurrence below 100 metres.

A. crassicarpa is a fast growing tropical tree with wide adaptibilty under natural condition than the other tree species ranging from the areas of impeded drainage to dry wood land sites in Northern Queensland. *A. crassicarpa* has been found to be the most vigorous colonizer on the degraded soils following slash and burn cultivation in Papua New Guinea. The species is also reported to be suitable for afforestation. It occurs in Queensland and extends to the tip of Cape York Peninsula. It is wide spread in the western province of Papua New Guinea, and in adjacent areas of Iriyan Jaya, Indonesia. Latitudinal range is $8\text{-}20^0$ S` with mean altitudinal occurrence from sea level to 200 metres

A. aulacocarpa is one of the largest *Acacias* which is commonly found in monsoon vine-forest, on the margin of rain forest along water courses extending into open eucalyptus forest. *A. aulacocarpa* has the widest distribution among the four species with a latitudinal range from 6-30^0 S` and altitudinal range from near sea level to 200 metres. It wide spread in the Western Province of Papua New Guinea and adjacent area of Indonesia.

About 40 species of *Acaccias* are found to be indigenous to the Indian subcontinent. A few more have been introduced from Australia and Africa. *A. dealbata* link, *A. decurrens* Willd., *A. mearnsii* de Willd and *A. pycnantha* Benth., are few of the important introduced species. Some of them are known to have high economic value in our country.

Among the exotic acacias *A. auriculiformis*, is being planted on a large scale throughout the state of Kerala on account of its fast growth and superior wood qualities (Wu and Wang, 1988). The wood make attractive furniture, door frames, window parts, cabinets and sliced veneer. In addition, the wood is used in paper and pulp manufacture. *Acacia mangium* a more recently introduced species also is being tried for its large scale planting in the present agro climatic condition.

The physiological process of the trees constitutes the machinery through which heredity and the environment operate to control growth and quality. Understanding the physiological differences among the natural populations of a species can be useful for developing a successful tree improvement programme. Tree growth and wood quality are greatly influenced by their anatomical characteristics as well. Therefore improvement programmes should include determining the amount, cause and nature of such variation in the species and how this variation can best be used.

Considering the above, the present study was taken up with the objective of evaluating the anatomical and physiological variation among certain selected provenances of four species of *Acacia* namely, *A. mangium* Willd., *A. auriculiformis*, Cunn. Ex., Benth., *A. crassicarpa* Cunn ex., Benth., *A. aulacocarpa*, Cunn. ex., to correlate this with their growth characteristics. The ultimate objective of the project was to identify the most suitable species/ provenances from among these for the ecoclimatic conditions of Kerala.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Genetic variability within a species is the basis for any tree improvement programme. The simplest method is through the exploitation of variability within a species existing between geographic sources (provenances), sites, stand, individual trees within stand and even within individual trees (Zobel and Talbert, 1984). The term 'Provenance' is a synonym for 'Origin' or geographic race (Rao, 1992) which usually denotes the original geographic area from where seeds or other propagules have been obtained. The word is being used by tree breeders to mean "ultimate natural origin" (Tewari, 1994). Nevertheless, the term has been variously defined in the literature. Some of the definitions of provenance are:

(i) a sub-division of a species consisting of genetically similar individuals, related by common descent and occupying a particular territory to which it has become adapted through natural selection (Wakely, 1959), (ii) the geographical source or place of origin from which a given lot of seeds or plants was collected, the material from such a source or origin, often restricted to imply material from a specified race (Empire Forestry Association, 1953), (iii) the original geographic source of a lot of seed (or pollen) (Wright, 1962), (iv) the geographic area and environment to which the parent trees, etc., are native and within which their genetic constitution has been developed through natural selection, (Society of American Foresters, 1971) and (v) it is the area on which any stand of tree is growing, the stand may be indigenous or non-indigenous (OECD, 1971).

2.1 Provenance testing and its significance

Success in the establishment and productivity of forest tree plantations is governed largely by the species used and the source of seed within species (Lacaze, 1978; Kumaravelu *et al.*, 1995). No matter how sophisticated the breeding techniques, the largest, cheapest and fastest gains in most forest tree improvement programmes are obtained by using suitable species and seed sources within species (Zobel and Talbert, 1984). Provenance research therefore is having paramount importance.

Provenance test is an experiment in which seeds are collected from a number of widely scattered stands (usually natural) and the seedlings are grown under similar conditions (Wright, 1976). Provenance testing has two main objectives - (i) to select the best performing and adapted seed source/provenance for further use in establishing large scale plantations (Kapur and Dogra, 1987; Tewari, 1994) and ii) for use as the best adapted and most productive base population for use in selection and further genetic improvement work (Tewari, 1994).

According to Nanson (1972) the first logical step in the breeding programme of any forest tree species is provenance testing. The significance of genetic variation studies and provenance testing in forest tree improvement is very well raised by different authors like Pryor (1963); Calaham (1964) and Wright (1976). In order to provide a sound choice of species and provenances for planting, extensive systematic exploration and testing are required (Burley, 1980; Palmberg, 1981; Turnbull, 1983). It can be said that the determination of the species or the geographic sources within a species that should be used in a given area is the first step in any tree improvement programme. Forest tree improvement programme starts with the study of available variations in the entire range of species distribution and delimitation of population capable of providing the best trees. This is done by provenance testing.

Systematic provenance testing was initiated in Europe and North America at the beginning of this century and international co-operation in provenance testing became a reality for organised seed source collection and distribution in the 1930's. International co-operation on *Picea abies* (Norway spruce) started with the IUFRO provenance trials in 1936 (Dietrichson and Lines, 1977). Provenance research in Canada also started in the late 1930's (Ying and Morgenstern, 1987).

In a provenance trial it is possible to measure many characteristics of nursery trials and subsequently in field-survival, growth pattern, morphology, chemistry and anatomy of trees (Tewari, 1994).

Substantiating the need for provenance testing Vivekanandan (1975) observed that with large scale planting of various species it is imperative that seeds of genetically improved quality and right provenance be used to raise plantation to produce timber of derived quality in the shortest possible time with minimum input of money and manpower.

2.2 General procedure of provenance testing

Zobel and Talbert (1984) have suggested two approaches for doing provenance testing. They are (i) range-wide tests and (ii) limited range tests. In range wide test, for a species with a comparitively small range, test trees are selected from 20 to 30 localities, and for species with larger range test trees are selected from 50 to 200 localities. Limited range tests are often used as follow-ups to range wide tests to sample intensively the region proved to give the best seed in general. Different experimental designs are adopted in provenance testing, which include randomised complete block design, incomplete block design, lattice design, fully randomised design, non orthogonal block design, lattin squares, family block designs, and systematic design.

Assessment of provenance trial is a lengthy and expensive process. So only practically important trials with substantial experimental variation are taken for assessment. Assessments in field are usually made on all times (Zobel and Talbert, 1984). Wright (1976) proposed a simplified design for combined provenance-progeny testing. It is said that with this the combined test can be done as simply as an ordinary provenance.

2.3 Provenance tests on various species

A review of the results of provenance trials carried out in some of the forest tree species other than the species used as experimental material is described below.

2.3.1 *Albizia*

Protein, oil, carbohydrate and starch contents of seeds of 12 provenances of *A. lebbeck* collected from sites in North and South India varied significantly (Kumar and Toky, 1994). In another report of Kumar and Toky (1996) significant differences in biometrical characters were also found among the 12 provenance selected for the trial. However, the variations were random and did not show significant relationship with the latitude or longitude of seed source.

2.3.2 *Casuarina*

Seeds of eight provenance of *Casuarina* were sown in the nursery beds and the height and collar diameter of 25 seedlings of each provenances were recorded after six months. Significant differences among provenances were noticed (Toky and Bisht, 1991).

Mishra and Banerji (1995) gave an account of provenance trial with 19 provenances of *Casuarina* species collected from different countries and found that the overall performance of *C. Cunnighamiana* and *C. equisetifolia* collected from Australia, Egypt and Israel were found to be the best.

2.3.3 *Dalbergia*

The improvements of Shisham (*Dalbergia sissoo*) has remained more or less stationary in India due to non-availability of germplasm of divergent forms. A provenance study, of *D. sissoo* has been laid out at Kanpur using six provenances and all belonging to UP region only (Gupta *et al.*, 1992). Data showed marked differences among the provenances. In another study, tree height, crown spread, self-pruning ability and age showed variation among provenances (Dhillon *et al.*, 1995)

Provenance trials in *Dalbergia* were conducted by Neil (1990), White *et al.* (1990) and Dhillon *et al.* (1995) also.

2.3.4 *Acacia nilotica*

Accumulation of free-proline is a general characteristic in this species. A comparative study of different provenances for the free-proline content in leaves of *A. nilotica* was done by Bagchi and Singh (1994). It is concluded that provenance variation in free-proline content exists and it is not related to the geographical distribution.

Results on height, volume index and diameters at base and diameter at breast height were evaluated from 10 provenances of *Acacia nilotica* (L.) Willd. ex Del (Babul) at the Forestry Research Farm of JNKVV, Jabalpur under rainfed conditions during the year 1993. Correlation analysis revealed significant positive association of volume index per tree with all characters. The four years result showed that there were significant differences between provenances in height, volume index, diameters at base and diameter at breast height (Krishnan and Toky, 1995).

2.3.5 Pines

Introduction trials on a systematic and regular basis were attempted in different parts of the country beginning from 1958, to identify the most promising species and their provenances for large scale plantation activity.

2.3.5.1 *Pinus caribaea*

Performance of this species was evaluated in relation to soil properties of each zone by Bari and Prasad (1989). In another species cum provenance study, height and diameter were analysed by Dwivedi and Thapar (1990). Among species, *P. caribaea* was found to be the best performer.

Dutt and Jamwal (1995) gave an account of growth and performance of four provenances of this species in Jammu-Tawi. Provenance x Site interaction was estimated for tree height and girth at breast height at three Nigerian Savanna sites and there was no significant provenance x site interaction in any of the two growth characteristics examined (Otegbeye, 1995).

Results on seed germination, height growth, diameter growth and revival percentage were evaluated from a provenance trial at Orissa by Swain and Patnaik (1996). It was established that there is a wide variation in germination percentage among the provenances but no corresponding effect on survival percentage.

2.3.5.2 *Pinus oocarpa*

Performances of the different provenances have been reported by Vivekanandan (1977), Greaves (1983), Bari and Prasad (1989) and others.

A study conducted by Otegbeye (1990a) showed no significant difference among provenances. Similar results were also obtained by Zashimuddin, *et al.* (1991) in a trial conducted at Bangladesh. It was concluded that provenance trials with more seed sources might be established at various locations in Bangladesh to select the best provenances of the species of available.

2.3.5.3 ***Pinus patula***

The survival, growth, yield and wood basic density of three provenances of this species revealed no significant difference between provenances (Nassar *et al.*, 1993. But at the same time significant difference were reported by Nshubemuki *et al.* (1996). In a trial conducted at the same place where earlier work was done.

2.3.5.4 ***Pinus radiata***

Genetic variation in height, diameter at breast height, volume per tree, stem form, crown form, resistance to *Pineus pini* between 18 provenances and two genetic controls were analysed at age four and eight years at six sites in South Africa (Falkenhagen, 1991).

Prominent variations between provenances were observed in a provenance trial involving 18 provenances from 1978 International Collection (4 from Ano Nuevo, 6 from Monnterey, 3 from Cambria and 1 each from cedros and Guadaluge islands, plus 3 controls) grown at two locations in Greece in respect of tree height, diameter at breast height, bark thickness, stem straightness, growth form, number of whorls, number of branches per whorl, branch diameter and resistance to frost. The difference between the provenances within population were significant for all characters studied, indicating that selection within the best populations (Ano-Nuevo and Monterey) can be practised without a concern at the provenance level (Matziris 1995).

Alia *et al.* (1993), gave an account of performance of provenances of *Pinus pinaster* on five locations in central Spain in four replicated complete block design provenance tests. Total height, diameter, survival and stem form were analysed at age of 19 years. For height and diameter, site had the predominant effect, but high provenance site interaction was found.

2.3.5.5 *Pinus sylvestris* L. (Scot pine)

In Canada, provenance tests of scots pine have shown that Northern Ukraine in Southern Russia is a region of potential seed sources (Teich and Holst, 1970).

In tests of 25 provenance on two sites in Korea, the best sources were from Modal Vallnas, Sweden, and Abs, Sweden, but most provenances were not as productive as Japanese red pine (*Pinus densifolia*) check lots (Young *et al.*, 1986).

2.3.5.6 *Pinus taeda* L. (Loblolly pine)

Combined provenance and progeny selection and testing have been more intensive for *P. taeda* than for any other forest species in the world. Major improvements in growth, wood quality and tree form traits have been made through selection and testing in the North Carolina State-Industry Co-operative (Zobel and Talbert, 1984).

2.3.6 Eucalyptus

2.3.6.1 *Eucalyptus camaldulensis*

Growth and survival of 16 provenances were studied by Jha and Chimwal (1993) and they showed significant variations. In another study by Chandra *et al.* (1994), diameter and height growth exhibited considerable variation between provenances. The variation was generally associated with the site and climate conditions.

Several other workers (Kapur and Dogra, 1987; Abou-Gazia and El Baba, 1989; Banerjee and Singh, 1991) have also reported provenance trial of *E. camaldulensis* in different climatic conditions.

2.3.6.2 *Eucalyptus tereticornis*

No significant difference was observed between provenances in a study undertaken in Punjab by Kapur and Dogra (1987). Similar results were also reported by Chaturvedi *et al.* (1985) and Banerjee and Singh (1991).

However, studies conducted by Kumaravelu *et al.* (1995) in Tamil Nadu revealed significant differences among provenances in respect of the parameters evaluated. But at the same time, another study conducted in Tamil Nadu showed no statistical difference between provenances (Sundararaju *et al.*, 1995). They have used 13 provenances of *E. tereticornis* from Australia, Dehra Dun and local provenances.

Several other workers (Basu *et al.*, 1989; Banerjee *et al.*, 1990; Otegbey, 1990b) have also reported provenance trials of *E. tereticornis* in different climatic regions.

Height and diameter of 11 provenances of *Eucalyptus tereticornis* in a field trial within the Northern Guinea Savanna zone of Nigeria were studied by Otegbey, (1990b). Assessments of their total height and diameter were carried out at ages three, five and six years. Very highly significant differences were found in the total height of the provenances at ages three and six years while such differences were only significant at the 10 percent level at age five. Differences in the diameter of the provenances were not significant until after their sixth year of growth.

2.3.6.3 *Eucalyptus delegatensis*

A study conducted by John, *et al.* (1993) showed significant difference among Tasmanian and mainland Australian provenances in New Zealand grown *E. delegatensis.* Provenance trial was conducted at two sites in New Zealand and growth and (diameter) and form (primarily stem straightness) were assessed at age eight years. Tasmanian provenances overall had slightly larger diameter than Australian mainland provenances, but were significantly poorer in form than mainland ones.

2.3.6.4 Other species of Eucalyptus

Prominent variations were observed in a trial involving five species of Eucalyptus (Aradhya and Phillips, 1993). Reports are also there with *E.hybrid* (Kapur and Dogra,1987;) *E. brassica* (Jha, 1991), *E. microtheca* (Subramanian et al.,1991), *E. grandis* (Subramanian et al.,1992).

2.3.7 *Acacia*

The genus Acacia includes more than 1000 species of trees and shrubs distributed in Africa, America, Asia and Australia with the majority of species found in Australia (Annon 1982). The genus includes climbers which are distributed mainly in the warmer and drier regions of the world, chiefly in Australia and Africa. Of the two types of acacias, the typical bipinnate-leaved species are found throughout the tropics, whereas those with phyllodes are mainly Australian. About 40 species occur in India, in addition a few more have been introduced from Australia and Africa.

The ability to grow quickly helps young acacia plants to thrive successfully in areas infested with *Imperata cylindrica,* one of the noxious weedsin the tropics. It is estimated that there are 20 million hectares of *Imperata cylinderica* grasslands in Southeast Asia, 60 per cent of which are in Indonesia. In more recent years, fast growing acacia species such as *A. aulacocarpa,* A. *auriculiformis, A. crassicarpa* and *A. mangium* have proved successful for planting in *Imperata cylindrica* grass lands in Indonesia, Malaysia, Philippines and Thailand (Awang *et al.*, 1993)

Acacias are leguminous trees and have an ability to fix atmospheric nitrogen through symbiotic association with N-fixing organisms, including the root nodule-forming bacteria of the genus *Rhizobium*. They can fix signifiant amount of nitrogen, which has a positive influence on yields in N-deficient soils (Neil, 1990).

Acacias can tolerate salt also. Outstanding acacia of this group include *A. ampliceps, A. auriculiformis, A. ligulata, A. maconochieana, A. salicina* and *A. stenophylla.* All except for *A. auriculiformis* occur naturally on saline soils in Northern Australia (Thomson, 1987). This capacity to grow on poor soils in essential for land reclamation and restoration.

2.3.7.1. *Acacia aulacocarpa*

A.aulacocarpa. Cunn. ex Benth. the specific name refers to prominent furrowing and thickened transverse bands on the pod. The tree is heavy fast growing, capable of tolerating a wide variety of infertile sites in the humid and sub-humid tropics. It is found in the adjacent areas of Iriyan Jaya, Indonesia and Western province of Papua New Guinea. The wood is attractive for furniture and cabinet making and is a good fuel also.

2.3.7.2. *Acacia auriculiformis*

It was *introduced* into India in 1946 for lateritic soils in Bihar, Orissa and Bengal and being tried in Karnataka and in Uttar Pradesh. *A. auriculiformis* grows successfully in all types of soil and climate, especially for afforestations of grass lands, reforestation of degraded forests and landside planting (Kodira, 1991). *A. auriculiformis* a straight medium sized tree, up to 16 m in height with slightly angular branchlets, native to Australia.

Natural stands of *Acacia auriculiforms* are found in Australia, Papua New Guinea and Indonesia. In Australia it occurs on Cape York Peninsula, Queensland, mainly on Westward flowing river systems, and in northern areas of the Northern Territory. It is found in many areas of Western and Southern Papua New Guinea and extends into Irian Jaya and the Kri Islands of Indonesia. Latitude of main occurrence ranges from 8-16°S and altitude of main occurrence in ranges from mean sea level to 100m.

It is an excellent species to suppress grass and weeds and its wood is used widely as fuelwood, pulpwood in toy making and furniture.

2.3.7.3. *A. crassicarpa*

A. crassicarpa occursalong the north east coast and hinterland of Queensland. It is found north of 20°S and extends to the tip of Cape York Peninsula close to the sea and on offshore Islands. It is wide spread in the Western Provenance of Papua New Guinea and in the adjacent areas of Iriyan Jaya, Indonesia. Main occurrences are in the hot humid climatic zones with limited areas in the hot and warm humid zones. The wood is attractive and excellent for fuelwood and furniture.

2.3.7.4. *Acacia mangium*

Acacia mangium Willd, is a leguminous tree species in the family leguminosea, subfamily mimosoideae. *Acacia mangium* was unknown as an exotic until 1966 when it was introduced into Sabah, Malaysia by D.I. Nicholson, an Australian forester. Currently over 150,000 ha. of *A. mangium* have been planted world wide and the areas coverage is rapidly expanding.

A. mangium has a fragmented natural distribution which stretches from Indonesia (where it occurs on the Islands of Suria, Ceram and Aru) to Irian Jaya, the Western province of Papua New Guinea (PNG), and North East Queensland in Australia. The latitudinal range is 1-18° 57' S and longitudinal range in123° 22'-146° 17' E. The main altitudinal range is from just above sea level to about 100 m, with an upper limit of 780 m.

Among the exotic acacias planted in Kerala, mangium (*A. mangium*), a recent introduction is being planted on a large scale throughout the state on account of its fast growth and superior wood qualities (Wu and Wang, 1988). On very good sites, the tree is reported to have a mean annual increment in volume to the tune of 46 cum/ha. The wood makes attractive furniture, door frames, window parts, cabinets and sliced veneers. Because of its density and calorific value (4800-4900 Kcal/kg), the wood is useful as an excellent fuelwood also (Wu and Wang, 1988). In addition, the wood in useful in paper and pulp manufacture (Peh *et al.*, 1982). The species is also useful for ornamental purposes . Experiments have shown that the species has potential in some inter cropping combinations (for eg., with maize and peanuts). Non wood uses includes honey production, production of shiltake mushrooms and adhesives.

2.4 Biometrical parameters for provenance evaluation

2.4.1 Tree height

A trial at Pitamaruwa district of Sri Lanka (elevation 1160 m with a rainfall of 1580 mm) was conducted by using *A. auriculiformis, A. mangium, A crassicarpa, A. aulacocarpa, A. polystachya, A deanii, A. glaucocarpa, A. mearnsii, A. silvestris, A. polybotrya, A. oraria, A. parramattensis, A. leptocarpa, A. cincinnata, A. flawescens, A. rothii, A. decurrens* and *A. melanoxylon.* At the age of 2.5 years *A. crassicarpa* performed as the best species in height as well as diameter growth at breast height. Moderate growth was shown by *A. auriculiformis* and *A. decurens* and poor growth rates were recorded in *A. aulacocarpa, A. polystachya, A. deanii* and *A. silvestris* (Weerawardene and Vivekanandan, 1991).

A provenance trial was conducted at sites in Fujian and Jiangxi provinces of China were used to test 171 familes with wattle provenances from Australia. The two-year result showed that Tasmanian provenances were poor compared to the mainland provenances. Ganghou provenance (from South Gippsland, Victoria) was 25% greater in height and diameter at breast height than the provenances from Avoca, Tasmania.

Three provenance trials of *A. auriculiformis* at Seri Thong, Kanchanaburi and Sakaerat in Thailand were analysed for growth and survival at age 12 months. Twenty-seven provenance samples from three major natural occurrences of the species, viz., PNG, Queensland and Northern Territory and Australia were included. Generally the provenances originating from PNG grew faster than the provenances from Queensland and Northern Territory (Luangviriyasaeng and Pinyopusarerk, 1991).

Yang and Zeng (1991) reported a provenance trial, which was conducted, on nine acacia species (*A. aulacocarpa, A. auriculiformis, A. leptocarpa, A. cincinnata, A.*

oraria, A. confusa, A. polystachya, A. simsii, and *A. crassicarpa)* from Papua New Guinea, Northern Territory, Queensland and China. Four-year results showed significant differences between species for height and diameter growth. Provenance differences for *A. crassicarpa* and *A. aulacocarpa* were also highly significant with superior performance from Papua New Guinea provenances.

Significant differences were found between provenances (Salazar, 1989) on height, diameter at breast height, survival and percentage of forked stems for various provenances of *A. mangium* at two sites in Costa Rica (One with 14 provenances at 4 year old, the other with 6 provenances at 3 year old).

Faizuddin and Dalmago (1992) reported variations between 18 provenances (2 from Indonesia, 1 from Papua New Guinea and the rest from Queensland, Australia) of *Acacia mangium* in survival and resistance to pests and diseases at three sites. The results showed highly significant variation in survival among provenance under Masrbate and Bukidnon conditions and in resistance to pests and diseases at two sites (Ilows Norte and Bukidnon).

Twenty one provenances of *A. nilotica* sp.*indica* collected from 11°N to 31°N latitude and 19m to 650 m altitude in India were grown at Hisar by Balkrishan and Toky (1995). There were significant variations in stem height at six and 23 month stage after tansplantatiom. It was found that provenances from North-Western and Central India were superior than those from South India (Krishnan *et al* ., 1995)

2.4.2 Collar diameter

Provenance trial conducted in South East and South Asia, Australia and Fiji using 24 provenances of *Acacia mangium* showed significant variation in height with respect to diameter growth (Harwood *et al.*, 1992)

A trial was conducted by using five fast growing (*A. auriculiformis, Albizia procera, Eucalyptus camaldulensis, Prosopis juliflora*) and five slow growing (*Artocarpus chaplesia, Chukeasia tabularis, Dipterocarpus tebinatus, Syzygium grande and Xylia keerii*) species in 1988, at Madhpur in the district of Tangail. Significant differences among the provenances with respect to diameter at breast height at the age of 5.5 years were observed (Hussain *et al.* (1995).

2.4.3 Number of branches

Balkrishan and Toky (1995) reported significant variation between provenances. Provenances from north-western and central India were found to be superior than those from south India from a provenance trial using 21 provenances of *Acacia nilotica* ssp. *indica* collected from Hisar (11°N to 31°N latitude and 19 m to 650 m altitude) in India.

2.5 Physiological parameters

A tree's physiological processes constitute the machinery through which heredity and environment operate to control growth (Kramer and Kozlowski, 1979). Understanding physiological differences among natural populations of a species can thus be useful for developing a successful tree improvement programme.

The quantitative importance of transpiration is indicated by the fact that a Kanser cone plant loses over 200 litres of water during its life, or 100 times its own fresh weight (Miller, 1938) and a field of corn in Ilinois transpired over 20 cm or about 80 per cent of the precipitation during the growing season (Peters and Russell, 1959).

A deciduous forest in the humid southern Applachian loses 40-55 cm of water per year (Hoover, 1944), 25-30 per cent of the annual precipitation. Of all the water absorbed by plants, about 95 per cent is lost by transpiration. The rate of transpiration is affected by size, shape and orientation of stomata's but it is controlled primarily by stomatal resistance, which depends on the degree of stomatal opening. Stomatal opening in affected by internal and external CO_2 concentration, light intensity, atmospheric humidity and temperature. It is sometimes argued that transpiration in beneficial because it cools leaves, causes the ascent of sap, and increases the absorption of minerals (Clements 1921; Gates, 1966).

Rate of transpiration was positively correlated with leaf water potential (Schulze and Hall, 1982). Transpiration rates were often reduced significantly in certain *Acacia* species in drier soils (Long and Smith, 1987).

Srinivasan *et al.* (1989) reported variation between species in early growth and few drought adaptive attributes in five month old containerised seedlings of *Acacia.* A total of seven species, one each from Guatemala (*A. ferensiana*), Papua New Guinea (*A. auriculiformis*), Kenya (*A. albida*) and four from Australia (*A. Suma, A. mellifera, A. torlillis* and *A. senegal*) were planted in a statistically designed experiment and three years after planting *A. auriculiformis* had the lowest transpiration rate. Transpiration rates showed inverse relationships with all variables such as height, moisture content, total chlorophyll content and stomatal resistance except diameter at breast height.

Isolde (1989) observed a morning peak conductance and subsequent decrease for certain *Acacias* which was more pronounced under water stress, indicating a decisive stomatal regulation of transpiration. In a comparative study of water stress response of *Eucalyptus maculata* and *E. brockwayii* seedlings, Myers and Landsberg (1989) observed that transpiration rates were higher in *E. brockwayii*. Transpiration is the dominant factor in plant water relation because it provides the energy gradient which causes the movement of water into and throughout plants (Myers and Landsberg, 1989).

A study conducted in two rain forest tree species (*Simarouba amara* and *Goupia glabra)* in a plantation revealed that transpiration may be limited by stomatal closure despite a high rainfall (Granier *et al.*, 1992).

2.5.2 Leaf water potential

The water potential of leaves can vary over a considerable range (above a critical value) without a marked effect on stomatal aperture. When critical water potential is reached stomata begins to close. Different species respond differently to water stress (Jarvis, 1980).

In *Helianthus annus* and *H. petiolaris*, water stress induced a gradual and similar decrease in leaf conductance from 1.6 to 0.3 μ mol m^{-2} s^{-1} as water potential decreased from -0.5 to -2.0 MPa (Sobrado and Turner, 1983).

In many species stomatal resistance to air humidity can be correlated with leaf water potential. A study conducted by Guehl *et al.* (1991) on the leaf gas exchange in response to drought found that stomata closed very rapidly in *Abies bornmulleriana* when water supply is held even prior to there being any important decrease in leaf predawn water potential.

During a summer drought, foliar predawn water potential and minimum water potential fell to - 4.8 MPa and -5.5 MPa respectively, in *Fraxinus excelsiar* (Cartier *et al.*, 1992). In *Quercus petreae*, imposed drought caused predawn leaf water potential to reach values as low as -2.0 MPa with a progressive decrease in irrigated trees whereas it progressively declined to -0.9 MPa in unirrigated trees. Minimum daytime leaf water potential in the unirrigated trees decreases from -1.0 to -1.1 MPa at the begining of drought period to -2.2 to -2.4 MPa after three months.

2.5.3 Leaf temperature

Leaf temperature status is an indirect measure of plant water status (Idso *et al.*, 1978a) when plants were well supplied with water, transpiration would be at the potential rate and the leaves will be relatively cool (Idso *et al.*, 1978a). Idso *et al.*, 1978b) observed a declining trend in transpiration during moisture deficient situation and the concomittent increase in leaf temperature. Such situations will lead to decline of total biomass production.

Decreasing soil moisture content resulted in reduced plant water status and stomatal conductance leading to elevated leaf temperature (Mtui *et al.*, 1981).

As a general rule, leaf resistance changes with changing leaf temperature, but whether resistance increases or decreases with increasing temperature depends upon the status of other factors. For a long time it was thought that resistance increased with temperature. Wuenscher and Kozlowski (1971) measured the change in transpiration rates and leaf resistances with leaf temperature for *Quercus microcarpa, Q. velutina, Q. alba, Q. rubra* and *Acer saccharum*.

2.5.4 Stomatal responses

Brown and Escombe (1900) reported the first work about the investigation of water loss from leaves as a diffusion process through pores.

Bange (1953) and Gates (1966) have shown that though sub stomatal cavities offer some resistance to the diffusion of water vapour from the cell wall to the stomata, neglect of substomatal cavity resistance involves an error in the total resistance between 2 and 5 per cent.

Reduction of water loss by stomatal closure is an effective means of postponing dehydration, especially where responsive stomata are associated with low cuticular transpiration, as in most xerophytes. Many xerophytes have high rates of transpiration in moist soil, but as the soil dries, the stomata close in the morning and finally stay closed all day. Although this conserves water, it can reduce photosynthesis of sclerophyllous vegetation below the compensation point (Dunn *et al.*, 1976). Stoma begins to close when the turgor of guard cells decreases. Stomata usually close during relatively early stages of leaf water deficit often long leaves wilt (Kozlowski, 1976).

The reduction of epidermal turgor in plants surrounded by dry air can result in stomatal closure, eventhough bulk leaf water potential is high (Kozlowski, 1976).

Stomatal diffusive resistance was found unaffected by leaf water potential in certain plants (Gutknecht *et al.*, 1977).

The critical leaf water potential for stomatal closure reported for different species should not be taken too seriously because the value varies for different clones and cultivars (Pallardy and Kozlowski, 1981) and because the response of stomata to leaf water deficits in modified significantly by factors like internal CO_2 concentration, air humidity, wind, age of leaf, osmotic adjustment etc. (Davies *et al.*, 1974; Kozlowski and Pallardy, 1979).

In *Alnus glutinosa* seedlings, water stressed individuals showed a much lower initial leaf conductance after which it has gradually dropped as leaf water potential decreased (Seiler, 1985).

Vance and Running (1985) observed that in *Larix occidentalis* seedlings, minimum stomatal conductance declined with decreasing leaf water potential. Leaf conductance declined exponentially with decreasing predawn water status in *Ulmus americana* seedlings (Walters and Reich, 1989). Ellsworth and Reich, (1992) correlated the leaf conductance with predawn leaf water potential in *Acer saccharum* seedlings.

Stomata respond extremely rapidly to changes in light, temperature, carbon dioxide, water and other environmental factors (Raschke, 1975).

Differences in stomatal control of transpiration are correlated with differences in drought tolerance of mesophytes such as sorghum cultivars (Teare *et al.*, 1973), and poplar clones (Ceulemans *et al.*, 1978).

Stomatal closure during the middle of the day has been reported for many species of forest trees (Kramer and Kozlowski, 1979; Kozlowski, 1982). Although mid day stomatal closure has been attributed to several causes an important factor is the lag of absorption behind transpiration, which induces leaf dehydration and reduction in leaf water potential to a critical level associated with stomatal closure.

Cowan and Farquhar (1977) proposed that stomata tend to adjust in a manner that keeps the ratio of photosynthesis to transpiration fairly constant over a wide range of stomatal opening. Driessche (1991) observed a reverse trend of increasing stomatal conductance in lodgepole pine seedlings when severe nursery drought was imposed. Granier *et al.* (1992) observed mid day stomatal closure and resultant reduced sap flow in *Cowpia glabra,* a rainforest tree species.

2.5.5 Stomatal frequency

The number of stomata per unit of leaf surface varies widely with species and environmental conditions, ranging from 6000 to 8000/cm^2 in corn, 8000 to 15000 in sorghum, about 15000 in alfalfa and clover and 3000 in apple to 1,00,000 in scarlet oak (Miller, 1938; Meyer *et al.*, 1973).

2.6 Anatomical parameters

2.6.1 Moisture content

Ong (1984) has reported that green wood moisture content varies from 75 per cent at the top of the trunk to 105 per cent at the bottom. In that study the moisture content was not affected by sites, but there were considerable differences among the trees growing on similar sites.

An empirical study of moisture content behaviour in *Acacia* and Eucalyptus plants by Rajesh Kumar (1993) revealed that moisture content in the different plant parts shows a distinct affinity towards the seasonal changes. The moisture content steadily increases with the growth of the plants but varies with the changes in the seasons.

The water content in wood and bark of a tree in general varies due to a number of factors such as tree species, density, position in the stem, locality factors and seasons (Rawat *et al.*, 1993).

Rawat *et al.* (1993) reported moisture content variations in the hole and back of 12 species (three conifers - *Pinus kesiya, P. patula, Cryptomeria japonica*) six evergreen species (*A. auriculiformis, A. mearnsii, A. nilotica, C. equisetifolia, Eucalyptus hybrid,* and *E. grandis*) and three deciduous species (*Dalbergia sissoo, Ailanthus excelsa, Poplus deltoides*). Moisture content recorded higher in conifers (163-213 per cent) than in non-conifers (29-133 per cent) and was highest in *P. patula* (from West Bengal).

2.6.2 Specific gravity

Purkayastha *et al.* (1984) has shown that specific gravity varied with locality. Pipatwattanakal (1989) examined provenances variation in the wood density of a six-year-old *A. mangium* trial at Lad-Krating, with values of 0.3 to 0.4 differences among the 16 provenances studied was not significant.

Specific gravity and fibre length were evaluated in three ten year old green ash (*Fraxinus pennyslvanica* Marsh.), in a genetic tests in East Texas which contained 42 open pollinated families representing seven East Texas provenances. Specific gravity was significantly affected by plantation, provenance, family within provenance and the plantation x family within provenance interaction (Lawe and Greene, 1990).

Sulaiman and Lin (1993) reported variation in specific gravity of five year old *Acacia mangium* from the Balu Arang plantation, Selangor, Malaysia, that, specific gravity in a radial direction increased from the centre to the outer region near the bark. Trends with height varied amongst trees but the overall pattern was decrease with increasing height. Low specific gravity values were found in most of the juvenile wood.

Provenance evaluation of *A. mangium* and *A. auriculiformis* on four sites in Zaire on specific gravity at ages three, nine, 15 and 21 months showed significant variation between provenances (Khasa *et al.*, 1995).

2.6.3 Heartwood percentage

Purkayastha *et al.* (1984) have shown that proportion of heartwood varied with locality and growth in *Eucalyptus tereticornis.*

The width of sapwood varies widely with great number of factors, including species (Larsen and Okkomen, 1969), (Panshin and de Zeeuvo, 1980), site (Long and Smith, 1987), elevation (Larsen and Okkomen, 1969) and climate (Chalk, 1951).

It is also reported that there is a positive relationship between the foliage mass or area and the sapwood width because of the water conduction function of sapwood, Grier and Waring, 1974; Kaufmann and Troendle, 1981; Waring and Schlesinger, 1985; Keane and Weetman, 1987; Epinosa Bancalari *et al.*, 1987).

2.6.4 Fibre variation

Singh (1985) reported that fibre / vessel ratio varied within the trees of a locality and had a marked influence on paper strength and surface properties.

Wu and Wang (1988) reported radial and longitudinal variation in fibre length in *Acacia mangium* and *A. auriculiformis*.

Fibre length was evaluated in three ten year old green ash (*Fraxinus pennysylvanica*) in a genetic tests in East Texas which contained 42 open pollinated families representing seven East Texas Provenances. Fibre length was significantly affected by family with provenance and the plantation x provenance interaction (Lawe and Greene, 1990).

2.6.5 Parenchyma

Parenchyma tissue of *Acacia mangium* is distinct under a lens and lighter in colour than the fibre cells. It is of paratracheal type, some conspicuously surrounding the vessels or vessel groups, whereas the others consist of narrow sheaths around the vessels. Some axial parenchyma cells contain crystal deposits of calcium compounds (Peh and Khoo, 1998).

2.6.6 Rays

It is widely and uniformly distributed in *A. mangium* barely visible to the naked eye on cross and not prominent on radial surface (Peh and Khoo 1998; Wu *et al.* 1988; Moh Hamami *et al.*, 1992).

2.6.7 Vessels

Vessels in *Acacia mangium* were diffused with a tendency to align in oblique lines; tyloses generally absent; gum like deposits present (Peh and Khoo 1998; Wu *et al.*, 1988; Mohd Hamami *et al.*, 1992).

MATERIALS AND METHODS

MATERIALS AND METHODS

The present investigation was conducted at the experimental area of College of Forestry, Kerala Agricultural University, Thrissur, Kerala (10^0 32` N latitude and 76°16` E longitude). The climate is warm and humid with mean annual rainfall 2756 mm. Soils at the experimental location are laterite of pH 5.45 (soil organic matter content 2.04 per cent, available potassium 0.0034 per cent, available phosphorous 0.0015 per cent and nitrogen content 0.13 per cent) with predominant parent material of gneiss series. The area is situated 23m above mean sea level.

3.1 Experimental materials

The experimental materials consisted of seeds from 11 provenances of *Acacia,* which include five provenances of *A. mangium* and two provenance each of *A.auriculiformis*, *A.crasicarpa,* and *A. aulacocarpa* (PlatesI to V) obtained from the Australian Tree Seeds Centre, Division of Forestry, CSIRO (Common Wealth Scientific and Industrial Research Organisation), Australia (Table 1). The performances of the 11 provenances were evaluated in a field.

3.2 Experimental methods

The experimental was laid out in a Randomized Complete Block Design (RCBD) replicated thrice. The gross plot size varied from plot to plot. Ten trees were selected

Table 1 Geographical location and seedlot number of the provenances studied

Treatment	CSIRO seedlot number	Species	Locality	Origin	Latitude		Longitude		Altitude
					Degree	Minutes	Degree	Minutes	
P1	19286	*Acacia mangium*	Research Seed Orchard	QLD	18	16	146	02	80
P2	19233	*A. mangium*	Wipim to Oriomo	PNG	84	90	143	00	10
P3	19134	*A. mangium*	Balimo Aramia River	PNG	80	30	142	38	15
P4	18994	*A. mangium*	Claudie River	QLD	12	47	143	17	20
P5	16727	*A. manium*	7KMSSE Mossman	QLD	16	28	142	22	7
P6	18855	*A. auriculiformis*	Orchard Melville1	NT	11	34	130	34	20
P7	19253	*A. auriculiformis*	Kings Plain Lake	QLD	19	41	147	04	150
P8	19259	*A. crassicarpa*	Kapal Oriomo	PNG	85	20	143	03	30
P9	17552	*A. crassicarpa*	Bensbach WP	PNG	85	30	141	17	20
P10	16979	*A. aulacocarpa*	W of Wipim WP	PNG	84	00	142	43	40
P11	17551	*A. aulacocarpa*	Bensbach-Balamuk WP	PNG	85	30	141	17	25

QLD – Queensland, Australia, NT – Northern Territory, Australia, PNG – Papua, New Guinea

Plate I General view of the experimental plot at Vellanikkara, Thrissur

Plate II *Acacia mangium*

Plate III *Acacia auriculiformis*

Plate IV *Acacia crassicarpa*

Plate V *Acacia aulacocarpa*

from each plot using random numbers. The trees were field transplanted at a spacing of 2 x 2m in August,1996.

3.3 Observations

3.3.1 Biometric observations

Biometrical observations of the trees such as height, collar girth and number of branches were measured at monthly intervals.

3.3.1.a Height

Heights of the trees were measured by using an optical Clinometer at monthly intervals and the date expressed in metres.

3.3.1.b Collar girth

Girths at the collar region of the trees were measured at monthly intervals by tailor's tape and the data expressed in centimeters.

3.3.1.c Number of branches

The number of branches produced by the trees were counted and recorded monthly.

3.3.2 Physiological Observations

3.3.2. a Leaf area index (LAI)

The leaf area index was measured using a Canopy Analyser (Model LAI-2000, Licor, USA). Six measurements were made from random locations in each plot. Data were recorded at 20 MAP, 25 MAP and 28 MAP.

3.3.2.b Stomatal frequency

For counting the stomatal frequency, matured leaves were taken from selected 10 trees from each replication. A thin film of quick setting adhesive (Quickfix from M/s. Wembley's Laboratories Ltd, Punjab) was applied on the lower (dorsal) and upper (ventral) side of the leaves to get a replica of the leaf surface. After setting the gum, it was peeled off and put on a microscopic slide and observed under a microscope with magnification 10x X 45x. Stomatal frequency was counted in 10 microscopic fields for each replication and the mean expressed in number per square centimeters.

3.3.2.c Leaf water potential

A scholander type pressure chamber (Soil Moisture Equipment corporation, Ohio, USA) was used for finding out the leaf water potential. Measurements were made on two trees from each plot. The leaves were enclosed in a poly bag before being detached (Turner, 1998). The balancing pressure was taken as the water potential (Millburn, 1979). Measurements were taken at predawn and after noon hours separately for each treatment at 28 and 32 MAP and the mean expressed in MPa.

3.3.2.d Leaf diffusive resistance

The leaf diffusive resistance is expressed as stomatal conductance. A steady state porometer (Model LI –1600 , Licor, Nebraska, USA) was used to measure the diffusive resistance (stomatal resistance) of the leaves. Physiologically mature leaves well exposed to solar radiation were selected for observations. Measurements were recorded at predawn and after noon hours on four trees from each plot at 28 and 32 MAP and the mean expressed in μ mol $m^{-2}s^{-1}$.

3.3.2.e Transpiration rate

Transpiration rate was recorded by using the steady state porometer on the same leaf on which stomatal resistance was measured. Observations were made on four mature trees from each plot at 28 and 32 MAP and the mean expressed in $\mu g\ H_2Ocm^{-2}s^{-1}$.

3.3.2.f Leaf temperature

Steady state porometer was used for recording the leaf temperature of the trees. Observations were taken from the same leaf used in measuring stomatal resistance at 28 and 32 MAP and the mean expressed in degree Celsius (°C).

3.3.3 Anatomical characteristics

3.3.3.a Moisture content

The observations were taken from the same specimens used for measuring the specific gravity. Moisture content of the wood on fresh weight basis and oven dry weight basis were estimated using the formula

Moisture content (green weight basis) = $(W_i-W_o) / W_i \times 100$

Moisture content (oven dry weight basis) = $(W_i- W_o) \times 100$

where,

W_i, W_o are the weight of the specimens at green weight basis and oven dry weight basis, respectively.

3.3.3.b Specific gravity

Specimens of size 2.5 x 2.5 cm were collected from the lower branches of the trees representing all the provenances in three replications. Specific gravity at green, air an oven dry conditions were estimated using the following formula as per IS method of sampling (Annon,1982).

Specific gravity (green condition) = W_i / V_i

(air dry condition) = W_a / V_a

(ovendry condition) = W_o / V_o

where,

Wi, W_a and W_o is the weight of the specimen at green, air dry and and ovendry conditions.

Vi, V_a and V_o are the volumes of the specimens at green, air dry and ovendry conditions.

3.3.3.c Heartwood percentage

Heartwood percentage was recorded with the help of Presler's Increment Borer. Wood cores were taken at breast height representing four radii and relative proportion of heartwood to sap wood was estimated on the average of their observations.

3.3.3.d. Dimensions of fibres, vessels, ray parenchyma and axial parenchyma

The length and width of the fibres, vessels, ray parenchyma and axial parenchyma were recorded with the help of light microscope with magnification 10x X 45x and expressed in microns.

3.4 Statistical analysis

The data were subjected to nested analysis for Randomized Complete Block Design (Panse and Sukatme, 1989), using DATAPLUS and GENSTAT. For comparing the seasonal variations the data were analysed in split and Dunken's Multiple Range test (DMRT) was used for comparison of means.

RESULTS

RESULTS

Evaluation of five provenances of *Acacia mangium* and two each of *A. auriculiformis, A. crassicarpa* and *A. aulacocarpa* obtained from the Australian Tree Seed Centre, Division of Forestry, CSIRO (Commonwealth Scientific and Industrial Research Organisation), Australia was carried out for their growth, physiological and anatomical variations for a period of one year. The results obtained from the study are presented here under.

4.1 Biometric observations

The observations on height, collar girth and number of branches of five provenances of *A. mangium,* two provenances each of *Acacia auriculiformis, A. crassicarpa* and *A. aulacocarpa* were recorded at monthly intervals. The data of total 11 provenances and four species of *Acacia* during the study period are presented in Tables 2,3,4,5,6 and 7.

4.1.1 Height

The data presented in Table 2 and 3 relates to the mean height of 11 provenances and four species of *Acacia,* respectively. Their performance during the study period is represented in Fig. 1, 2, 3 and 4. At 33 months after planting (MAP), the maximum growth in terms of height (12.69 m) was recorded by the provenance Balimo Aramia River (P_3) of *A. mangium* and the minimum height of (8.28 m) was recorded by the provenance Bensbach Balamuk WP (T_{11}) of *A. aulacocarpa.*

Table 2 Mean height (m) of the provenances of the four species of *Acacia*

Provenancess	21 MAP	22 MAP	23 MAP	24 MAP	25 MAP	26 MAP	27 MAP	28 MAP	29 MAP	30MAP	31 MAP	32 MAP	33 MAP
A. mangium													
P_1	10.69^{A}	10.83^{A}	10.96^{A}	11.07^{A}	11.22^{A}	11.36^{AB}	11.48^{A}	11.61^{A}	11.71^{AB}	11.88^{A}	12.05^{A}	12.15^{A}	12.32^{A}
P_2	10.87^{A}	10.98^{A}	11.09^{A}	11.24^{A}	11.38^{A}	11.53^{A}	11.67^{A}	11.85^{A}	12.06^{A}	12.12^{A}	12.25^{A}	12.39^{A}	12.57^{A}
P_3	10.83^{A}	10.97^{A}	11.09^{A}	11.26^{A}	11.41^{A}	11.56^{A}	11.73^{A}	11.88^{A}	11.97^{A}	12.23^{A}	12.39^{A}	12.57^{A}	12.69^{A}
P_4	9.43^{ABC}	9.64^{ABC}	9.86^{AB}	10.06^{AB}	10.21^{AB}	10.42^{ABC}	10.54^{AB}	10.75^{AB}	11.04^{AB}	11.22^{AB}	11.34^{AB}	11.48^{AB}	11.61^{AB}
P_5	7.91^{CD}	8.04^{CD}	8.21^{CD}	8.35^{CD}	8.46^{CD}	8.61^{DE}	8.82^{CD}	8.95^{CD}	9.12^{CD}	9.18^{CD}	9.29^{CD}	9.42^{CD}	9.54^{CD}
A. auriculiformis													
P_6	9.25^{ABC}	9.43^{ABC}	9.57^{ABC}	9.76^{ABC}	9.91^{ABC}	10.07^{ABCD}	10.20^{ABC}	10.44^{ABC}	10.69^{ABC}	10.84^{AB}	11.88^{AB}	11.24^{AB}	11.40^{AB}
P_7	8.61^{BC}	8.80^{BC}	8.97^{BC}	9.16^{BC}	9.35^{BC}	9.52^{CD}	9.68^{BC}	9.86^{BC}	10.04^{BC}	10.20^{BC}	10.33^{BC}	10.47^{BC}	10.65^{BC}
A. crassicarpa													
P_8	9.83^{AB}	9.97^{AB}	10.12^{AB}	10.24^{AB}	10.38^{AB}	10.49^{ABC}	10.65^{AB}	10.75^{AB}	10.78^{ABC}	10.80^{AB}	10.35^{AB}	10.99^{AB}	11.11^{AB}
P_9	9.66^{AB}	9.80^{AB}	9.94^{AB}	10.08^{AB}	10.22^{AB}	10.32^{AB}	10.47^{AB}	10.62^{AB}	10.76^{ABC}	10.88^{AB}	11.00^{AB}	11.18^{AB}	11.31^{AB}
A. aulacocarpa													
P_{10}	6.74^{AD}	6.90^{D}	7.04^{D}	7.20^{D}	7.33^{D}	7.46^{E}	7.62^{D}	7.75^{D}	7.91^{D}	8.05^{D}	8.18^{D}	8.30^{D}	8.44^{D}
P_{11}	6.68^{D}	6.81^{D}	6.97^{D}	7.08^{D}	7.22^{D}	7.35^{E}	7.51^{D}	7.65^{D}	7.78^{D}	7.98^{D}	8.05^{D}	8.20^{D}	8.28^{D}
F	*	**	*	**	**	*	*	*	*	*	**	**	**
SEM (±)	0.52	0.50	0.49	0.49	0.48	0.55	0.48	0.49	0.51	0.49	0.48	0.47	0.48

Values with same alphabets do not differ significantly at any given time.
* Significant at 5% level ** Significant at 1% level; MAP: Months After Planting
P1- Research Seed Orchard,QLD; P2- Wipim To Oriomo, PNG; P3- Balimo Aramia River, PNG; P4- Claudie River,QLD; P5-7KMMSSE Mossman,QLD; P6- Orchard Melville-1, NT; P7- King's Plain Lake, QLD; P8- Kapal Oriomo,PNG; P9- Bensbach WP,PNG; P10- W of Wipim, WP, PNG; P11- Bensbach –Balamuk,WP, PNG

Table 3 Mean height (m) of the four species of *Acacia*

Species	21 MAP	22 MAP	23 MAP	24 MAP	25 MAP	26 MAP	27 MAP	28 MAP	29 MAP	30 MAP	31 MAP	32 MAP	33 MAP
A. mangium	9.94^{A}	10.09^{A}	10.24^{A}	10.40^{A}	10.54^{A}	10.70^{A}	10.85^{A}	10.87^{A}	11.18^{A}	11.33^{A}	11.46^{A}	11.60^{A}	11.75^{A}
A. auriculiformis	8.93^{A}	9.10^{A}	9.27^{A}	9.46^{A}	9.63^{A}	9.80^{A}	9.94^{A}	10.15^{A}	10.37^{A}	10.52^{A}	10.70^{A}	10.85^{A}	11.02^{A}
A. crassicarpa	9.75^{A}	9.88^{A}	10.03^{A}	10.16^{A}	10.30^{A}	10.49^{A}	10.56^{A}	10.69^{A}	10.71^{A}	10.81^{A}	10.93^{A}	11.08^{A}	11.21^{A}
A. aulacocarpa	6.64^{B}	6.85^{B}	7.00^{B}	7.14^{B}	7.28^{B}	7.4^{B}	7.56^{B}	7.7^{B}	7.85^{B}	8.01^{E}	8.12^{B}	8.25^{B}	8.36^{B}
F	**	**	**	**	**	**	**	**	**	**	**	**	**
SEM (±)	0.15	0.15	0.15	0.14	0.14	0.16	0.14	0.15	0.15	0.14	0.14	2.3	2.3

Values with same alphabets do not differ significantly at any given time.
** Significant at 1% level; MAP: Months After Planting

Fig. 1 Mean height of the provenances of *Acacia* at 33 months after planting

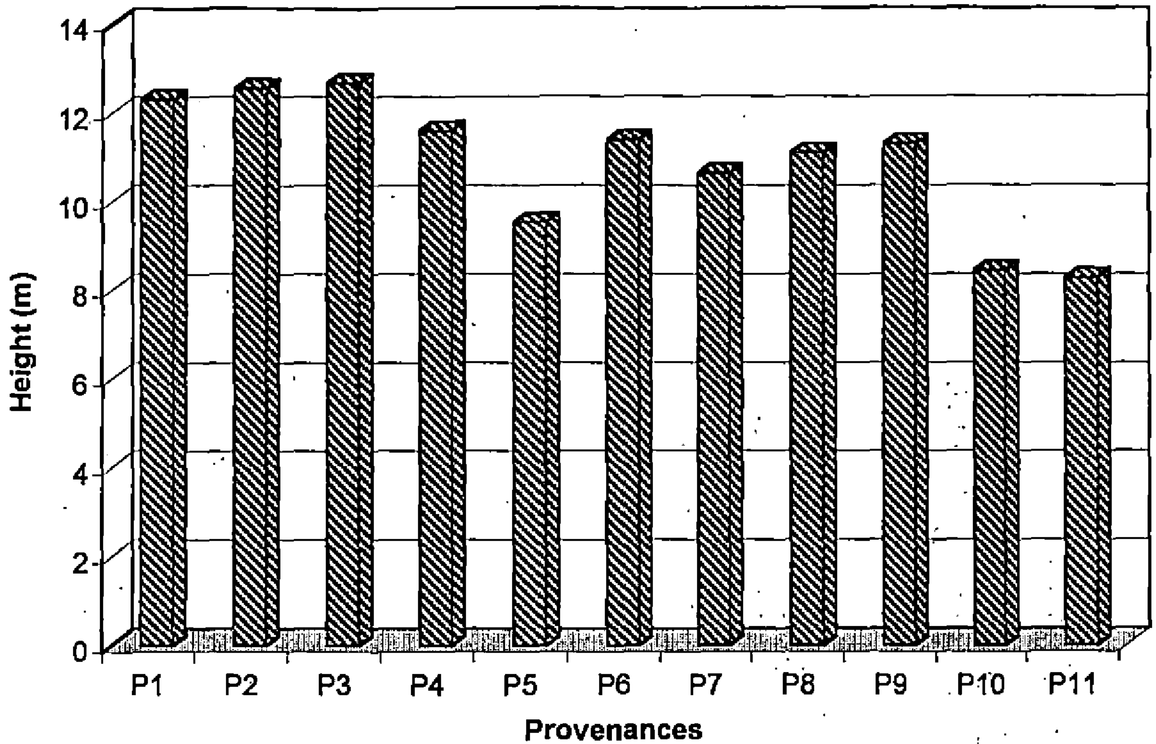


Fig.2 Growth in terms of height of the four species of Acacia

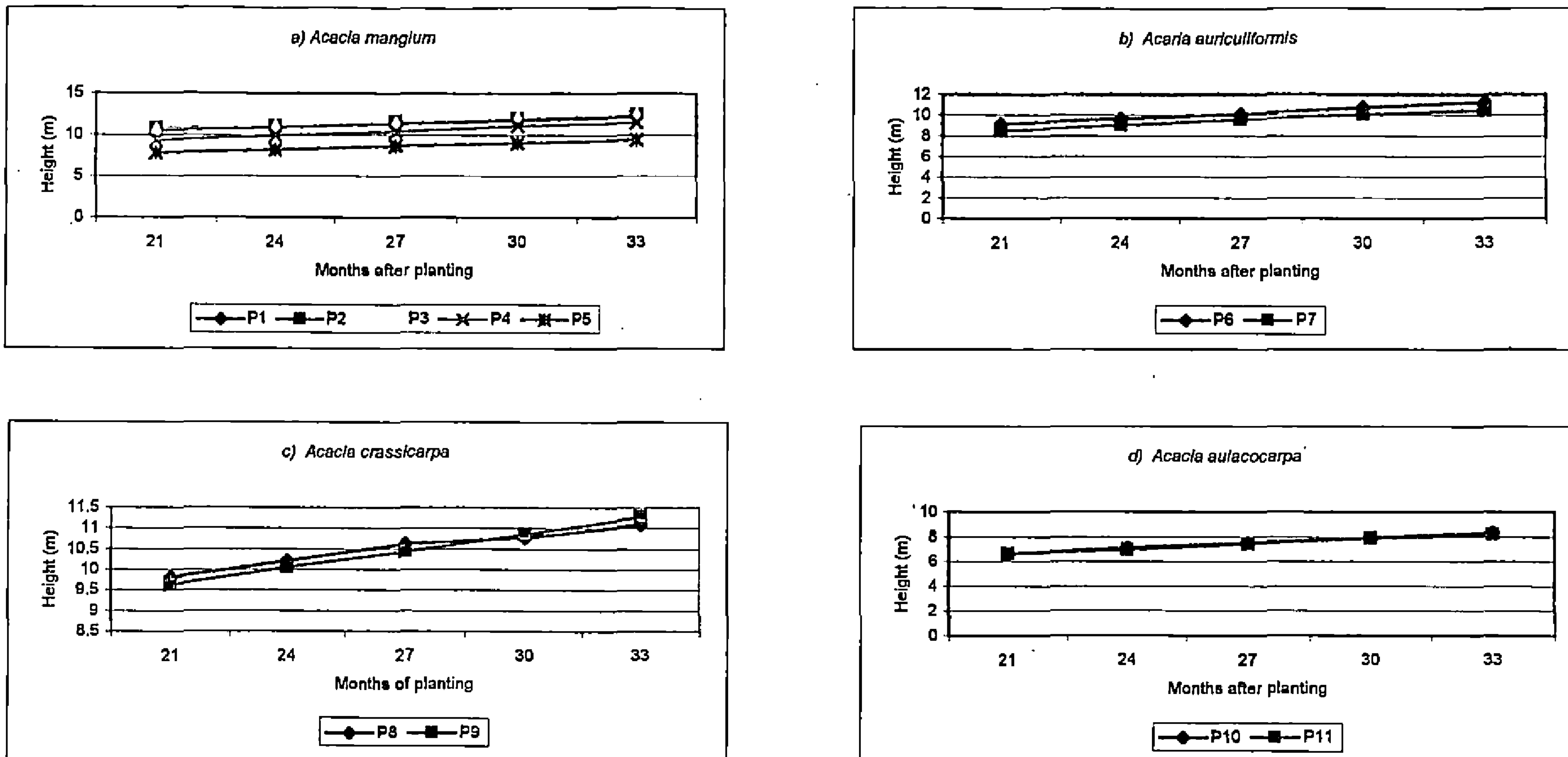


Fig.3 Mean height of the four species of *Acacia* at 33 months after planting

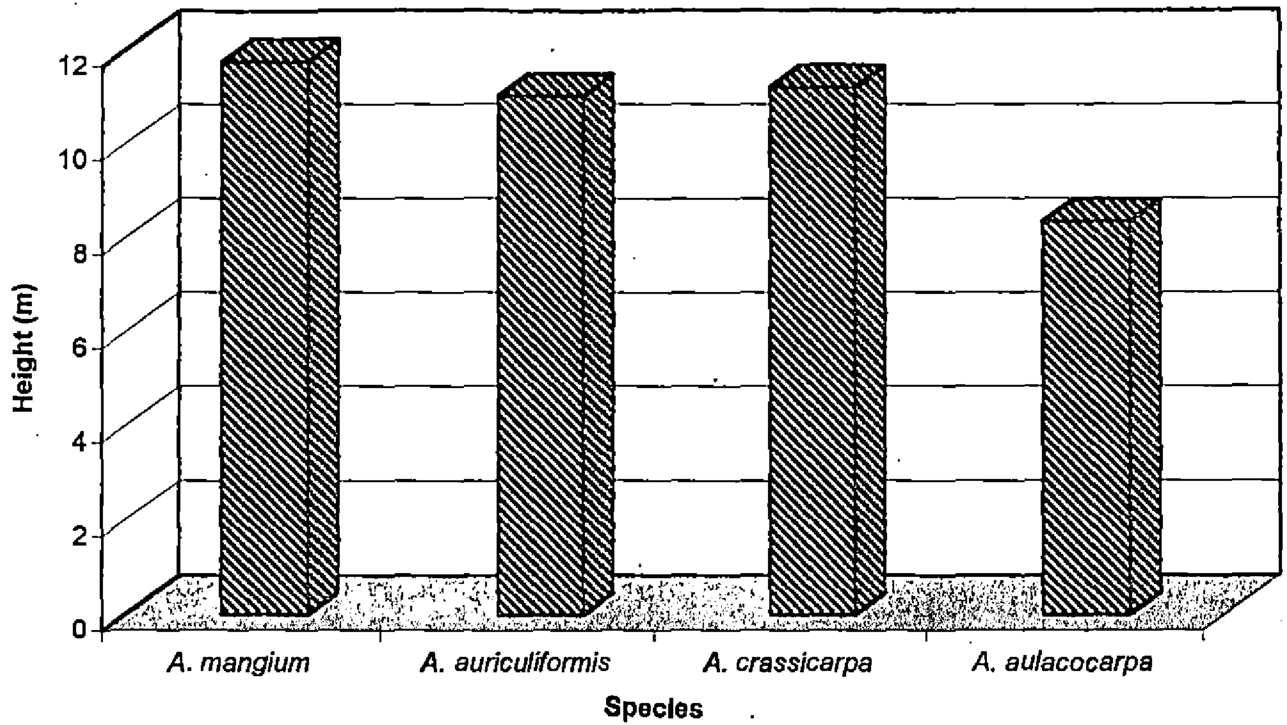
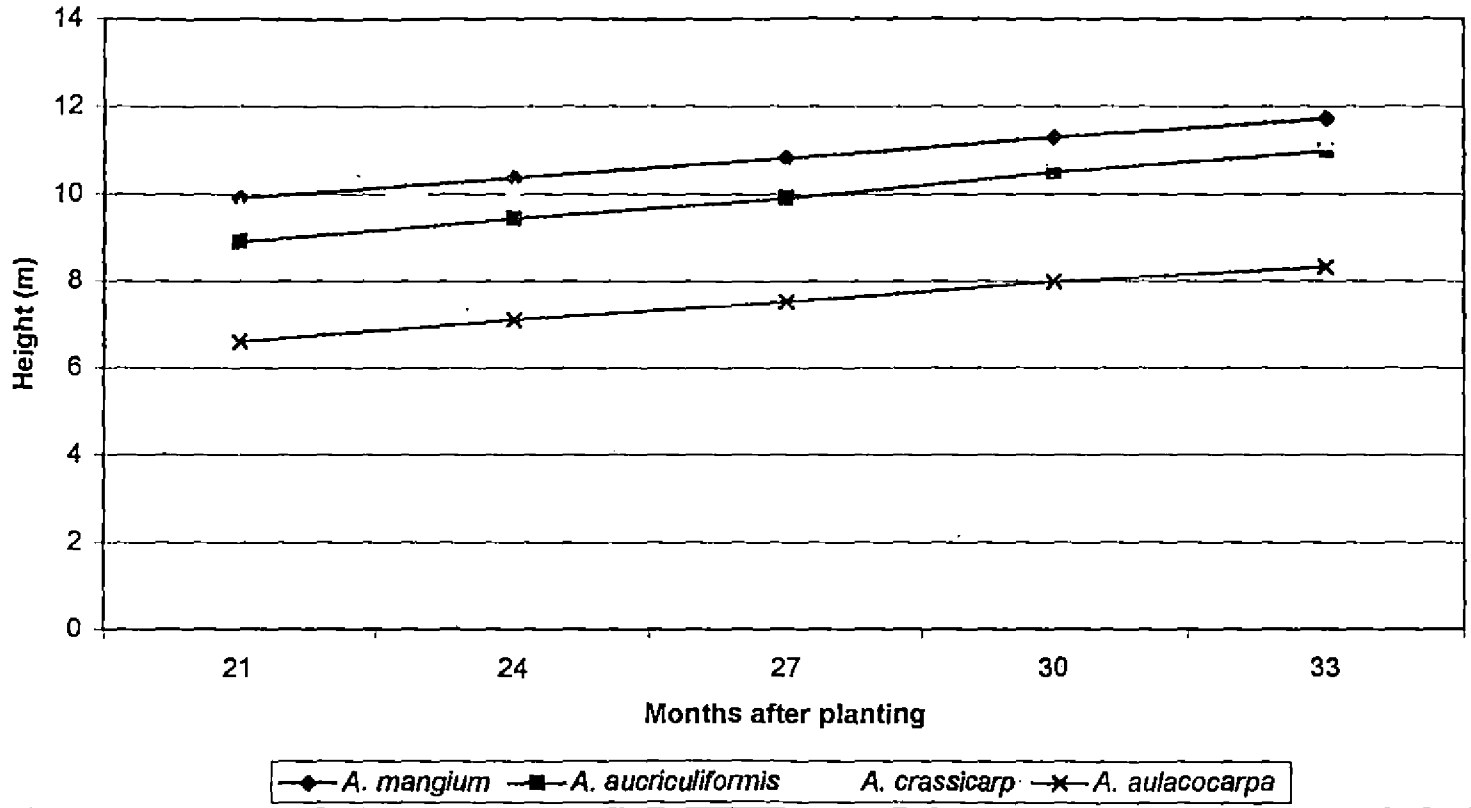


Fig.4 Growth in terms of height of four *Acacia* species



The provenances of *A. aulacocarpa*, viz., W of Wipim WP (P_{10}) and Bensbach-Balamuk, WP (P_{11}), and *A. auriculiformis* viz., Orchard Melville 1 from Northern Territory (P_6) and King's Plain Lake (P_7) and *A. crassicarpa* viz., Kapal Oriomo (P_8) and Bensbach WP (P_9) did not vary in height significantly at 33 MAP.

The provenances of *A. mangium* except 7KMSSE Mossman (P_5) did not vary significantly at 33 MAP. The performance of provenances Research Seed Orchard (P_1), Wipim to Oriomo (P_2) and Balimo Aramia River (P_3) were found to be superior throughout the study period. At 33 MAP, among the five species, *A. mangium* was showing *the* maximum height of 11.75m. However, this was on par with *A. auriculiformis* and *A. crassicarpa.* The trend remained the same throughout the study period, with *A. aulacocarpa* exhibiting significantly low height (Table 3, Fig.4).

4.1.2 Collar girth

Data on collar girth of five provenances of *A. mangium,* two provenances each of *A. auriculiformis, A. crassicarpa* and *A. aulacocarpa* recorded during the study period are presented in the Table 4 and 5, respectively. Their performance during the study period is represented in fig. 5, 6, 7 and 8.

At 33 MAP, the maximum growth in terms of collar girth (59.26 cm) was recorded by the provenance, Wipim to Oriomo (P_2) of *A. mangium* and minimum collar girth of 36.38 cm was recorded by the provenance Bensbach-Balamuk WP (P_{11}) of *A. aulacocarpa*.

The two provenances each of *A. auriculiformis, A. aulacocarpa* and *A. crassicarpa* showed no significant differences. The five provenances of *A. mangium*

Table 4 Mean collar girth (cm) of the provenances of four species of *Acacia*

Provenances	21 MAP	22 MAP	23 MAP	24 MAP	25 MAP	26 MAP	27 MAP	28 MAP	29 MAP	30 MAP	31 MAP	32 MAP	33 MAP
A. mangium													
P_1	33.46^{AB}	35.25^{AB}	37.44^{AB}	38.90^{AB}	40.44^{A}	42.17^{A}	43.22^{A}	46.20^{A}	48.29^{AB}	50.25^{A}	52.16^{A}	53.17^{A}	56.68^{AB}
P_2	30.83^{ABC}	33.07^{ABC}	36.16^{A}	37.34^{AB}	39.07^{AB}	40.95^{AB}	45.22^{A}	45.88^{A}	48.43^{AB}	50.30^{A}	53.07^{A}	56.36^{A}	59.26^{A}
P_3	34.03^{A}	37.23^{A}	38.51^{A}	40.66^{A}	42.59^{A}	44.54^{A}	44.64^{A}	48.16^{A}	50.16^{A}	51.73^{A}	52.44^{A}	55.15^{A}	57.05^{A}
P_4	33.64^{A}	35.35^{A}	36.81^{A}	37.77^{AB}	39.25^{AB}	41.14^{AB}	42.82^{AB}	44.78^{A}	46.22^{ABC}	47.27^{AB}	51.60^{A}	51.78^{A}	54.06^{ABC}
P_5	28.16^{ABC}	29.77^{ABCD}	31.69^{AB}	33.22^{BC}	34.83^{BC}	36.59^{BC}	38.67^{BC}	40.01^{AB}	41.44^{CD}	41.15^{CD}	44.57^{B}	48.53^{B}	49.99^{CD}
A. auriculiformis													
P_6	26.43^{BCD}	27.77^{BCDE}	28.93^{BC}	31.27^{CD}	32.91^{C}	34.56^{C}	35.71^{C}	37.98^{AB}	37.83^{D}	40.76^{CD}	42.36^{BC}	43.67^{BC}	47.31^{DE}
P_7	19.91^{D}	21.43^{E}	23.05^{C}	24.45^{E}	26.55^{DE}	27.32^{D}	30.41^{C}	32.45^{C}	34.06^{B}	35.61^{DE}	37.76^{CD}	40.29^{BC}	41.79^{EF}
A. crassicarpa													
P_8	24.49^{CD}	25.42^{CDE}	28.42^{BC}	30.91^{CD}	33.69^{C}	35.57^{C}	38.20^{C}	40.06^{AB}	42.32^{BCD}	42.88^{BC}	44.55^{B}	50.33^{A}	49.76^{CD}
P_9	22.28^{ABC}	24.32^{ABC}	27.90^{AB}	29.48^{CDE}	31.45^{CD}	33.95^{C}	35.26^{C}	38.91^{AB}	41.67^{CD}	43.30^{BC}	45.38^{B}	48.46^{B}	50.51^{BCD}
A. aulacocarpa													
P_{10}	20.49^{D}	22.28^{DE}	23.20^{C}	25.56^{DE}	26.76^{DE}	28.39^{D}	29.86^{CD}	31.42^{C}	33.24^{B}	34.38^{E}	35.81^{D}	38.76^{C}	41.04^{F}
P_{11}	20.24^{D}	21.68^{E}	23.47^{C}	24.47^{E}	25.70^{B}	27.26^{D}	28.73^{CD}	30.10^{C}	31.51^{B}	32.99^{E}	33.54^{D}	35.29^{C}	38.38^{F}
F	**	**	**	**	**	**	**	**	**	**	**	**	**
SEM (±)	2.17	2.37	2.13	1.79	1.68	1.68	1.84	1.84	1.95	1.83	1.94	1.94	2.00

Values with same alphabets do not differ significantly at any given time.
** Significant at 1% level MAP: Months After Planting
P1- Research Seed Orchard,QLD; P2- Wipim To Oriomo, PNG; P3- Balimo Aramia River, PNG; P4- Claudie River,QLD; P5-7KMMSSE Mossman,QLD; P6- Orchard Melville-1, NT; P7- King's Plain Lake, QLD; P8- Kapal Oriomo,PNG; P9- Bensbach WP,PNG; P10- W of Wipim, WP, PNG; P11- Bensbach –Balamuk,WP, PNG

Table 5 Mean collar girth (cm) of the four species of *Acacia*

Species	21 MAP	22 MAP	23 MAP	24 MAP	25 MAP	26 MAP	27 MAP	28MAP	29MAP	30MAP	31MAP	32MAP	33 MAP
A. mangium	32.02	34.13	36.12	37.58^{A}	39.23^{A}	41.08^{A}	42.92	45.01	46.91	48.14^{A}	50.77	53.11	55.41^{A}
A. auriculiformis	23.17	24.60	25.99	27.86^{B}	29.73^{BC}	30.94^{BC}	33.06	35.22	36.95	38.18^{BC}	40.06	41.98	44.5^{BC}
A. crassicarpa	26.81	27.98	30.75	31.19^{B}	32.57^{B}	34.76^{AB}	38.23	39.99	41.99	43.09^{AB}	44.97	49.39	50.13^{AB}
A. aulacocarpa	20.36	21.95	23.33	25.01^{B}	26.23^{C}	27.82^{C}	29.3	30.76	32.37	33.69^{C}	34.68	37.03	39.71^{C}
F	NS	NS	NS	*	*	*	NS	NS	NS	*	NS	NS	*
SEM (±)	0.65	0.71	0.64	0.53	0.50	0.50	0.55	0.56	0.58	0.55	0.58	0.61	0.60

Values with same alphabets do not differ significantly at any given time.
* Significant at 1% level NS – Not significant
MAP: Months After Planting

Fig.5 Mean collar girth of the provenances of *Acacia* at 33 months after planting

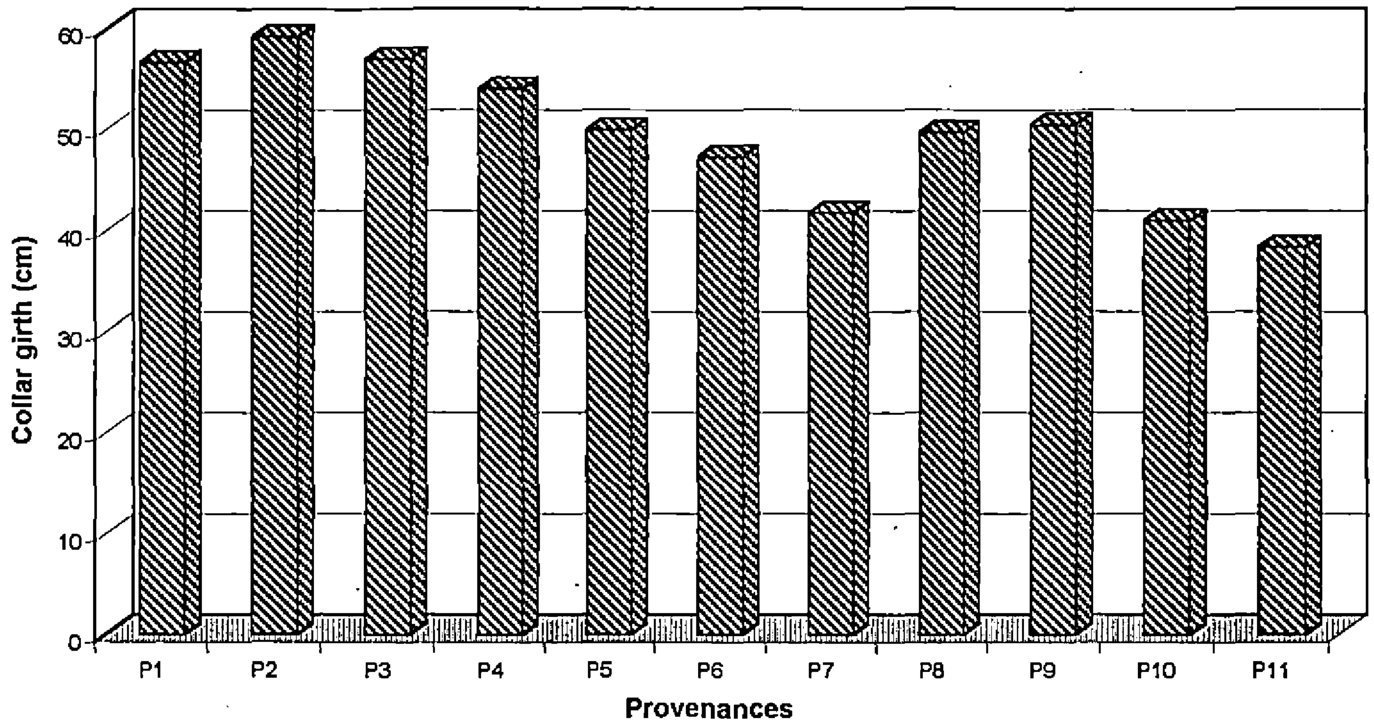


Fig.6 Growth in terms of collar girth of the provenances of four species of *Acacia*

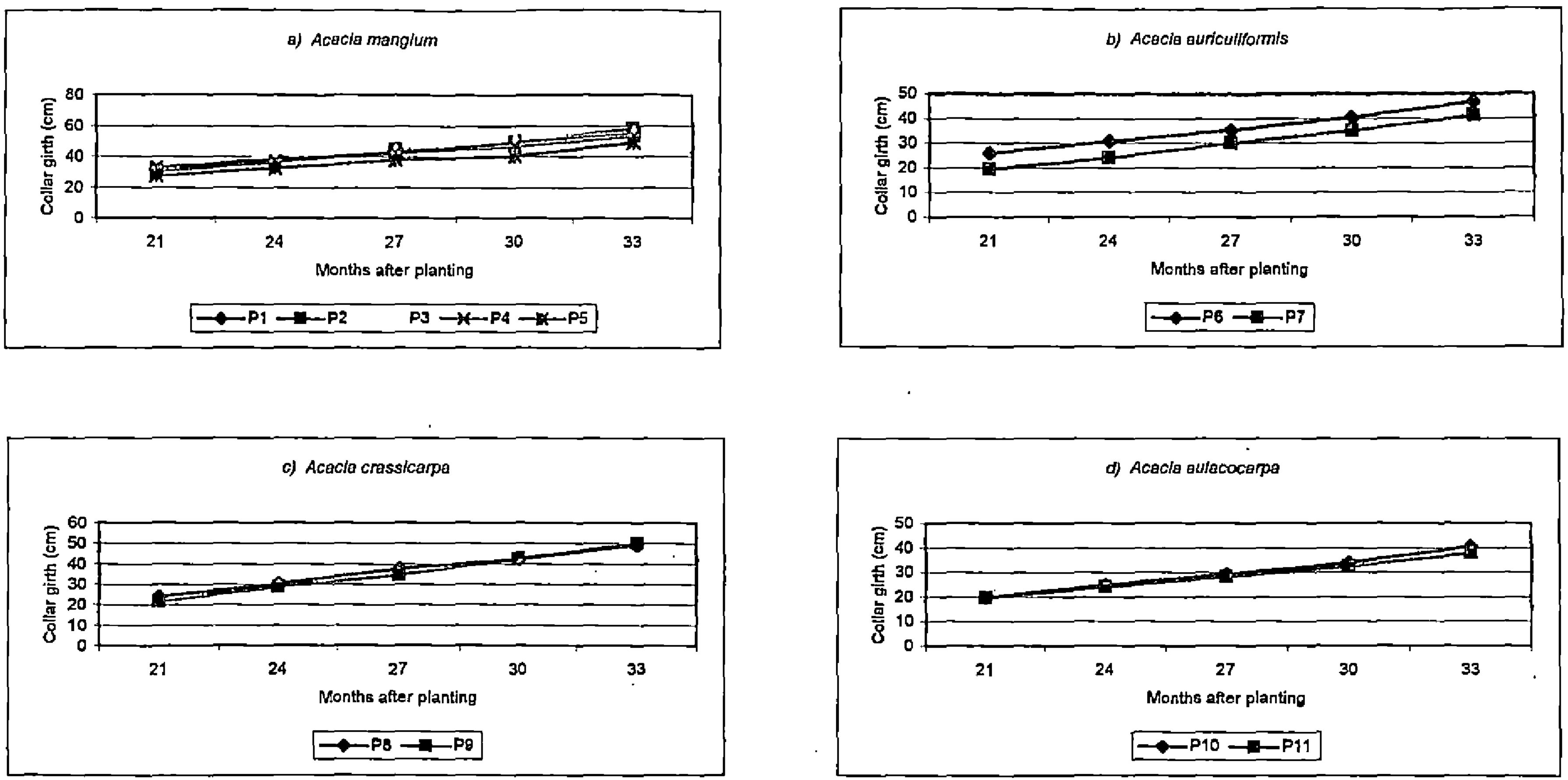
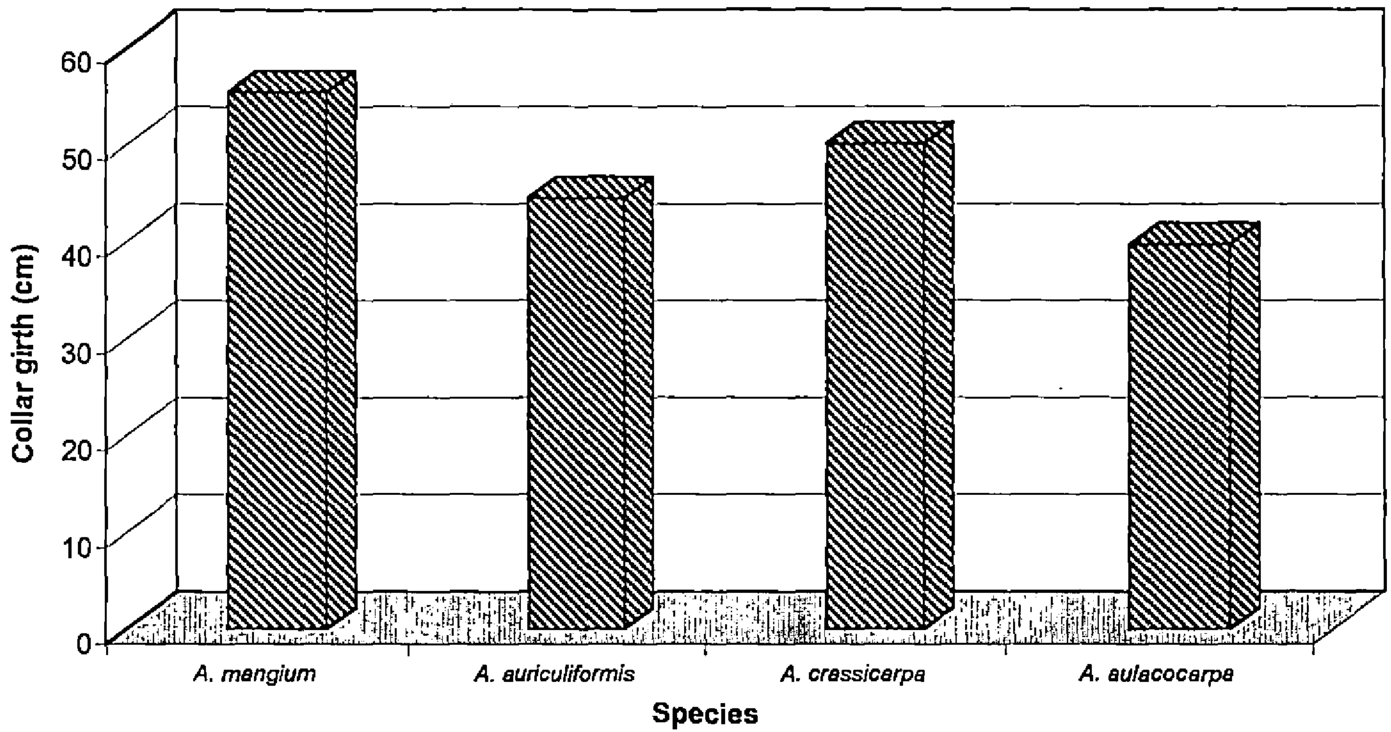


Fig.7 Mean collar girth of the four species of *Acacia* at 33 months after planting



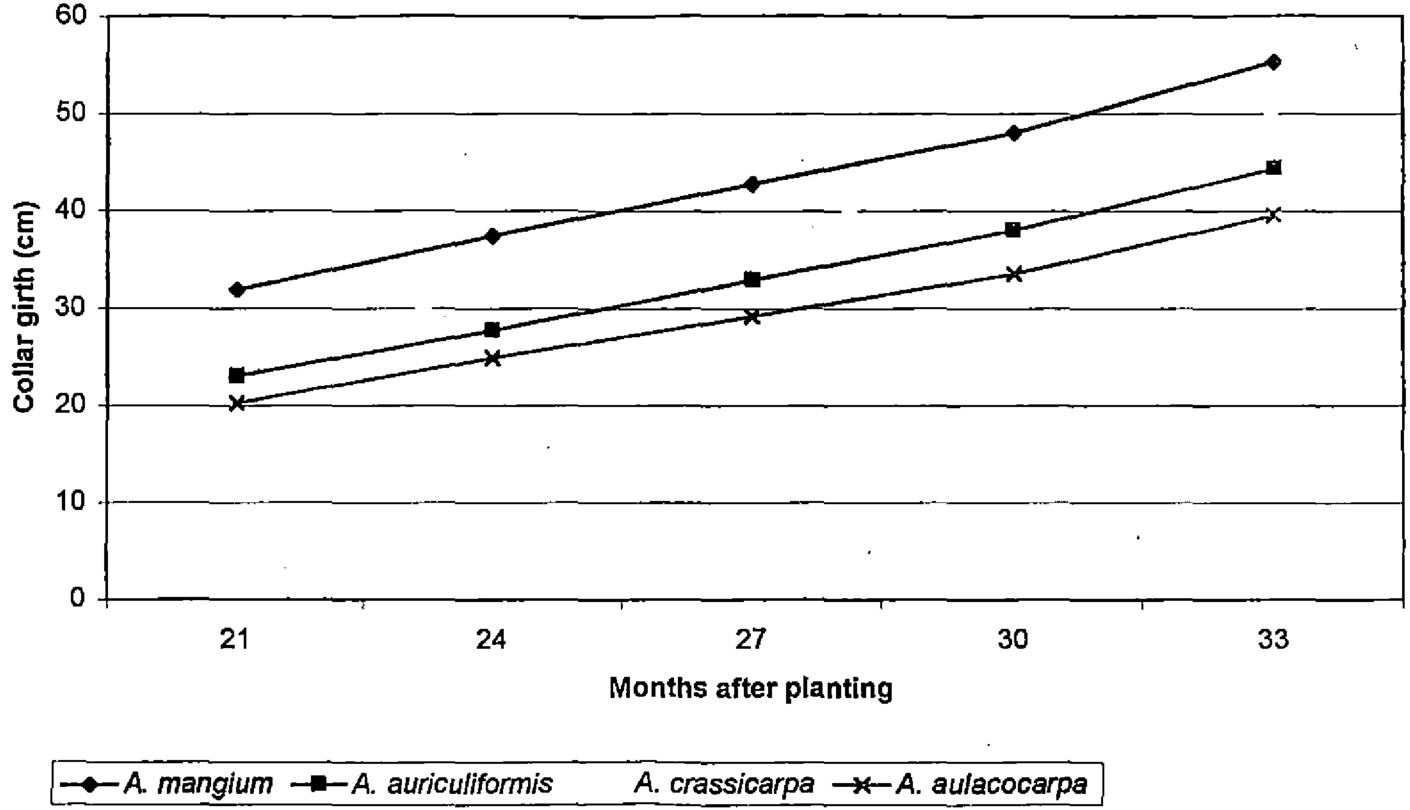


Fig.8 Growth in terms of collar girth of four species of *Acacia*

except 7KMSSE Mossman (P_5) showed non-significant differences at 33 MAP. Research Seed Orchard (P_1) from Queensland, Wipim to Oriomo (P_2) and Balimo Aramia River from Papua New Guinea (P_3) showed higher values of collar girth throughout the study period. The growth rate remained more or less same in all the provenances (Fig.6). At33 MAP, significant variations were observed between the four species viz., *A. mangium*, *A. auriculiformis*, *A. crassicarpa* and *A.aulacocarpa* (Table 5, Fig.7). *A. mangium* was having the highest collar girth (55.41cm). The rate of growth exhibited the same trend in all species (Fig.8).

4.1.3 Number of branches

Data on number of branches recorded at monthly intervals for five provenances of *A. mangium*, two provenances each of *A. auriculiformis*, *A. crassicarpa* and *A. aulacocarpa* were recorded and are presented in Table 6 and 7, respectively. Their performance during the study period is represented in Fig.9, 10, 11 and 12.

At 33 MAP the maximum number of branch was recorded by the provenances Orchard Melville I (P_6) from Northern Territory, Australia and minimum number of branch was recorded by the provenance 7KMSSE Mossman (P_5) from Queensland of *A. mangium*. (Table 6, Fig.9).

The two provenances each of *A. mangium, A. crassicarpa and A. aulacocarpa* showed no significant difference, where as those of *A. auriculiformis* showed significant variations.

Among the four species, *A. auriculiformis* produced the maximum number of branches where as the *A. mangium* produced the least. (Table 7, Fig.11). The rate of

Table 6 Mean branch number of the provenances of *Acacia*

Provenances	21MAP	22 MAP	23 MAP	24 MAP	25 MAP	26 MAP	27 MAP	28 MAP	29 MAP	30 MAP	31 MAP	32 MAP	33 MAP
A. mangium													
P_1	36.5^{D}	39.1^{CDE}	38.6^{D}	44.2^{CDEF}	45.9^{CDE}	50.9^{CDE}	52.1^{DEF}	54.6^{C}	56.0^{CD}	59.2^{CD}	61.80^{C}	65.0	67.1^{BCDE}
P_2	35.8^{D}	36.1^{DE}	36.4^{F}	39.0^{EFG}	42.9^{DE}	45.0^{DEF}	47.6^{F}	49.7^{CD}	52.2^{D}	54.3^{D}	56.5^{CD}	59.0	61.2^{E}
P_3	28.2^{E}	30.8^{EF}	39.5^{D}	36.8^{FG}	40.1^{EF}	43.2^{EF}	46.8^{F}	49.5^{CD}	52.6^{D}	55.0^{D}	55.8^{D}	62.8	62.8^{CDE}
P_4	37.7^{D}	39.5^{CDE}	39.5^{D}	43.6^{DEF}	45.5^{CDE}	46.5^{DE}	49.2^{EF}	49.9^{CD}	52.0^{D}	54.8^{D}	55.5^{D}	59.6	62.9^{DE}
P_5	19.2^{F}	21.8^{F}	24.3^{E}	26.8^{G}	28.8^{F}	31.8^{F}	33.8^{G}	35.9^{G}	38.1^{E}	40.6^{E}	42.6^{E}	44.5	46.9^{F}
A. auriculiformis													
P_6	80.4^{A}	84.8^{A}	91.5^{A}	91.7^{A}	95.5^{A}	97.7^{A}	101.8^{A}	105.6^{A}	107.8^{A}	110.5^{A}	113.0^{A}	122.2	125.4^{A}
P_7	56.7^{B}	61.8^{B}	54.0^{B}	63.7^{B}	66.1^{B}	67.1^{B}	75.6^{B}	73.4^{B}	75.6^{B}	78.5^{AB}	76.7^{B}	89.0	84.4^{BC}
A. crassicarpa													
P_8	49.9^{BC}	48.7^{BCD}	50.0^{A}	54.2^{BCD}	57.2^{BCD}	58.5^{BCD}	62.7^{BCDE}	64.2^{BC}	66.9^{BC}	70.1^{BC}	75.6^{B}	82.4	77.9^{BCDE}
P_9	49.0^{C}	50.3^{BC}	56.2^{A}	53.5^{BCDE}	55.4^{BCD}	57.4^{BCDE}	59.2^{CDEF}	60.8^{BC}	62.7^{BCD}	66.0^{C}	69.6^{BC}	74.1	77.3^{BCDE}
A. aulacocarpa													
P_{10}	51.4^{BC}	53.9^{B}	56.2^{A}	59.0^{BC}	62.5^{B}	63.7^{BC}	66.9^{BC}	70.1^{B}	66.4^{BC}	76.0^{BC}	79.4^{B}	74.1	87.8^{B}
P_{11}	52.2^{BC}	52.5^{BC}	52.0^{A}	52.9^{BCDE}	58.7^{BC}	62.0^{BC}	63.5^{BCD}	64.5^{BC}	66.0^{BC}	70.3^{BC}	69.6^{BC}	74.1	82.9^{BCD}
F	**	**	**	**	**	**	**	**	**	**	**	NS	**
SEM (±)	4.50	4.35	4.00	4.56	4.40	4.50	4.20	4.00	3.90	4.00	4.20	4.20	4.30

Values with same alphabets do not differ significantly at any given time.
** Significant at 1% level; NS – Not significant; MAP: Months After Planting
P1- Research Seed Orchard,QLD; P2- Wipim To Oriomo, PNG; P3- Balimo Aramia River, PNG; P4- Claudie River,QLD; P5-7KMMSSE Mossman,QLD; P6- Orchard Melville-1, NT; P7- King's Plain Lake, QLD; P8- Kapal Oriomo,PNG; P9- Bensbach WP,PNG; P10- W of Wipim, WP, PNG; P11- Bensbach –Balamuk,WP, PNG

Table 7 Mean branch number of four species of *Acacia*

Species	21 MAP	22 MAP	23 MAP	24 MAP	25 MAP	26 MAP	27 MAP	28 MAP	29 MAP	30 MAP	31 MAP	32 MAP	33 MAP
A. mangium	31.50^{C}	33.50^{C}	31.60	38.10^{C}	40.60^{C}	43.50^{C}	45.90^{C}	47.90^{C}	50.20^{B}	52.80^{C}	61.80^{C}	66.00	59.10^{D}
A. auriculiformis	68.50^{A}	73.30^{A}	75.10	77.70^{A}	80.80^{A}	82.40^{A}	88.60^{A}	89.05^{A}	91.70^{C}	94.50^{A}	94.90^{A}	105.50	109.90^{A}
A. crassicarpa	49.50^{B}	49.50^{B}	53.10	53.90^{B}	56.30^{B}	58.00^{B}	60.90^{B}	62.50^{B}	64.80^{A}	68.00^{B}	72.60^{B}	78.20	77.60^{C}
A. aulacocarpa	51.80^{B}	53.20^{B}	54.10	55.90^{B}	60.90^{B}	62.80^{B}	65.20^{B}	66.80^{B}	66.20^{B}	73.20^{B}	74.51^{B}	74.10	85.40^{B}
F	*	*	NS	**	**	**	**	**	**	**	**	NS	**
SEM (±)	1.37	1.31	1.31	1.37	1.34	1.38	1.29	1.39	1.39	1.46	1.27	1.25	1.95

Values with same alphabets do not differ significantly at any given time.
* Significant at 5% level ** Significant at 1% level NS – Not significant
MAP: Months After Planting

Fig.9 Mean branch number of the provenances of *Acacia* at 33 months after planting

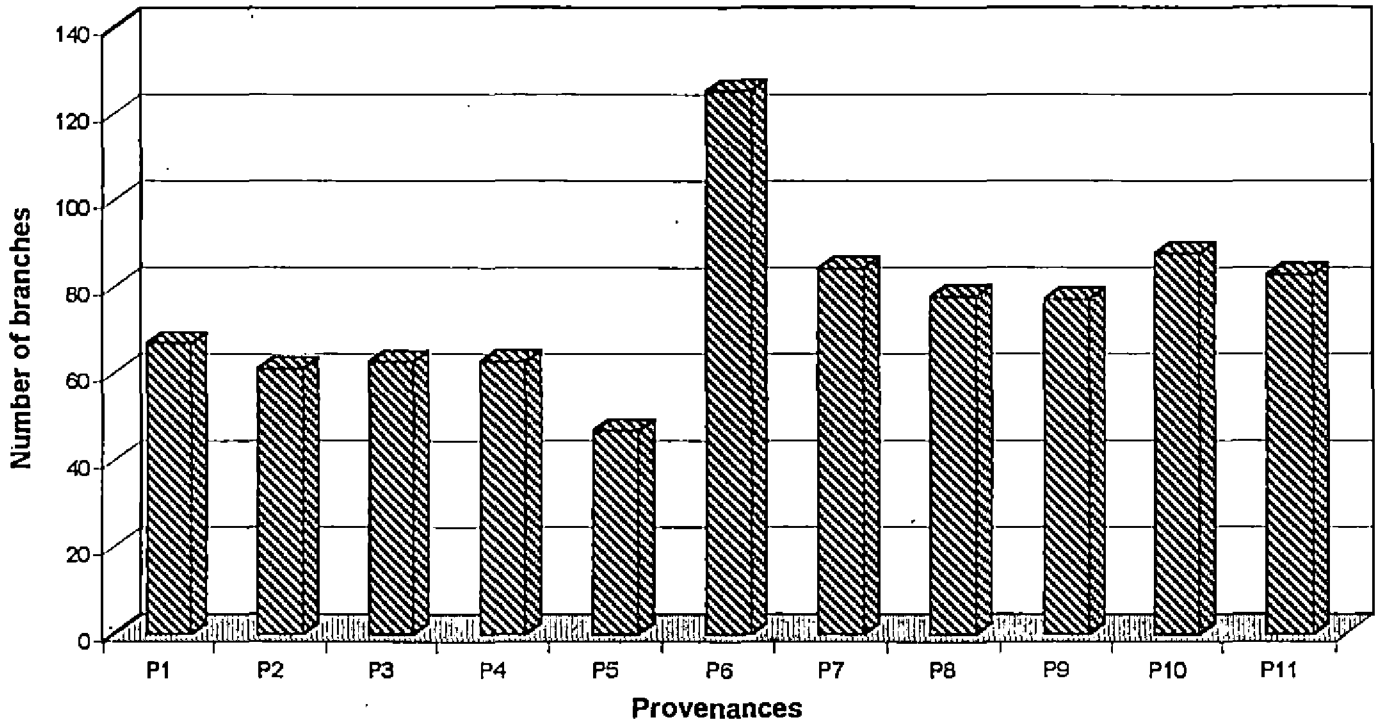


Fig.10 Growth in terms of branch number of the provenances of four species of *Acacia*

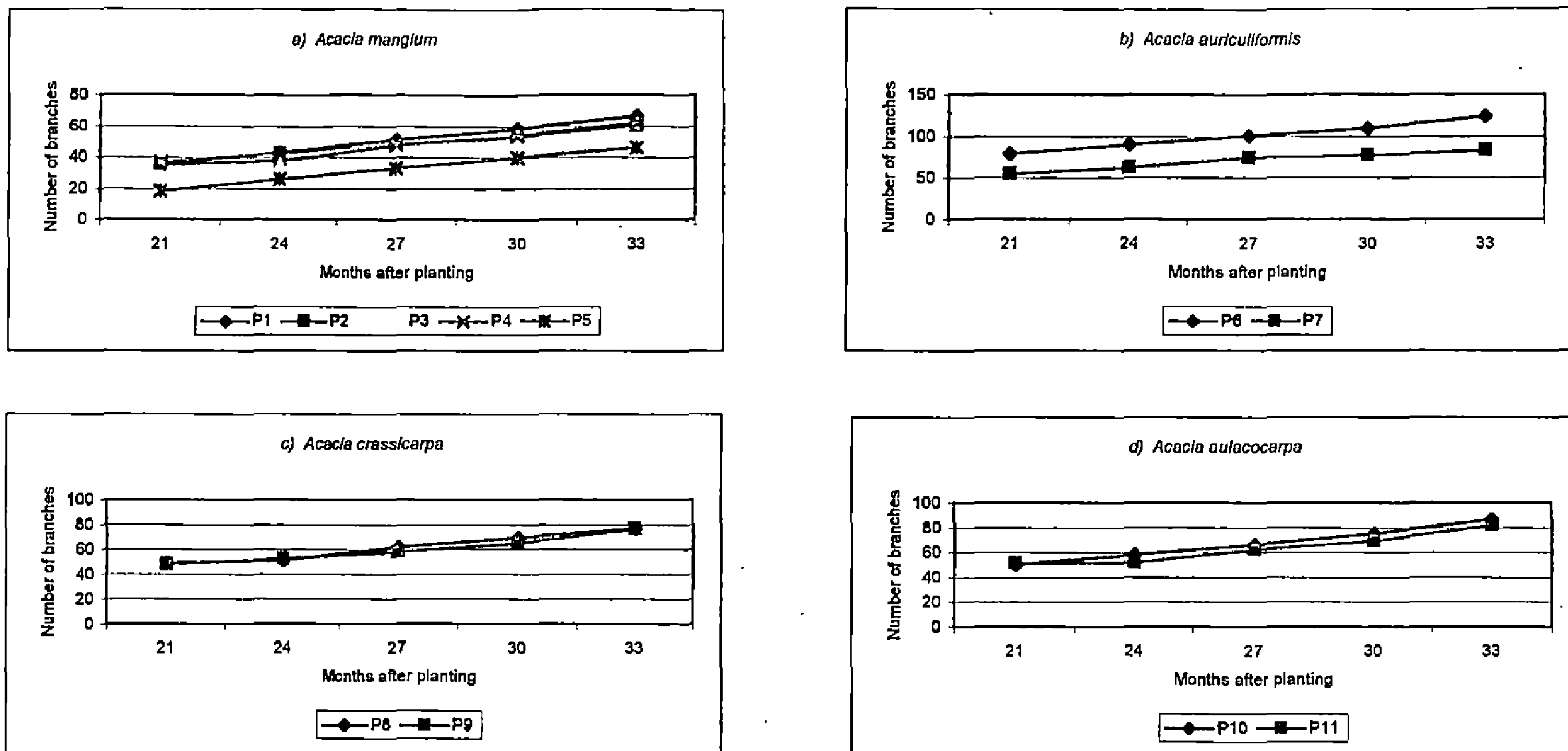
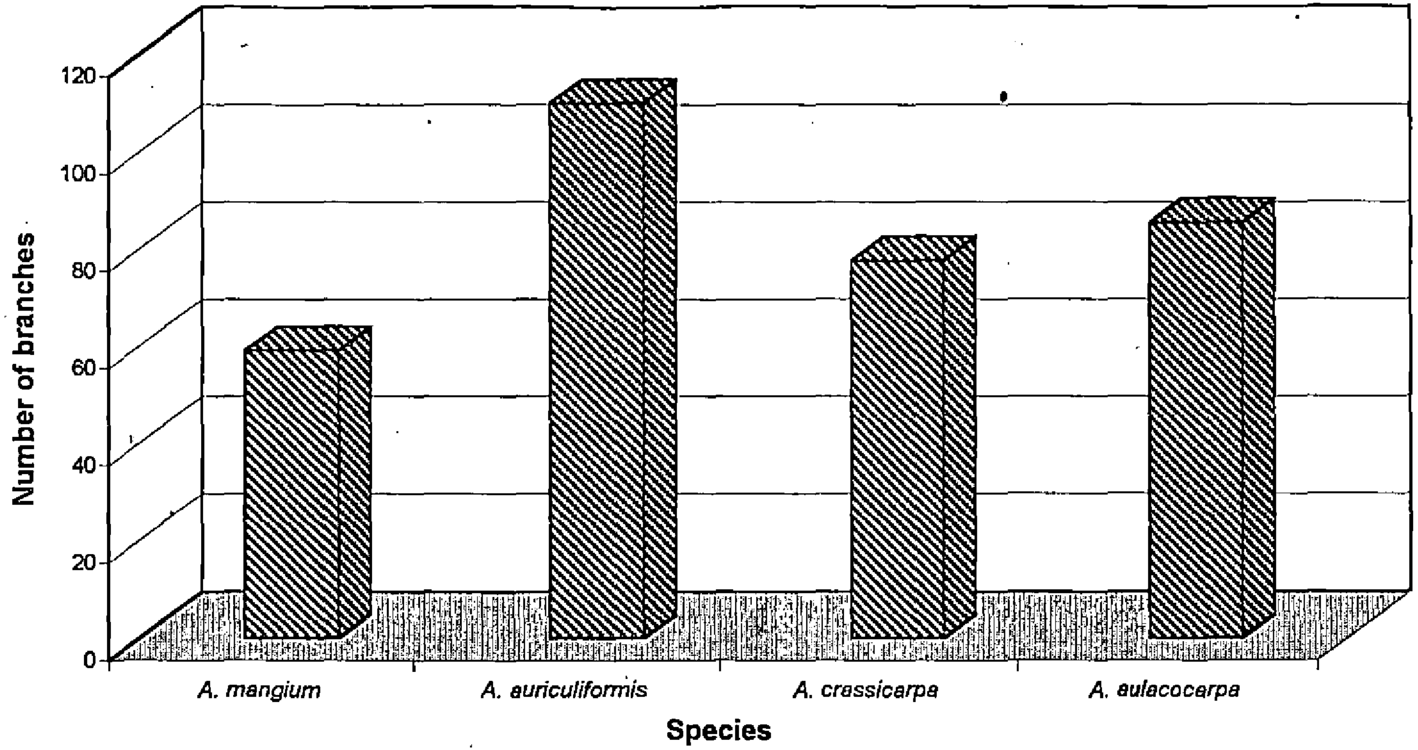


Fig.11 Mean branch number of the four species of *Acacia* at 33 months after planting



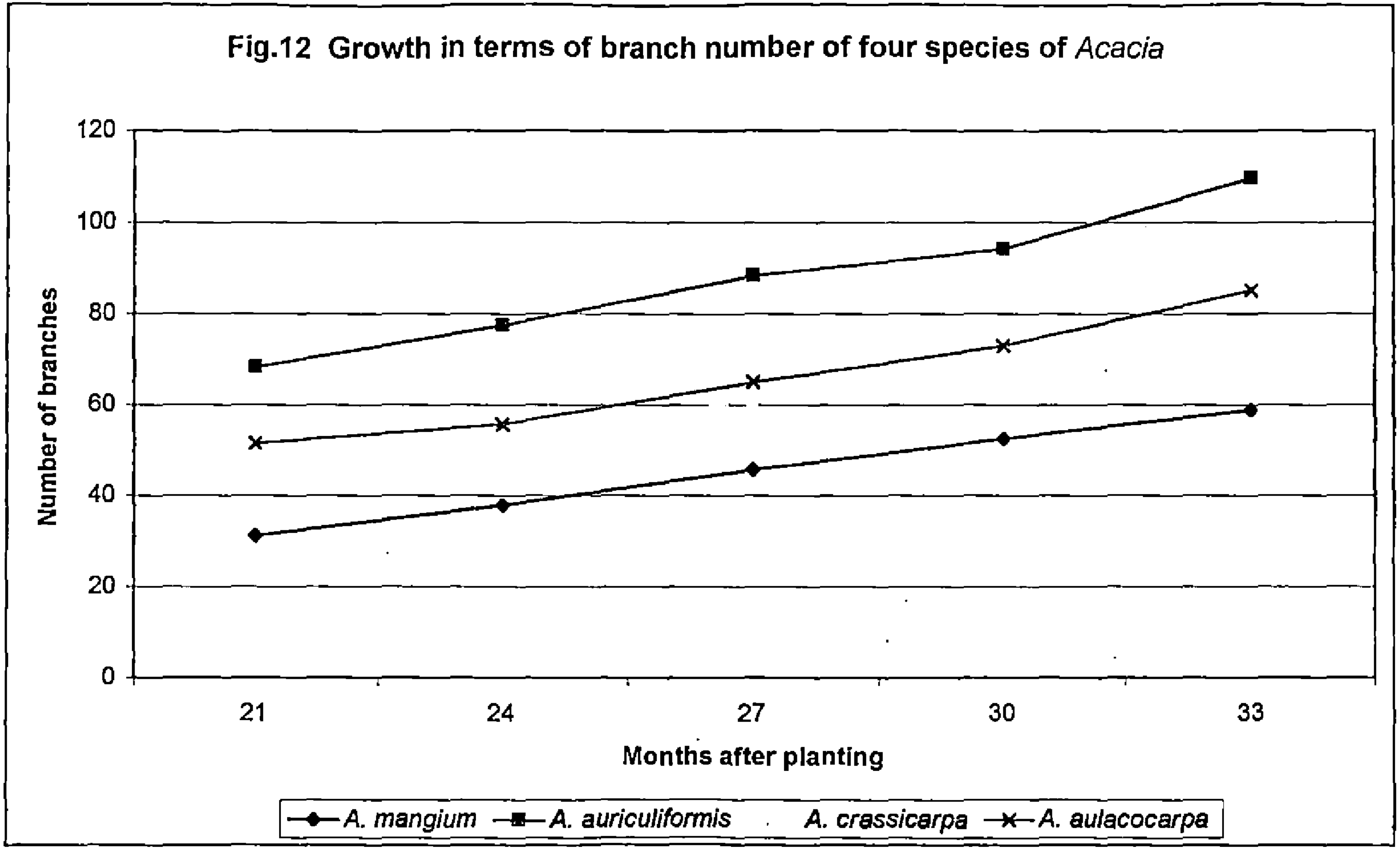


Fig.12 Growth in terms of branch number of four species of *Acacia*
Number of branches
120
100
80
60
40
20
0
21
24
27
30
33
Months after planting
A. mangium
A. auriculiformis
A. crassicarpa
A. aulacocarpa

production of branches at different stages of growth followed the same trend in all the species (Fig.12).

4.2 Physiological parameters

4.2.1 Leaf area index

The leaf area index (LAI) recorded during 20, 25 and 28 MAP for the provenances of the four species are given in Table 8 and 9 respectively.

There was no significant variation in leaf area index (LAI) between the provenances throughout the study period. However, significant variation between the species was observed throughout the study period except during December-January 1999. Among the four species *A. mangium* showed maximum leaf area index (5.06) and minimum (3.0) was recorded in *A. auriculiformis* (Table 9).

4.2.2 Stomatal frequency

The mean stomatal frequency of the provenances and the four species are presented in the Table 10 and 11.

Stomatal frequency with respect to ventral (upper) surface of leaves showed no significant variations, while the frequency on the dorsal (lower) leaf surface showed significant variation. Generally the dorsal surface recorded the higher frequency compared to the ventral surface.

Provenances of *A. aulacocarpa* namely, W of Wipim WP (P_{10}) and Bensbach-Balamuk, WP from Papua New Guinea showed significant variation with respect to stomatal frequency of the dorsal leaf surface.

Table 8 Leaf area index of the provenances of four species of *Acacia*

Provenances	LAI		
	20 MAP (April)	25 MAP (September)	28 MAP (December)
A. mangium			
P_1	4.14	4.91	4.16
P_2	5.05	4.77	6.20
P_3	4.75	5.35	5.30
P_4	4.92	5.70	4.76
P_5	3.82	4.16	4.87
A. auriculiformis			
P_6	3.27	4.78	4.33
P_7	1.42	3.19	1.67
A. crassicarpa			
P_8	2.78	2.68	4.34
P_9	3.50	3.09	3.08
A. aulacocarpa			
P_{10}	4.30	5.08	5.17
P_{11}	4.00	4.20	4.85
F	NS	NS	NS
SEM (±)	0.41	0.33	0.70

P1- Research Seed Orchard,QLD; P2- Wipim To Oriomo, PNG; P3- Balimo Aramia River, PNG; P4- Claudie River,QLD; P5-7KMMSSE Mossman,QLD; P6- Orchard Melville-1, NT; P7- King's Plain Lake, QLD; P8- Kapal Oriomo,PNG; P9- Bensbach WP,PNG; P10- W of Wipim, WP, PNG; P11- Bensbach –Balamuk,WP, PNG
CD for MAP (seasons) : 2.31; MAP: Months After Planting

Table 9 Leaf area index (LAI) of the four species of *Acacia*

Species	LAI		
	MAP20 (April)	25 MAP(September)	28 MAP(December)
A. mangium	4.54^{A}	4.98^{A}	5.06
A. auriculiformis	2.34^{C}	3.98^{B}	3.00
A. crassicarpa	3.14^{B}	2.88^{C}	3.71
A.aulacocarpa	4.54^{A}	4.98^{A}	5.06
F	**	*	NS
SEM (+)	0.12	0.16	0.21

Values with same alphabets do not differ significantly at any given time.
** Significant at 1% level * Significant at 5% level NS - Not significant
CD for MAP (seasons): 2.31 MAP: Months After Planting

Table 10 Stomatal frequency (No/cm^2 x 10^3) of the provenances of four species of *Acacia*

Provenances	20 MAP		25 MAP		28 MAP		32 MAP	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
A. mangium								
P1	36.34^{D}	36.95^{G}	37.86^{E}	38.25^{E}	38.21^{E}	39.03^{E}	37.28^{E}	36.87^{F}
P2	38.83^{E}	43.56^{D}	39.93^{C}	42.67^{B}	41.76^{B}	44.27^{K}	37.95^{D}	42.13^{B}
P3	37.15^{F}	35.94^{H}	37.15^{F}	37.88^{F}	38.05^{G}	40.84^{D}	36.69^{F}	34.77^{H}
P4	35.36^{G}	38.72^{E}	34.06^{G}	39.85^{C}	37.01^{I}	36.68^{G}	34.37^{G}	36.26^{G}
P5	38.97^{E}	46.61^{A}	38.25^{D}	20.09^{I}	38.14^{F}	44.41^{A}	39.96^{C}	44.50^{A}
A. auriculiformis								
P6	41.66^{B}	44.17^{C}	40.43^{B}	43.54^{A}	40.01^{D}	42.68^{B}	43.17^{B}	40.60^{C}
P7	43.86^{A}	45.44^{B}	42.95^{A}	39.83^{D}	41.23^{C}	40.84^{C}	43.31^{A}	40.15^{B}
A. crassicarpa								
P8	21.46^{J}	20.67^{J}	20.24^{J}	20.07^{J}	16.77^{K}	17.81^{J}	21.20^{J}	21.65^{J}
P9	18.44^{K}	19.43^{K}	18.25^{K}	18.63^{K}	18.30^{A}	18.67^{I}	17.71^{K}	20.22^{K}
A. aulacocarpa								
P10	34.97^{H}	37.06^{F}	33.54^{H}	37.33^{G}	37.26^{H}	36.93^{F}	25.85^{I}	38.17^{E}
P11	31.05^{I}	31.72^{I}	27.83^{I}	32.85^{H}	31.35^{J}	32.57^{H}	31.24^{H}	32.71^{I}
F	*	*	**	*	*	NS	NS	*
SEM±	0.41	0.51	0.31	0.51	0.40	0.41	0.42	0.48

Values with same alphabets do not differ significantly at any given time; CD for seasons 1.64 (upper), 2.06 (lower)
P_1- Research Seed Orchard,Qld P2- Wipim to Oriomo, PNG P3- Balimo Aramia River, PNG P4- Claudie River,QLD P5-7KMSSE Mossman,QLD; P6- Orchard Melville-1,NT; P7- King's Plain Lake, QLD P8- Kapal Oriomo,PNG P9- Bensbach WP,PNG P10- Wipim Po Oriomo,PNG P11- Balimo Aramia River, PNG
MAP – Months After Planting

Table 11 Stomatal frequency (No/cm^2 x 10^3) of the four species of *Acacia*

Species	20 MAP		25 MAP		28 MAP		32 MAP	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
A. mangium	37.34^B	40.35^B	37.45^B	35.75^B	39.64^B	41.05^B	37.21^B	38.91^B
A. auriculiformis	42.75^A	44.80^A	41.69^A	41.48^A	40.62^A	41.76^B	43.24^A	40.37^A
A. crassicarpa	19.95^D	20.05^D	19.25^D	19.35^D	17.53^D	18.24^D	19.46^D	20.93^D
A. aulacocarpa	33.01^C	34.39^C	30.69^C	35.09^C	34.31^C	34.75^C	28.55^C	35.44^C
F	*	*	**	*	*	NS	NS	*
SEM(±)	0.34	0.48	0.24	0.47	0.36	0.38	0.34	0.44

Values with same alphabets do not differ significantly at any given time.
** Significant at 1% level; * Significant at 5% level; NS - Not significant
CD for MAP (seasons): 199.13 (Upper); 189.10 (lower); MAP: Months After Planting

Two provenances of *A. auriculiformis*, Orchard Melville 1 (P_6) and King's Plain Lake (P_7) were on par. Similarly provenances of *A. crassicarpa* also were on par.

The five provenances of *A. mangium*, were also on par. The four species showed significant variation in stomatal frequency on both the dorsal (lower) and ventral (upper) leaf surface. *A. auriculiformis* recorded the maximum stomatal frequency followed by *A. mangium* (Table 11). Comparing between the four MAP, variation with respect to lower leaf surface was not significant, while the variation with respect to upper leaf surface was significant.

4.2.3 Leaf water potential

Variations in the leaf water potential (ψ) of the 11 provenances and the four species of *Acacia*, during 28 and 32 MAP for predawn and afternoon hours are given in the Table 12 and 13.

The predawn leaf water potential and the water potential in the after noon exhibited significant variation between the provenances during 28 MAP, while they were non significant during 32 MAP. Leaf water potentials recorded in all the provenances decreased with the progress of the day. During 28 and 32 MAP the maximum water potential during pre-dawn hours was recorded by the provenances Orchard Melville 1 (P_6) and King's Plain Lake (P_7) of *A. auriculiformis*, while the maximum during noon hours was recorded by Claudie River (P_4) and 7KMSSE Mossman (P_5) of *A. mangium* (Table12).

Among the four species *A. auriculiformis* showed the minimum water potential during 28 MAP, in noon hours followed by *A. mangium*. Similarly in the predawn

Table 12 Leaf water potential of the provenances of the four species of *Acacia*

Provenances	28 MAP (December)		32 MAP (April)	
	predawn	afternoon	predawn	afternoon
A. mangium				
P_1	-1.78^{CD}	-15.43^{DE}	-2.32	-13.28
P_2	-1.33^{D}	-21.67^{AB}	-3.07	-18.50
P_3	-1.77^{CD}	-18.83^{BC}	-3.42	-19.15
P_4	-5.40^{A}	-18.70^{BC}	-5.82	-22.23
P_5	-1.30^{D}	-22.18^{A}	-2.92	-22.20
A. auriculiformis				
P_6	-4.03^{B}	-21.07^{AB}	-5.42	-20.60
P_7	-5.23^{A}	-7.63^{F}	-5.35	-19.90
A. crassicarpa				
P_8	-1.88^{CD}	-12.90^{E}	-2.07	-15.87
P_9	-1.78^{CD}	-19.33^{BC}	-1.95	-15.40
A. aulacocarpa				
P_{10}	-2.77^{C}	-18.83^{BC}	-2.55	-13.40
P_{11}	-1.73^{CD}	-16.82^{CD}	-1.73	-15.63
F	*	*	NS	NS
SEM(±)	0.24	0.67	0.48	1.71

Values with same alphabets do not differ significantly at any given time.
CD for MAP (seasons): NS MAP: Months After Planting
P_1- Research Seed Orchard,QLD P2- Wipim to Oriomo, PNG P3- Balimo Aramia River, PNG P4- Claudie River,QLD P5-7KMSSE Mossman,QLD P6- Orchard Melville-1,NT; P7- King's Plain Lake, QLD P8- Kapal Oriomo,PNG P9- Bensbach WP,PNG P10- W of Wipim, WP, PNG P11- Bensbach –Balamuk,WP, PNG

Table 13 Leaf water potential (MPa) of the four species of *Acacia*

Species	Water potential			
	20 MAP (April)		28 MAP (December)	
	predawn	afternoon	predawn	afternoon
A. mangium	-2.32^{B}	-19.36^{A}	-3.51	-19.07
A. auriculiformis	-4.63^{A}	-14.35^{D}	-5.39	-20.25
A. crassicarpa	-1.83^{C}	-16.12^{C}	-2.01	-15.63
A. aulacocarpa	-2.25^{B}	-17.82^{B}	-2.14	-14.52
F	**	**	NS	NS
SEM(±)	0.10	1.48	0.20	0.73

Values with same alphabets do not differ significantly at any given time
** Significant at 1% level NS - Not significant MAP: Months After Planting
CD for MAP: (seasons) 0.35 (predawn); 0.36 (after noon)

hours also the same trend was observed. The leaf water potential exhibited significant variation between both 28 and 32 MAP.

4.2.4 Leaf diffusive resistance

The data pertaining to leaf diffusive resistance of the provenances and species recorded during 20 and 28 MAP are presented in the Table 14 and 15.

There were no significant differences between the provenances. The maximum value of leaf diffusive resistance was recorded by the provenances Claudie River (P_4) and 7KMSSE Mossman (P_5) of *A. mangium* during 28 MAP. *A. auriculiformis* was found to give the maximum stomatal conductance at all the time periods while *A. aulacocarpa* generally exhibited much low values (Table 16 and 17).

The leaf diffusive resistance did not vary among the four species also. In a comparison between 20 and 28 MAP variation between the seasons was observed with respect to leaf diffusive resistance.

4.2.5 Transpiration rate

The data pertaining to transpiration rate of the provenances recorded during two seasons namely, 20 and 28 MAP is presented in the Table 18 and 19. The data for the four species are presented in Table 19.

The data recorded during 20 and 28 MAP showed no significant difference between the provenances, except at predawn hours at 20 MAP. King's Plain Lake (P_7), one of the provenances of *A. auriculiformis was* significantly superior to rest of the provenances. The five provenances of *A. mangium*, two each of *A. crassicarpa* and

Table 14 Leaf diffusive resistance (m mol $m^{-2}s^{-1}$) of the provenances of *Acacia*

Provenances	20 MAP (April)		28 MAP (December)	
	Predawn	afternoon	predawn	after noon
A. Mangium				
P_1	4.27	2.58	1.85	1.98
P_2	2.24	2.83	2.67	5.22
P_3	3.00	2.91	2.57	3.17
P_4	3.77	3.49	2.13	4.16
P_5	3.95	3.78	2.33	4.14
A. auriculiformis				
P_6	2.39	2.69	2.97	2.97
P_7	8.64	1.61	2.00	2.06
A. crassicarpa				
P_8	5.17	2.48	3.12	2.27
P_9	5.85	2.79	1.73	5.13
A. aulacocarpa				
P_{10}	3.09	3.24	2.55	3.36
P_{11}	3.23	2.03	2.13	3.43
F	NS	NS	NS	NS
SEM(±)	1.27	1.62	0.43	1.04

NS – Not significant
CD for MAP : 0.33 (predawn); 0.74 (after noon); MAP: Months After Planting
P1- Research Seed Orchard,QLD; P2 - Wipim To Oriomo, PNG; P3 - Balimo Aramia River, PNG; P4 - Claudie River,QLD; P5 - 7KMMSSE Mossman,QLD; P6 - Orchard Melville-1, NT; P7 - King's Plain Lake, QLD; P8 - Kapal Oriomo,PNG; P9 - Bensbach WP,PNG; P10 - W of Wipim, WP, PNG; P11- Bensbach –Balamuk,WP, PNG

Table 15 Leaf diffusive resistance (m mol m^{-2} s^{-1}) of the four species of *Acacia*

Species	Leaf diffusive resistance			
	20 MAP (April)		28 MAP (December)	
	predawn	afternoon	Predawn	afternoon
A. mangium	2.09	2.45	6.56	5.90
A. auriculiformis	1.97	1.97	9.23	2.51
A. crassicarpa	2.13	2.38	6.63	3.70
A.aulacocarpa	2.03	1.71	6.56	3.73
F	NS	NS	NS	NS
SEM(±)	0.38	0.31	0.13	0.49

NS - Not significant; CD for MAP: 0.98 (predawn);0.22 (after noon)
MAP: Months After Planting

Table 16 Stomatal conductance (m mol m^{-2} s^{-1}) of the provenances of *Acacia*

Provenances	20 MAP (April)		28 MAP (December)	
	predawn	Afternoon	predawn	afternoon
A. mangium				
P_1	149	162	224	202
P_2	291	143	160	105
P_3	145	145	161	130
P_4	151	123	195	100
P_5	121	108	178	140
A. auriculiformis				
P_6	175	154	142	174
P_7	133	250	244	198
A. crassicarpa				
P_8	156	161	132	177
P_9	111	162	231	117
A. aulacocarpa				
P_{10}	131	123	159	154
P_{11}	126	244	149	162
F	NS	NS	NS	NS
SEM(±)	34.02	34.63	40.62	34.51

Values with same alphabets do not differ significantly at any given time.
NS – Not significant
CD for MAP (seasons) : 78.1(predawn); 69.6 (after noon) MAP: Months After Planting
P1- Research Seed Orchard,QLD; P2 - Wipim To Oriomo, PNG; P3 - Balimo Aramia River, PNG; P4 - Claudie River,QLD; P5 - 7KMMSSE Mossman,QLD;
P6 - Orchard Melville-1, NT; P7 - King's Plain Lake, QLD; P8 - Kapal Oriomo,PNG; P9 - Bensbach WP,PNG; P10 - W of Wipim, WP, PNG; P11- Bensbach –Balamuk,WP, PNG

Table 17 Stomatal conductance (m mol m^{-2} s^{-1}) of the four species of *Acacia*

Species	20 MAP (April)		28 MAP (December)	
	predawn	afternoon	predawn	Afternoon
A. mangium	151	136	186	139
A. auriculiformis	154	202	193	186
A. crassicarpa	105	165	181	147
A. aulacocarpa	129	183	154	154
F	NS	NS	NS	NS
SEM(±)	10.26	10.41	12.24	10.44

NS - Not significant; CD for MAP (seasons): 23.06 (predawn); 24.42 (after noon)
MAP: Months After Planting

Table 18 Transpiration rate ($\mu g\ H_2O\ cm^{-2}s^{-1}$) of the provenances of *Acacia*

Provenances	20 MAP (April)		28 MAP (December)	
	Predawn	afternoon	predawn	afternoon
A.mangium				
P_1	5.65^{DCD}	12.75^{A}	7.65	13.40
P_2	4.47^{CDE}	13.47^{A}	5.68	7.67
P_3	4.29^{CDE}	9.46^{BC}	4.85	8.15
P_4	5.22^{CD}	7.69^{C}	6.33	7.90
P_5	5.01^{CD}	9.34^{BC}	5.76	7.57
A.auriculiformis				
P_6	2.13^{E}	7.58	8.28	9.57
P_7	11.72^{A}	10.67^{B}	10.17	13.43
A.crassicarpa				
P_8	6.24^{BC}	9.83^{BC}	4.90	11.20
P_9	8.15^{B}	9.77^{BC}	8.37	7.96
A.aulacocarpa				
P_{10}	3.52^{DE}	10.46^{B}	5.71	9.51
P_{11}	4.15^{CDE}	9.53^{BC}	7.42	9.59
F	**	**	NS	NS
SEM(±)	0.76	1.64	0.43	1.42

NS – Not significant
CD for MAP : 2.29 (predawn); 3.73 (after noon) MAP: Months After Planting

P1- Research Seed Orchard,QLD P2- Wipim To Oriomo, PNG P3- Balimo Aramia River, PNG P4- Claudie River,QLD P5-7KMSSE Mossman,QLD P6- Orchard Melville-1, NT
P7- King's Plain Lake, QLD P8- Kapal Oriomo,PNG P9- Bensbach WP,PNG P10- W of Wipim , WP, PNG P11- Bensbach –Balamuk,WP, PNG

Table 19 Transpiration rate (µg H_2O $cm^{-2}s^{-1}$) of the four species of *Acacia*

Species	Transpiration rate			
	20 MAP (April)		28 MAP (December)	
	predawn	afternoon	predawn	afternoon
A. mangium	4.93^{AB}	10.54	6.05	8.94
A. auriculiformis	6.93^{A}	9.12	9.23	11.50
A. crassicarpa	7.20^{A}	9.80	6.63	9.58
A.aulacocarpa	3.83^{B}	10.00	6.56	9.55
F	**	NS	NS	NS
SEM(±)	0.94	1.61	0.89	1.61

Values with same alphabets do not differ significantly at any given time
** Significant at 1% level; NS - Not significant; MAP: Months After Planting
CD for MAP (seasons): 0.69 (predawn); 0.54 (after noon)

A. aulacocarpa were at par among themselves. Comparison of four species, for their transpiration rate (Table 17) revealed that they were all at par during all the periods of study. In a comparison between the seasons the transpiration rate exhibited significant differences between the seasons.

4.2.6 Leaf temperature

Data on the leaf temperature of the provenances and species are given in Table 20 and 21, respectively. The provenances did not differ among themselves in this character during both 20 and 28 MAP. In comparison between the four species, the leaf temperature was not significant. The leaf temperature ranged from 26.8^0C to 29.3^0C during morning hours while it was between 33.0 to 37.4^0C at after noon hrs. In comparison between the 20 and 28 MAP variation in the leaf temperature between 20 and 28 MAP was significant for noon hours while, for predawn hours it was not so.

4. 3 Anatomical parameters

4.3.1 Heartwood percentage

Data on the heartwood percentage of different provenances and species are presented in Table 22 and 23,respectively.

Significant variation in heartwood percentage was observed between the provenances (Table 22). The maximum heartwood percentage (64.49) was recorded by the provenance Bensbach WP (P_9) of *A. crassicarpa* which was at par with Orchard Melville 1 of *A. auriculiformis* (64.01). A significantly low heartwood percentage was recorded in the provenances Bensbach-Balamuk, WP (P_{11}) of *A. aulacocarpa* (30.93). Five provenances of *A. mangium* showed no significant variations.

Table 20 Leaf temperature (°C) of the provenances of *Acacia*

Provenances	20 MAP (April)		28 MAP (December)	
	predawn	afternoon	predawn	afternoon
A. mangium				
P_1	28.93	34.00	28.10	34.70
P_2	28.33	34.00	28.02	34.67
P_3	26.80	34.38	27.65	34.38
P_4	29.06	34.59	28.31	3459
P_5	28.53	35.77	27.27	35.77
A. auriculiformis				
P_6	28.80	33.03	27.82	33.03
P_7	28.90	37.44	28.50	34.44
A. crassicarpa				
P_8	28.70	34.81	27.70	34.81
P_9	29.03	34.45	29.34	34.45
A. aulacocarpa				
P_{10}	29.06	34.49	28.23	34.49
P_{11}	29.00	34.90	27.42	34.90
F	NS	NS	NS	NS
SEM(±)	0.18	2.3	0.38	0.62

NS – Not significant
CD for MAP (seasons) : 0.65 (predawn); 1.06 (after noon) MAP: Months After Planting
P1- Research Seed Orchard,QLD; P2 - Wipim To Oriomo, PNG; P3 - Balimo Aramia River, PNG; P4 - Claudie River,QLD; P5 - 7KMMSSE Mossman,QLD;
P6 - Orchard Melville-1, NT; P7 - King's Plain Lake, QLD; P8 - Kapal Oriomo,PNG; P9 - Bensbach WP,PNG; P10 - W of Wipim, WP, PNG; P11- Bensbach –Balamuk,WP, PNG

Table 21 Leaf temperature (°C) of the four species of *Acacia*

Species	20 MAP (April)		28 MAP (December)	
	predawn	afternoon	predawn	afternoon
A.mangium	28.3	34.5	27.9	34.9
A. auriculiformis	28.9	35.2	28.2	34.6
A.crassicarpa	28.9	34.6	28.5	34.6
A.aulacocarpa	29.0	34.7	27.8	34.7
F	NS	NS	NS	NS
SEM (±)	0.38	0.62	0.35	0.60

NS: Not significant
CD for MAP (seasons): 0.19 (predawn); 0.15 (after noon)
MAP: Months After Planting

Table 22 Heartwood percentage of the provenances of *Acacia*

Species	Heartwood (Percentage)
Treatments	
A. mangium	
P_1	53.2^{BC}
P_2	52.67^{BC}
P_3	60.31^{AB}
P_4	59.55^{AB}
P_5	51.72^{BC}
A.auriculiformis	
P_6	64.01^{A}
P_7	50.53^{BC}
A.crassicarpa	
P_8	46.01^{CD}
P_9	64.49^{A}
A.aulacocarpa	
P_{10}	37.94^{DE}
P_{11}	30.93^{E}
F	**
SEM (±)	2.99

Values with same alphabet do not differ significantly.
** Significant at 1% level

P1- Research Seed Orchard, QLD; P2- Wipim To Oriomo, PNG; P3- Balimo Aramia River, PNG; P4- Claudie River, QLD; P5-7KMMSSE Mossman, QLD; P6- Orchard Melville-1, NT; P7- King's Plain Lake, QLD; P8- Kapal Oriomo, PNG; P9- Bensbach WP, PNG; P10- W of Wipim, WP, PNG; P11- Bensbach -Balamuk, WP, PNG

Table 23 Heartwood percentage of the four species of *Acacia*

Species	Heartwood (percentage)
A. mangium	55.49^{A}
A. auriculiformis	57.27^{A}
A. crassicarpa	55.25^{A}
A. aulacocarpa	34.44^{B}
F	**
SEM (±)	0.90

Values with same alphabet do not differ significantly.
** Significant at 1% level

Among the four species, *A. auriculiformis, A. crassicarpa* and *A. mangium* were on par, and *A. aulacocarpa* recorded a significantly low heartwood percentage in comparison to the other three species (Table 23).

4.3.2 Specific gravity

The data showing the specific gravity at green, air dry and oven dry conditions of the provenances and species are given in Table 24 and 25, respectively.

Specific gravity under green, air and oven dry conditions showed statistically no variation between the provenances or species. The maximum specific gravity under green condition was recorded in the provenance 7KMSSE Mossman (P_5) followed by Balimo Aramia River (P_3) of *A. mangium*. The minimum specific gravity was recorded by the provenance Kapal Oriomo (P_8) and Claudie River (P_4) of Papua New Guinea and Queensland, respectively (Table 24).

Except provenance Kapal Oriomo (P_8) of *A. crassicarpa and* provenance Claudie River (P_4) of *A. mangium* all the nine provenances recorded specific gravity under green condition above 1.0. Specific gravity under air dry condition was maximum for Wipim to Oriomo (P_2) and Research Seed Orchard (P_1) of *A. mangium.* The maximum specific gravity at air-dry condition (0.603) was recorded by 7KMSSE Mossman (P_5) of *A. mangium.* At oven dry condition, the maximum was recorded by the provenance, Research Seed Orchard (P_1) of *A. mangium* (0.67) and the minimum was recorded by Bensbach-Balamuk WP (P_{11}) of *A. aulacocarpa* of (0.54).

Among the four species studied, *A. auriculiformis* recorded maximum values under green, air and oven dry condition (1.068 ,0.666 and 0.65 respectively).

Table 24 Specific gravity of the provenances of the four species of *Acacia*

Provenances	Specific gravity		
	Green	Air dry	Oven dry
A. mangium			
P_1	1.01	0.72	0.67
P_2	1.06	0.73	0.62
P_3	1.09	0.66	0.59
P_4	0.98	0.66	0.60
P_5	1.14	0.60	0.60
A. auriculiformis			
P_6	1.08	0.65	0.60
P_7	1.05	0.57	0.50
A. crassicarpa			
P_8	0.93	0.61	0.57
P_9	1.00	0.62	0.56
A. aulacocarpa			
P_{10}	1.07	0.65	0.62
P_{11}	1.01	0.67	0.54
F	NS	NS	NS
SEM(±)	0.04	0.75	0.61

NS – Not significant

P1- Research Seed Orchard,QLD; P2 - Wipim To Oriomo, PNG; P3 - Balimo Aramia River, PNG; P4 - Claudie River,QLD; P5 - 7KMMSSE Mossman,QLD; P6 - Orchard Melville-1, NT; P7 - King's Plain Lake, QLD; P8 - Kapal Oriomo,PNG; P9 - Bensbach WP,PNG; P10 - W of Wipim, WP, PNG; P11- Bensbach –Balamuk,WP, PNG

Table 25 Specific gravity of the four species of *Acacia*

Species	Specific gravity		
	Green	Air dry	Oven dry
A. mangium	1.05	0.67	0.61
A. auriculiformis	1.06	0.66	0.59
A. crassicarpa	0.96	0.58	0.56
A.aulacocarpa	1.04	0.62	0.58
F	NS	NS	NS
SEM(±)	0.01	22.73	0.18

NS - Not significant

Under green condition *A. aulacocarpa, A. auriculiformis* and *A. mangium* recorded specific gravity above 1.0 (Table 25).

4.3.3 Moisture content

The moisture content for the provenances of four species are presented in the Table 26 and 27.

There were no significant variations in wood moisture content of the provenances or species. Under green condition, the maximum percentage of moisture content was recorded by the W of Wipim WP (P_{10}) of *A. aulacocarpa,* (55.93) and the minimum was recorded by Wipim to Oriomo (P_2) Queensland of *A. mangium* (43.67).

W of Wipim WP (P_{10}) and Bensbach-Balamuk, WP (P_{11}) of *A. aulacocarpa,* Kapal Oriomo (P_8)) and Bensbach WP (P_9) of *A. crassicarpa,* and 7KMSSE Mossman of *A. mangium* showed moisture content above 50 percentage on fresh weight basis.

On dry weight basis, provenances from Papua New Guinea of *A. crassicarpa* and *A. aulacocarpa* recorded the moisture content above 100 percentage.

Among the four species *A. aulacocarpa* recorded maximum percentage of moisture content under fresh weight and oven dry weight basis (Table 27).

4.3.4 Dimensions of fibres

The data on fibre dimension (length and width) of the provenances and four species are presented in Table 28.

Table 26 Moisture content of the provenances of the four species of *Acacia*

Provenances	Moisture content (percentage)	
	fresh weight basis	dry weight basis
A. mangium		
P_1	45.80	84.95
P_2	43.67	77.54
P_3	47.52	91.06
P_4	48.37	95.16
P_5	51.74	110.49
A. auriculiformis		
P_6	44.38	80.40
P_7	44.67	82.32
A. crassicarpa		
P_8	53.30	121.60
P_9	65.65	112.74
A. aulacocarpa		
P_{10}	55.92	127.99
P_{11}	53.81	118.39
F	NS	NS
SEM(±)	16.10	41.00

NS – Not significant

P1- Research Seed Orchard,QLD P2- Wipim To Oriomo, PNG P3- Balimo Aramia River, PNG P4- Claudie River,QLD P5-7KMSSE Mossman,QLD P6- Orchard Melville-1,NT
P7- King's Plain Lake, QLD P8- Kapal Oriomo,PNG P9- Bensbach WP,PNG P10- W of Wipim, WP, PNG P11- Bensbach –Balamuk,WP, PNG

Table 27 Moisture content of the four species of *Acacia*

Species	Moisture content	
	fresh weight basis (percentage)	oven dry weight basis (percentage)
A. mangium	47.42	91.84
A. auriculiformis	52.00	81.36
A. crassicarpa	59.47	117.17
A.aulacocarpa	54.86	123.19
F	NS	NS
SEM(±)	4.86	5.22

NS - Not significant

Table 28 Dimensions of fibres of the provenances and four species of *Acacia*

Provenances	Fibers		Fibers	
	Length (microns)	Width (microns)	Length (microns)	Width (microns)
A. mangium			0.544^{C}	0.042^{A}
P_1	0.613^{B}	0.040^{F}		
P_2	0.510^{F}	0.052^{E}		
P_3	0.533^{EF}	0.050^{E}		
P_4	0.546^{DE}	0.041^{F}		
P_5	0.520_{EF}	0.041^{F}		
A. auriculiformis			0.910^{A}	0.028^{B}
P_6	0.900^{A}	0.030^{B}		
P_7	0.920^{F}	0.025^{B}		
A. crassicarpa			0.576^{B}	0.023^{B}
P_8	0.566^{CD}	0.021^{AB}		
P_9	0.586^{CD}	0.025^{B}		
A. aulacocarpa			0.208^{D}	0.029^{B}
P_{10}	0.203^{B}	0.031^{B}		
P_{11}	0.213^{G}	0.028^{B}		
F	**	**	**	**
SEM(±)	0.01	0.71	0.10	0.80

P_1 - Research Seed Orchard,Qld P2 - Wipim to Oriomo, PNG P3 - Balimo Aramia River, PNG P4 - Claudie River,QLD P5 - 7KMSSE Mossman,QLD P6 - Orchard Melville-1,NT; P7- King's Plain Lake, QLD P8 - Kapal Oriomo,PNG P9 - Bensbach WP,PNG P10 - Wipim Po Oriomo,PNG P11- Balimo Aramia River, PNG

Significant variations in the length and width of fibres were observed between the provenances (Table 28). The maximum fibre length (0.92 microns) was recorded by the provenance King's Plain Lake (P_7) of *A. auriculiformis,* while the minimum was recorded by the provenance W of Wipim WP (P_{10}) and Bensbach-Balamuk WP (P_{11}) of *A. aulacocarpa.* Provenances of *A. mangium* were at par with provenances of *A. crassicarpa.*

Among the four species, *A. auriculiformis* recorded maximum fibre length followed by *A. mangium* and *A. crassicarpa.* The *A. aulacocarpa* recorded a significantly low fibre length in comparison with other three species (Table 29).

Similarly, significant variations in fibre width between the provenances were observed (Table 28). The five provenances of *A. mangium* recorded maximum fibre width in comparison to other provenances.

Among the four species, *A.mangium* exhibited maximum fibre width and *A.crassicarpa recorded* the minimum fibre width among the four species (Table 28).

4.3.5 Dimensions of vessels

The length and width of the vessels of the provenances and species are given in the Table 29. The cross section, tangential and radial longitudinal sections of vessels are shown in the Plates VI to XVII.

The provenances of *A.mangium* recorded maximum vessel length in comparison with other provenances. Provenances of *A. auriculiformis* showed the minimum vessel length. Provenances of *A. auriculiformis and A. crassicarpa* had wider vessels in comparison to the provenances of *A. mangium* and *A. aulacocarpa.*. Among the four species, *A. mangium* recorded the maximum vessel width followed by *A. crassicarpa*

Table 29 Dimensions of vessels of the provenances of *Acacia*

Provenances	Vessels		Vessels	
	Length (microns)	width (microns)	length (microns)	width (microns)
A. mangium			0.585^{A}	0.092^{A}
P_1	0.103^{EF}	0.091^{A}		
P_2	0.110^{DEF}	0.088^{B}		
P_3	0.936^{A}	0.098^{A}		
P_4	0.910^{B}	0.097^{A}		
P_5	0.866^{C}	0.088^{A}		
A. auriculiformis			$0.91A^{A}$	0.097^{A}
P6	0.090^{F}	0.910^{B}		
P7	0.091^{E}	0.102^{B}		
A. crassicarpa			0.130^{A}	0.116^{B}
P8	0.126^{D}	0.128^{B}		
P9	0.134^{D}	0.104^{B}		
A. aulacocarpa			0.123^{A}	0.101^{B}
P10	0.124^{DE}	0.095^{A}		
P11	0.122^{DE}	0.107^{B}		
F	**	**	**	**
SEM (±)	0.008	0.007	0.60	0.61

Values with same alphabets do not differ significantly.
** Significant at 1% level
P_1- Research Seed Orchard,QLD P2- Wipim to Oriomo, PNG P3- Balimo Aramia River, PNG P4- Claudie River,QLD P5-7KMSSE Mossman,QLD P6- Orchard Melville-1,NT; P7- King's Plain Lake, QLD P8- Kapal Oriomo,PNG P9- Bensbach WP,PNG P10- W of Wipim , WP, PNG P11- Bensbach –Balamuk,WP, PNG

and *A. aulacocarpa*. *A. mangium, A. auriculiformis* and *A. crassicarpa* were at par. *A. crassicarpa* recorded the minimum vessel width in comparison with the other three species (Table 31).

4.3.6 Dimensions of ray parenchyma

The data showing the length and width of ray parenchyma of the provenances and four species are given in Table 30 and Plates VI to XVII.

Provenances of *A, mangium* namely Research Seed Orchard (P_1) and 7KMSSE Mossman (P_5) showed the maximum ray parenchyma length of 0.4 and 0.41 microns, respectively. Provenances of *A. auriculiformis* and *A. aulacocarpa* were at par.

The width of ray parenchyma observed in the provenances of *A. mangium* was minimum in comparison with provenances of *A. auriculiformis*. Provenance of *A. crassicarpa* and *A. aulacocarpa* were at par.

Among the four species, *A. mangium* recorded the maximum length, while minimum length observed in *A. crassicarpa.*

4.3.7 Dimensions of axial parenchyma

The data on the dimensions of axial parenchyma of the provenances of the four *Acacia* species are given in Table 31 and Plates VI to XVII.

The maximum length for axial parenchyma was observed in the provenances of *A. mangium* followed by the provenances of *A. auriculiformis*. The provenances of *A. crassicarpa* and *A. aulacocarpa* were at par.

Table 30 Dimensions of ray parenchyma of the provenances and four species of *Acacia*

Provenances	ray parenchyma		ray parenchyma	
	length (microns)	width (microns)	Length (microns)	Width (microns)
A. mangium			0.349^{A}	0.034^{A}
P_1	0.400^{A}	0.037^{A}		
P_2	0.296^{BCD}	0.039^{A}		
P_3	0.314^{BC}	0.032^{A}		
P_4	0.323^{B}	0.028^{A}		
P_5	0.412^{A}	0.034^{A}	0.314^{AB}	0.027^{A}
A.auriculiformis			0.314^{AB}	0.027^{A}
P_6	0.332^{B}	0.250^{B}		
P_7	0.296^{BCD}	0.290^{B}		
A.crassicarpa			0.259^{B}	0.036^{B}
P_8	0.254^{D}	0.035^{A}		
P_9	0.264^{CD}	0.038^{A}		
A.aulacocarpa			0.303^{AB}	0.029^{B}
P_{10}	0.326^{B}	0.030^{A}		
P_{11}	0.280^{BCD}	0.028^{A}		
F	**	**	**	**
SEM (±)	0.01	0.01	0.01	0.01

Values with same alphabets do not differ significantly
** Significant at 1% level
P_1- Research Seed Orchard,QLD P2- Wipim to Oriomo, PNG P3- Balimo Aramia River, PNG P4- Claudie River,QLD P5-7KMSSE Mossman,QLD P6- Orchard Melville-1,NT; P7- King's Plain Lake, QLD P8- Kapal Oriomo,PNG P9- Bensbach WP,PNG P10- W of Wipim , WP, PNG P11- Bensbach –Balamuk,WP, PNG

Table 31 Dimensions of axial parenchyma of the provenances and four species of *Acacia*

Provenances	axial parenchyma		axial parenchyma	
	length (microns)	width (microns)	length (microns)	width (microns)
A. mangium			0.427^{A}	0.041^{B}
P_1	0.406^{BC}	0.045^{AB}		
P_2	0.520^{A}	0.058^{A}		
P_3	0.480^{AB}	0.032^{CD}		
P_4	0.413^{BC}	0.028^{D}		
P_5	0.316^{CD}	0.042^{BC}		
A.auriculiformis			0.296^{B}	0.027^{A}
P_6	0.280^{D}	0.051^{CD}	0.296^{B}	
P_7	0.313^{CD}	0.041^{BC}		
A.crassicarpa			0.265^{B}	0.036^{B}
P_8	0.260^{D}	0.051^{C}		
P_9	0.270^{D}	0.051^{C}		
A.aulacocarpa			0.263^{AB}	0.029^{B}
P_{10}	0.250^{DD}	0.031^{D}		
P_{11}	0.276^{D}	0.038^{D}		
F	**	**	**	**
SEM (±)	0.03	0.48	0.03	0.048

Values with same alphabets do not differ significantly.
* Significant at 5% level ** Significant at 1% level NS – Not significant
P_1- Research Seed Orchard,QLD P2- Wipim to Oriomo, PNG P3- Balimo Aramia River, PNG P4- Claudie River,QLD P5-7KMSSE Mossman,QLD P6- Orchard Melville-1,NT; P7- King's Plain Lake, QLD P8- Kapal Oriomo,PNG P9- Bensbach WP,PNG P10- W of Wipim , WP, PNG P11- Bensbach –Balamuk,WP, PNG

Plate VI Cross section of *Acacia mangium*

Plate VII Cross section of *Acacia auriculiformis*

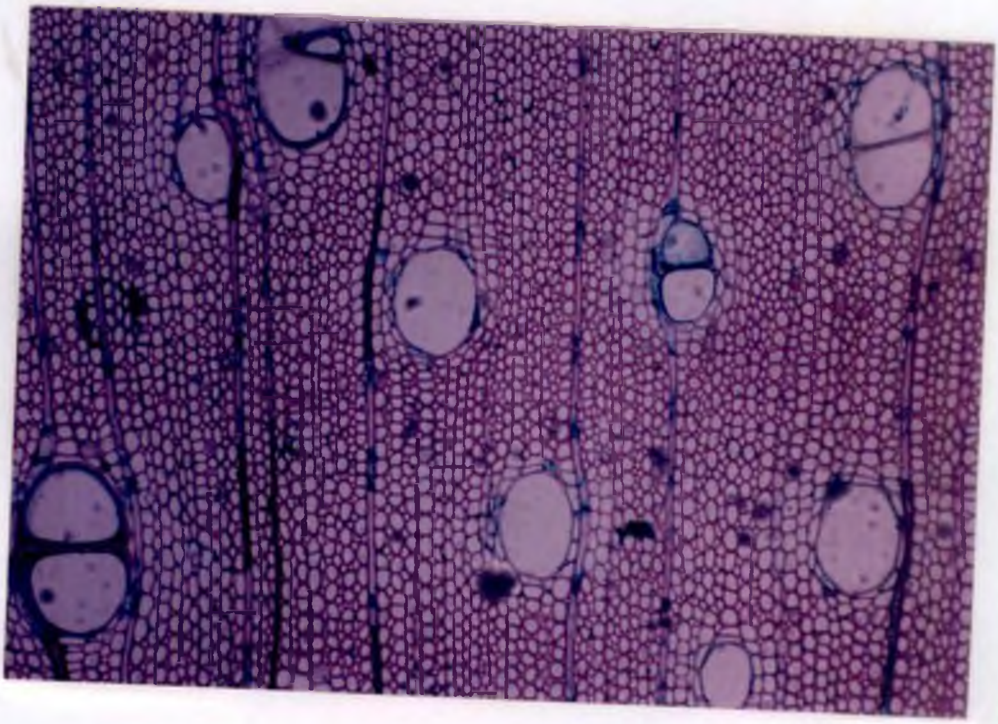
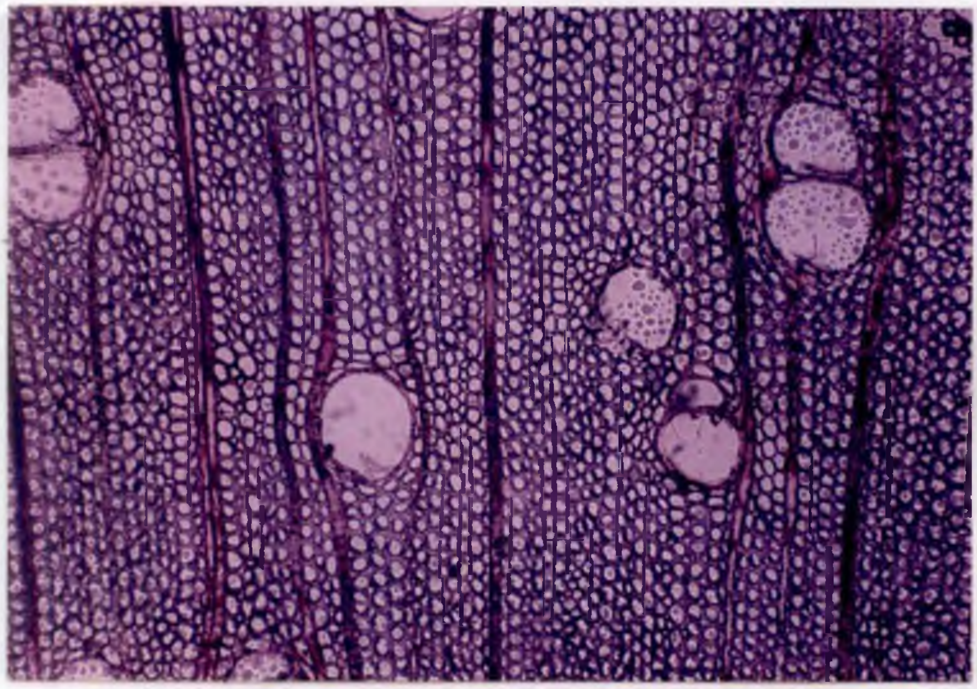


Plate VIII Cross section of *Acacia crassicarpa*

Plate IX Cross section of *Acacia aulacocarpa*



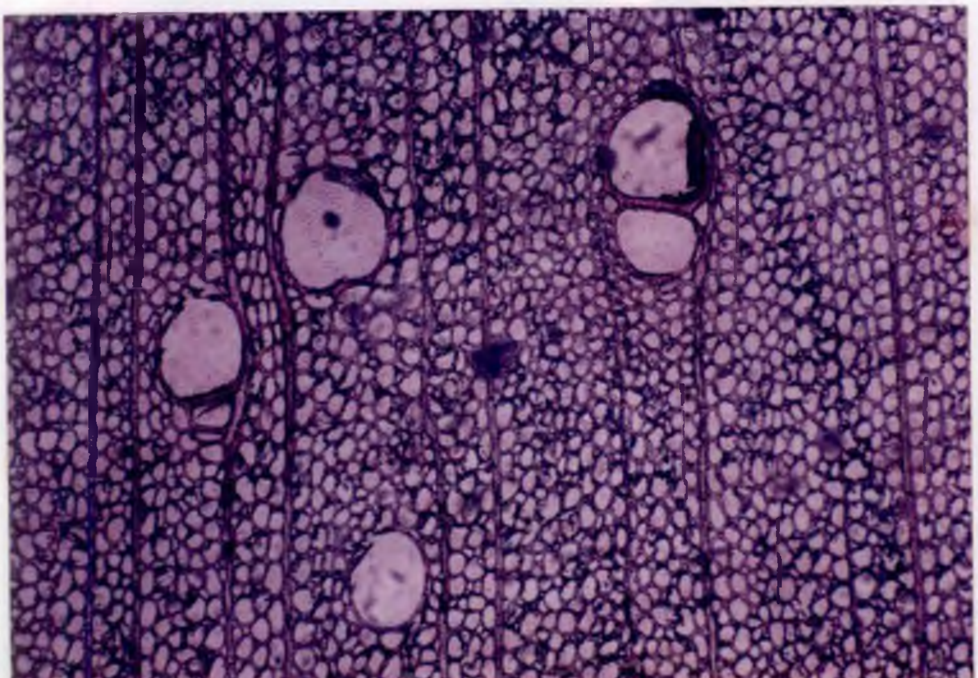
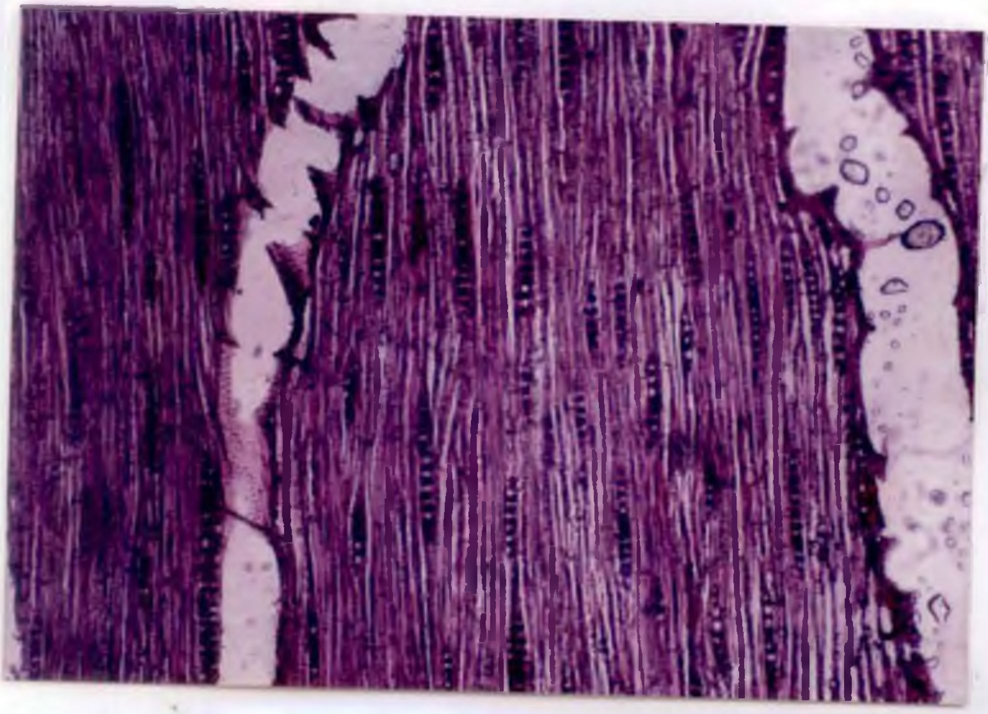


Plate X   Tangential longitudinal section of *Acacia mangium*

Plate XI   Tangential longitudinal section of *Acacia auriculiformis*



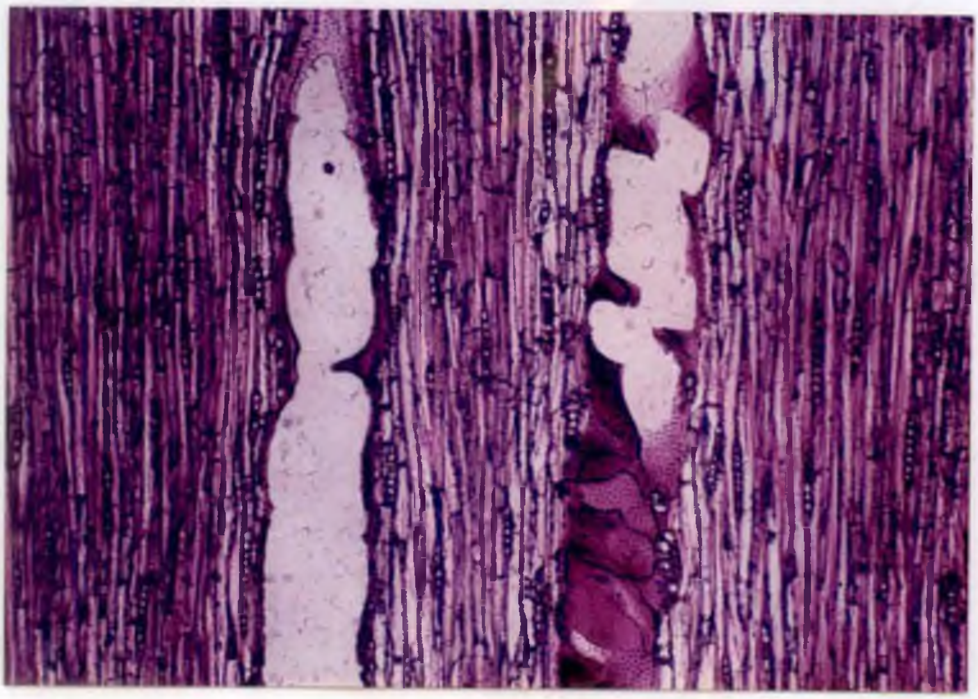
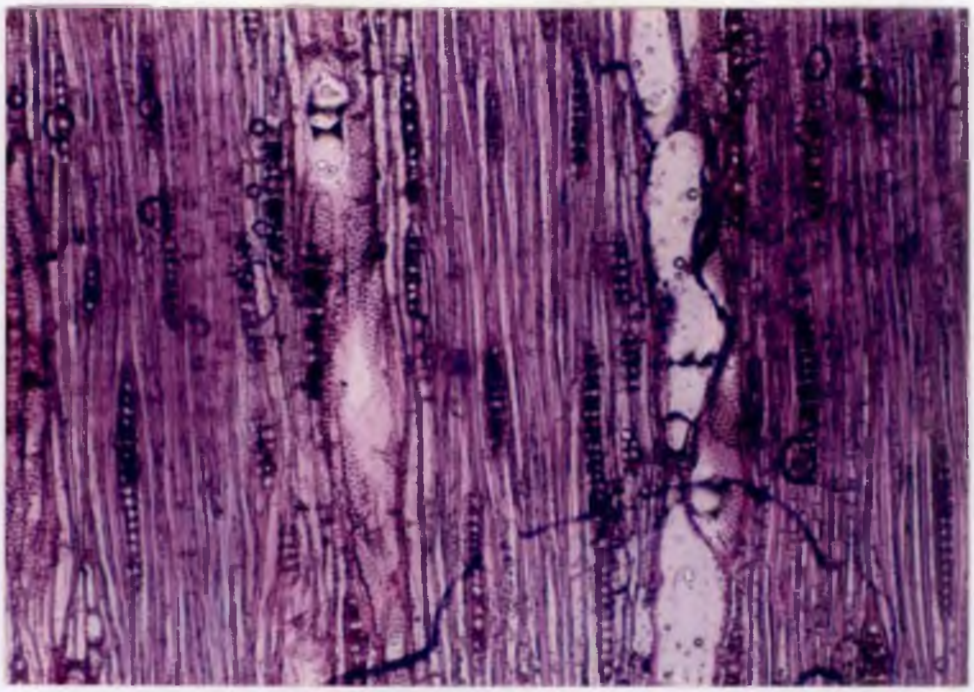


Plate XII Tangential longitudinal section of *Acacia crassicarpa*

Plate XIII Tangential longitudinal section of *Acacia aulacocarpa*



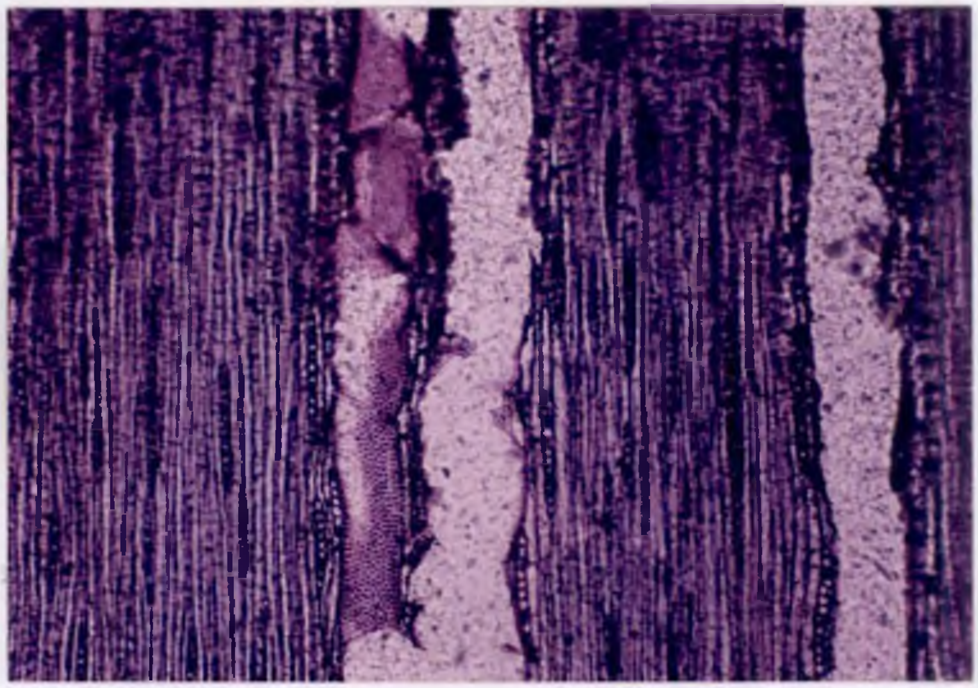
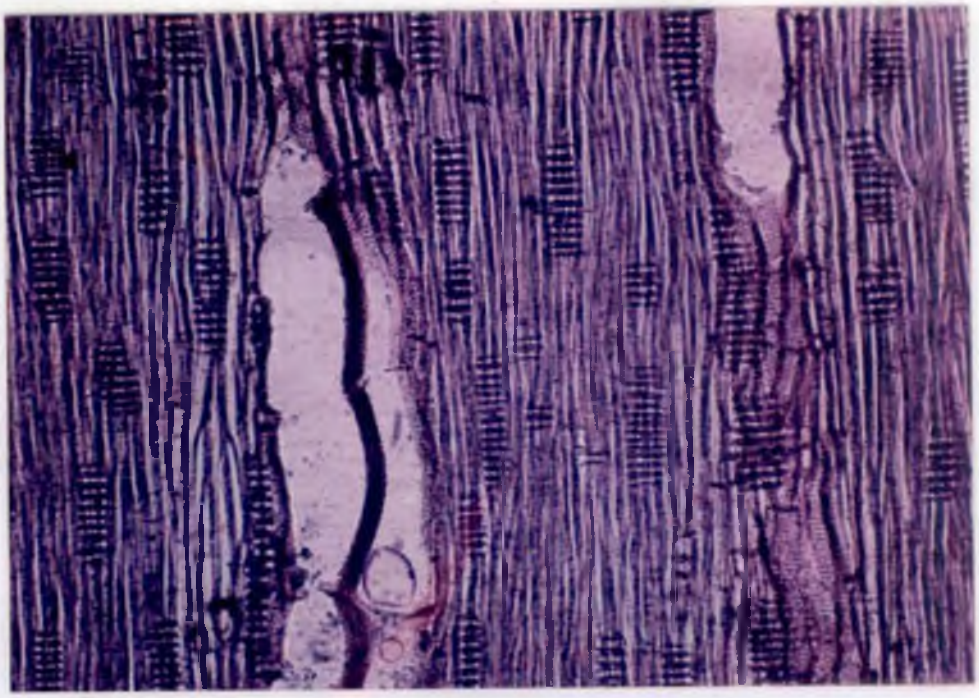


Plate XIV Radial tangential section of *Acacia mangium*

Plate XV Radial tangential section of *Acacia auriculiformis*



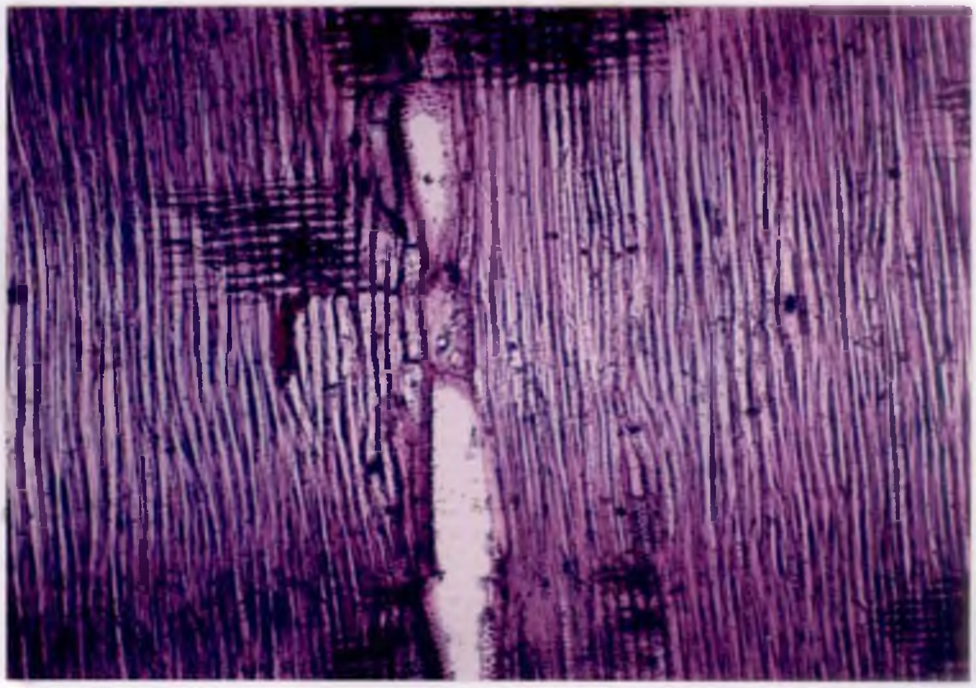
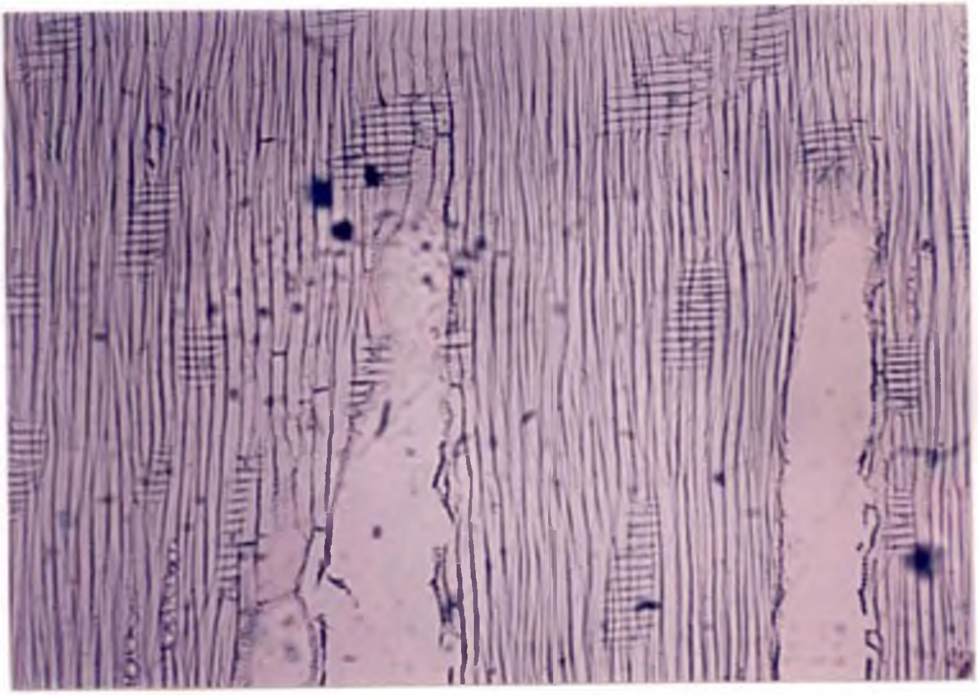


Plate XVI Radial tangential section of *Acacia crassicarpa*

Plate XVII Radial tangential section of *Acacia aulacocarpa*



The width of axial parenchyma was maximum for provenances of *A crassicarpa followed* by *A. auriculiformis.* Among the five provenances of *A. mangium,* Wipim to Oriomo (P_2) recorded the maximum length (0.058 microns) and minimum was recorded in Claudie River (P_4) (0.028 microns).

DISCUSSION

DISCUSSION

Significance of the studies on genetic variation and provenance evaluation in forest improvement programmes is very well accepted by tree breeders. No matter how sophisticated the breeding techniques, the largest, cheapest and fastest gains are obtained by using suitable species and seed source within species. A tree's physiological process constitutes the machinery through which heredity and environment operate to control its growth. Therefore, understanding the physiological processes of trees in natural populations will be of tremendous use for developing a successful tree breeding programme. Another important factor contributing to the success of tree breeding is the information regarding the anatomical properties of wood including cellular characteristics, specific gravity etc., which has direct effect on the strength of wood. Therefore, information regarding variation in these wood properties also has implications in a successful tree breeding programme.

Data generated on the various biometric, physiological and anatomical characteristics of 11 provenances belonging to four species of acacia are described here under.

5.1 Biometric characteristics

Provenances or geographic sources are known to generally differ among themselves and are considered as valuable material for breeding programme (Zobel and Talbert, 1984). A number of investigations carried out earlier has revealed the existence of significant variation in biometrical characteristics between provenances in a number of species (Salazar, 1989; Dwivedi and Thapar, 1990; Toky and Bisht, 1991; Gupta et al., 1992; Kumar and Toky, 1996). In the present study, the 11 provenances exhibited significant difference between growth parameters namely, height, collar girth and branch number throughout the study period. As far as the height and collar girth were concerned, provenances of *A. mangium* were generally surpassing the rest of the provenances while, the two seed sources of *A. aulacocarpa* consistently performed poor growth. In an earlier report also, *A. aulacocarpa* was found to be much inferior in a provenance evaluation consisting of 23 provenances belonging to 12 species of acacia (Weerawardane *et al.*, 1991).

With reference to the mean height as well as the growth rate the provenances of *A. mangium* were at par with those of *A. auriculiformis* and *A. crassicarpa*. However, for collar girth, three provenances among five in *A. mangiun* were significantly superior to all the other provenances. The *A. mangium* provenance 7 KMSSE Mossman from Queensland was, however, inferior to the rest of the *A. mangium* provenances in both the growth attributes discussed above. The two provenances of *A. auriculiformis* also exhibited significant variation among themselves as far as height is concerned. These two provenances, however, were comparable for their collar girth. In both these species, the inferior performing provenances were from Queensland, Australia. Such an observation of poor performance of Queensland provenances in comparison to Papua New Guinea exhibited by *A. mangium* and *A. auriculiformis* has been reported by Khasa et al., (1995). The generally faster growing habit of provenances originating from Papua New Guinea in comparison to Queensland provenances has been reported by other authors also

(Luangviriyasaeng and Pinyopusarerk, 1991; Yang and Zeng, 1991; Faizuddin and Dalmago, 1992).

As far as the number of branches produced, during the study period is concerned all the provenances of *A. mangium* except 7KMSSE Mossman from Queensland exhibited low number in comparison to the provenances of other three species. *A. crassicarpa* and *A. aulacocarpa* were showing profuse branching with significantly higher number. In *A. mangium* the two provenances from Papua New Guinea and one from Queensland were comparable and superior to other Queensland provenances. Significant difference in the production of branches has been reported earlier in a study conducted by Balakrishan and Toky (1995 a) using 21 provenances of *A. nilotica* in India. The different provenances of *A. auriculiformis* and *A. crassicarpa* were comparable among themselves, while those of *A. aulacocarpa* were at par produced higher number of branches.

In a comparison of the four species, namely, *A.mangium*, *A. auriculiformis, A. crassicarpa* and *A.aulacocarpa* during the present study with reference to their growth characteristics the former three were at par as far as the height is concerned. However, with reference to collar girth *A. mangium* was surpassing the rest of the species. Therefore, it can be tentatively suggested that the fast growth habit with reference to height and collar girth makes *A. mangium* the most suitable species in plantation programme. It is expected that this species will be giving a better timber under conditions similar to the testing situations.

The peculiar character noticed in the case of *A. mangium* was shedding their lower branches during the drier months. This may be due to the non-availability of water during the drier periods or it can be considered as a mechanism for conserving available water in the plant or may be a defensive system to cope up with low availability of water. Moreover, this may be a genetic quality in order to cope up with the water and food loss from over matured organs. The lesser number of branches combined with early self pruning habit associated with *A. mangium* can be considered as a favourable attribute in timber production with quality bole characteristics.

The significantly superior performance of *A. auriculiformis* as far as the branch number is concerned, can be considered as an advantage under certain specific conditions of planting. Wherever, fast growth and shade are the attributes as in the case of avenue planting, social forestry programmes etc this species appear to be more suited. Moreover, the higher branch number can also contribute to higher yield of firewood.

The superiority of *A.auriculiformis* with respect to branch production may be due to genetic character of the species. More number of branches and leaves persumably indicate that more biomass is allocated to leaves in order to increase the photosynthetic efficiency of plants and this may be the reason for the *A. auriculiformis* at par with *A. mangium* as far as the height growth is concerned.

Significant variation in growth characteristics of different species of acacia has been reported earlier by a number of authors. In one of the studies in Sri Lanka (elevation 1160m and mean annual rainfall 1580 mm) using 18 species of acacia including the four species of our study, it has been reported that *A. crassicarpa* was the best as far as height and collar girth at the age of 2.5 years are concerned. *A. aulacocarpa* on the other hand, performed very poor as seen in our observations. *A. auriculiformis* had a moderate growth while *A. mangium* performed much below average (Weerawardane and

Vivekanandan,1991). Significant differences between species of acacia for growth characters has been reported by Yang and Zeng (1991). Evaluation of growth performace of species of *Pinus*, Eucalyptus etc have also exhibited significant variation among the species (Dwivedi and Thapar,1990; Aradhya and Philips, 1993). In the former, *Pinus carribaea* was the best performer under north Indian conditions.

The relatively poor performance of *A. aulacocarpa* for their growth characteristics in our investigation during the entire study period has been substantiated by earlier reports also. In a comparison of 12 acacias *A. aulacocarpa* exhibited minimum growth performance, while *A. auriculiformis* was one of the best performers (Chittachumnek *et al.*, 1991).

5.2 Physiological characteristics

A thorough knowledge of the various physiological characteristics of a species or provenance is of great importance in a successful tree improvement programme. This is because of the fact that the physiological processes of a tree constitute the machinery through which genetic and environmental components are operated (Kramer and Kozlowski,1979).

In this context, leaf area index (LAI) which is an expression of the leaf surface of the tree has great importance. LAI is calculated as the ratio of leaf area surface of a tree or stands to the ground area and this denotes the amount of leaf cover. LAI vary with plant size, age, spacing and other factors influencing leaf size. More leaf area persumably indicates that more biomass is allocated to leaves in order to increase the photosynthetic area in plants.

In the present study, leaf area indexes of the 11 provenances, belonging to the four species of acacia were estimated on the basis of plot means. These values did not show significant difference during 20, 25 and 28 MAP. At the end of the study period (28 MAP) the LAI ranged from 1.67 to 6.20 for King's Plain Lake (*A. auriculiformis*) and Wipim to Oriomo (*A. mangium*), respectively. In one of the earlier studies with *A. nilotica* variation in LAI between different provenances has been reported (Balakrishan and Toky, 1995).

It is an established fact that, the net productivity of the forest is highest when the leaves are so arranged that photosythetically active radiation is allocated as much as possible. This is attained when the LAI is approximately 4.0 (Kramer and Kozlowski, 1979). It is suggested that when LAI is 4.0 the light available to the individual plant is high leading to higher photosynthetic efficiency. However, in such situations the yield per ground area tends to be low due to the open stand. The mean maximum gross productivity is estimated to be at LAI values in the range of 8.0 to 10.0. The relatively lower values of LAI obtained in the present study is probably because the trees are still in the juvenile stage and further growth and canopy closure may give higher LAI estimates. It can therefore be persumed that once the trees reach their rotation age the normal LAI value of approximately 8.0 pertaining to most of the broad leaved evergreen trees will be attained.

Stomata of plant leaves are critical controller of gas exchange between plant and environment. The number of stomata per unit area of leaf surface as well as pore size greatly influences the physiological status of the plant. The number of stomata per unit of leaf surface varies widely with species and environmental conditions. In the 11 provenances of acacia studied the stomatal number varied from over 17,000 to 43,000/ cm^2 in the upper and from 20,000 to 44,000/ cm^2 in the lower side of leaves at 32 MAP (April). The range was more or less same during the different stages of growth. The provenances did differ significantly for this character.

The number of stomata was found to be significantly different among the four species of acacia also. The maximum number was recorded in *A. auriculiformis* the minimum being in *A. crassicarpa.* The number of stomata in the upper and lower sides were comparable in all the species. A significant variation in the number of stomata between the provenances and even between strains of the species has been reported in a number of cases (Pallardy and Kozlowski, 1981; Sena Gomes and Kozlowski, 1989). Seasonal variation in the stomata was observed in the provenances and species. This indicates that the environmental factors also are influencing the stomatal development and behavior. The stomata responds to the environmental factors which is favourable or unfavorable, in order to balance the physiological processes and further growth and development of the plants.

The importance of stomata has been highlighted due to the fact that most of the water lost by transpiration escapes and most of the CO_2 used in the photosynthesis enters through them. However, one of the critical factors that controls this exchange of water and gases is the stomatal aperture which inturn is regulated by both internal and external factors. The importance of stomatal number and its opening and closure in the physiological process of transpiration and photosynthesis has been highlighted by many authors (Kramer, 1983). In simple terms it can be assumed that species or provenances with lesser number of stomata per unit area may exhibit better drought tolerance as a result of lesser transpiration rate. On the other hand, higher stomatal frequency can be persumed to have an advantage due to the higher amount of CO_2 diffusion leading to greater photosynthetic efficiency of the plant. This in turn should contribute to better growth rate and biomass production. This type of a relationship can be seen in the comparison of the species. *A. mangium* and *A. auriculiformis* which were having significantly higher stomatal number in comparison to other two species, recorded higher growth rate with reference to height and collar girth as well. However, such a single factor, alone cannot be considered when discussing about growth and adaptability of species or strains. An interaction of a number of physiological parameters contributes to such traits.

Transpiration is one of the significant factors of plant which is considered as beneficial because it cools the leaves, causes ascent of sap and increases the absorption of water (Clements, 1921; Gates, 1986). It can as well be considered as an unavoidable evil because it often produces water deficits and injury by dehydration. Therefore, it is evident that an optimum rate of transpiration is essential for the maximum growth and adaptability of a species.

The transpiration rate in the different provenances and species of acacia in the present study showed significant variation during the summer months (20 MAP) while, it was comparable during the rainy season. In almost all the cases the transpiration rate was higher during after noon hours, obviously due to the higher ambient temperature. The number of stomata recorded in the different species and provenances did not reveal any direct relation with the rate of transpiration. It is an established fact that though the stomatal frequency contributes tremendously to transpiration rate this process is greatly influenced by both internal and external factors. This include leaf structure and exposure, stomatal behavior, anatomy of leaves, wind speed, light, atmospheric pressure etc.,

No indication of direct genetic contribution to the rate of transpiration is available. However, Srinivasan *et al.* (1989) have reported that in a comparison between five month old seedlings of seven species of acacia, *A. auriculiformis* has the lowest transpiration rate. The transpiration rate was found to have inverse relationship with the entire variables such as height, diameter, moisture content and stomatal resistance. However, this type of a relationship was not evident in the four species of acacia included in the present study. The transpiration rates were not significant, while the species differed as far as their growth characteristics are concerned. Transpiration rate often reduces in certain acacia species in drier soils.

The growth of woody and herbaceous plant is reduced more often by water deficits than by any other single factor. Evidences suggested that about 90 per cent of the variation in the width of annual rings of tropical species can be attributed to differences in water stress, which inturn is controlled by the relative rates of water absorption and water loss (Zahner, 1968). The degree of water stress is often described in terms of the water potential, which refers to a measure of the free energy status of water. Leaf water potential can be regarded as the direct indicator of leaf turgor and a good indicator of water stress of plants (Kallarackal and Somen, 1992). In a comparison of leaf water potential of different provenances of acacia during predawn and after noon hours of two seasons namely December and April it has been found that, all the provenances exhibited higher water potential in the predawn hours. The values ranged from –1.30 to -5.40 and –1.95 to –5.82 during December and April, respectively. In the after noon where the ambient temperature increased there was a significant reduction in the water potential and the range was between –7.63 to –22.18 in December and between –13.28 to –20.60 in April. The provenances were found to significantly differ in water potential during December. In a comparison between the four species of acacia also the trend was observed to be the same. Eventhough during the relatively cooler season of December, *A. crassicarpa* exhibited significantly higher water potential during the summer month of April all the species recorded comparable water potential. The comparison between the provenances as well as species therefore, indicate that, they respond more or less uniformly to water stress of the summer months as envisaged by their non significant leaf water potential status.

The leaf water potential status is influenced by both water absorption and transpiration. The role of the number and aperture of stomata on the water potential has been already established (Jarvis, 1980). When critical leaf water potential is reached stomata begins to close regulating the transpiration rate.

Lower leaf water potential during water stress is an indication of drought tolerance. *Acacia crassicarpa* in this contest appears to be better tolerating the water stress, in comparison to other three species. *A. auriculiformis,* on the other hand, showed lower water potential in both the seasons irrespective of its wide adaptability. Higher transpiration rate of *A. auriculiformis* has already been observed in the present study. Kallarackal and Somen (1992) have also reported similar observation in this species.

It is suggested that the critical leaf water potential for stomatal closure reported for different species should not taken very seriously because the value varies with different clones and cultivars (Pallardy and Kozlowsky, 1981) and because of the response of the stomata to the leaf water deficits is modified significantly by factors like internal CO_2 concentration, air humidity, wind, age of leaf, osmotic adjustment etc., (Davics *et al.*, 1974; Kozlowski and Pallardy, 1979).

Stomatal aperture has important effects on both loss of water vapour and uptake of CO_2. The ability of the stomata to undertake this process can be expressed in terms of leaf diffusive resistance or its inverse parameter, stomatal conductance. Though the sub stomatal cavities have some resistance to diffusion of water vapour from the cell wall to the stomata, this is normally neglected as the error in the total resistance range only between two and five percent (Bange, 1953).

As in the case of leaf water potential as well as rate of transpiration, the leaf diffusive resistance was also comparable in all the provenances and species studied. However, between the two seasons of study namely, April and December, the diffusive resistance did differ significantly. A direct relation between the lower and higher transpiration rates of the predawn and after noon hours with that of diffusive resistance was not discernible. This indicates that, the lower transpiration in the morning hours was directly related with lower diffusive resistance. The higher transpiration encountered in all the provenances of the species was probably a manifestation of environmental conditions rather than the internal characteristics, especially stomatal closure. Reduction of water loss by stomatal closure is an effective means of checking the dehydration. Although this conserves water, this can reduce photosynthesis. A relation between leaf water potential and stomatal conductance has been established in so many tree species (Seiler, 1985).

In the present study, however, such a relationship was not clearly envisaged. The leaf diffusive resistance was more or less comparable with predawn and afternoon hours in all the provenances and species studied. This is against a significant decrease in the water potential during the after noon hours in all the treatments. Similar observation of lack of correlation between stomata, diffusive resistance and leaf water potential has been reported earlier in certain other species of plants (Cuttler *et al.*, 1977).

Leaf temperature is another parameter which can be considered as an indirect measure of plant water status (Idso *et al.*, 1978a). When plants are well supplied with water, transpiration will be at potential rate and leaves will be relatively cool. There is a decline in transpiration during moisture deficit and concomitant increase in leaf temperature. This inturn can lead to decline of total biomass production (Idso,*et al.*, 1978b). Eventhough, provenances and species of the present study did not exhibit significant difference among them with reference to leaf temperature, the two seasons of observation had been found to positively influence this character. The leaf temperature during predawn and after noon hours also exhibited considerable differences, the values being much higher during after noon. This obviously can be attributed to the higher ambient temperature which inturn enhances transpiration rate also. An increase in leaf temperature without an increase in the water content or absolute humidity of the air may tend to increase the rate of evaporation and transpiration, because of the higher vapour pressure gradient between the leaf and surrounding air. Increase in transpiration causes water deficit which inturn closes stomata and reduce the supply of CO_2 to the chloroplast. Such situations can lead to the reduction in photosynthesis resulting in the decline of total biomass production. In the present study, however, the provenance/species with higher vegetative growth did not exhibit discernible difference in their leaf temperature or transpiration rate.

As a general rule, leaf resistance changes with changing leaf temperature but whether resistance increases or decrease with increasing temperature depends upon the status of other factors. For a long time it was thought that, resistance increased with temperature. However, Wuenschester and Kozlowski (1971) could not find such a relationship in transpiration rate and leaf resistance with leaf temperature in a number of *Quercus* species they have investigated.

5.3 Anatomical characteristics

Anatomical characteristics of wood contribute greatly to the wood quality and utilization. The economic yield of timber itself is influenced by the various wood properties. Efficient utilization of timber is not possible without knowledge of the anatomical characteristics of wood. The latter not only determines to a large extent the properties of wood but also provides the only reliable means of its correct identification. In other words, study of anatomical characteristics of wood is very important as it enables one to know and understand the vagaries of these raw materials and make the best possible use of it.

Physiologically, heartwood is dead and does not take any active part in the life of the tree except to give its rigidity. The sapwood, on the other hand however, is composed mostly of living cells and as its name implies, it primarily concern with the conduction of sap.

In an attempt to evaluate the usable timber yield of the different provenances of acacia it has been found that they differ significantly with reference to the heartwood content. The amount of heartwood expressed as the percentage of the total wood, varied from 30.9 to 64.0 in different provenances. Two provenances of *Acacia mangium* Balimo Aramia River and Claudie River as well as one of each *A. auriculiformis* and *A. crassicarpa,* namely Orchard Melville and Bensbach WP respectively, exhibited maximum heartwood production. In a comparison of the four species with reference to this character all the species except *A.aulacocarpa* showed high proportion of heartwood (>55.0 percentage). The heartwood formation has been found to be influenced by genetic and environmental factors. In radiata pine this is inherited with a narrow sense heritability of 0.20 and broad sense heritabilities range from 0.30 to 0.45 (Zobel and Talbert, 1984) indicating the high influence of the environment. Purukayastha et al., (1984) have shown that proportion of heartwood also varied with locality and growth. The width of sapwood varies widely with number of factors, including climate (Chalk, 1951), species (Larsen and Okkomen, 1969), elevation (Keane and Weetman, 1987) and site (Long and Smith, 1987). It can be persumed that, lower heartwood percentage or conversely higher proportion of sapwood, can assist in better conduction of water and nutrients which may inturn lead to a better foliage production. In a perusal of the data generated during the investigation this type of a relationship could, however, not be deduced. *A. aulacocarpa* with a significantly low heartwood percentage (34.0) has given higher foliage mass as indicated by significantly superior LAI. *A. mangium* and their provenances recorded more than 50 percentage heartwood along with a relatively high LAI. In the case of *A. auriculiformis* also no such definite trend could be observed.

A positive relation between the sapwood and foliar mass persumably as a result of the water conduction function of sapwood has , however, been reported in a few forest tree species (Kaufmann and Troendle,1981; Waring and Schlesinger, 1985).

Branch heartwood percentage is not as significant in determining the properties of wood for various uses unlike stem heartwood percentage. However, this may be the influencing factor when the timber is used as pulp wood because of higher proportion of heartwood means more percentage of lignin and extractives undesirable for pulping.

Wood, being hygroscopic contains varying quantities of water not only in the freshly felled raw condition but also, air dry condition in service. The affinity of wood for water has far-reaching consequences in the utilization of wood, as this affects its several important properties. Knowledge of wood water relationship is therefore, essential for efficient processing of wood.

In an attempt to evaluate the moisture content on fresh and dry weight basis in acacia, it has been found that they did not differ significantly with reference to moisture content. The moisture content expressed as percentage at fresh weight basis varied from 43.0 to 65.0 in the different provenances. The provenances *of A. crassi*carpa namely, Kapal Oriomo and Benbasch WP as well as of *A. aulacocarpa* namely W of Wipim WP and Bensbach-Balamuk WP exhibited maximum moisture content. In a comparison of four species, with reference to this character they exhibited no significant variation.

As far as the moisture content on oven dry weight basis, except the two provenances of *A. aulacocarpa* and one of *A. crassicarpa* namely Kapal Oriomo and of *A. mangium* namely 7KMSSE Mossman exhibited more than 50 percent of the moisture content compared to the moisture content expressed at fresh weight basis.

In a comparison of four species with reference to this character *A. mangium*, *A. auriculiformis* and *A. crassicarpa* exhibited more than 50 percent of moisture content at oven dry weight basis with respect to fresh weight basis.

Rawat *et al.* (1993) established that the water content in wood and bark of a tree in general varies due to a number of factors such as tree species, density, position in the stem, locality factors and seasons. An empirical study of moisture content behavior in *Acacia* and Eucalyptus plants by Rajesh Kumar (1993) revealed that moisture content in the different plant parts showed a distinct affinity towards the seasonal changes. The moisture content steadily increased with the growth of the plants but varied with the changes in the seasons.

Zobel and Talbert (1984) established that specific gravity and moisture content were usually negatively related within a species, so higher the specific gravity the lower the moisture content. This negative relation has already been observed in the present study.

Specific gravity and wood density are expressions of how much wood substance is present in a given volume of wood. Wood specific gravity is the ratio of the weight of a given volume of wood to the weight of an equal volume of water at 4°C (grams of wood/grams of cubic centimeter of water) and is therefore a unitless measure.

Specific gravity is of key importance in forest product manufacture because it has a major effect on both yield and quality of fibrous and solid wood products (Davies, 1961) because it can be changed by silvicultural and genetic manipulation (Zobel, 1961). Specific gravity also determines the value and utility of wood and overshadows the importance of other wood properties (Zobel and Talbert, 1984). It also plays a major role in the use of wood as energy source.

In an attempt to evaluate the specific gravity of wood at green, dry and oven dry condition, representing different provenances of four species of acacia, it has been found that they did not differ significantly with reference to specific gravity at three conditions mentioned above. The specific gravity expressed at green, air dry and oven dry condition varied from 0.93 to 1.09, 0.57 to 0.73 and 0.50 to 0.67, respectively. The maximum specific gravity under green condition was recorded for the provenance 7KMSSE Mossman followed Balimo Aramia River of *A. mangium*. The minimum specific gravity was recorded by the provenance Kapal Oriomo and Claudie River of Papua New Guinea and Queensland respectively.

Purukayastha et al., (1984) have shown that specific gravity varied with locality. Lowe and Greene (1990) established the fact that specific gravity would vary with provenance, family within provenance and the plantation X family within provenance interaction. Sulaiman and Lim (1993) reported that juvenile wood would exhibit low specific gravity.

A trial conducted by Pipatwattanakal (1989) using 16 provenances of 16-year-old *A. mangium* showed that variation between the provenances with respect to specific gravity was non-significant. This fact has already has been observed in the present study.

Specific gravity is a character having high heritability of 0.55. Hence, specific gravity is indicative of strength properties. This has great importance in tree improvement. Hence, the species and provenances showing high specific gravity may be suitable for structural uses, while those with low specific gravity may be suitable for pulping.

Fibres are vertically aligned narrow elongated and thin walled cells with pointed tapering ends, which make up the bulk of the wood by weight in most hardwoods. the main function is to give mechanical support to the tree and like the vessels they are absent in non porous or coniferous woods.

Cell size and relative cell dimensions have a major influence in the quality of pulp and paper products (Chalk, 1951) and on solid wood products. Fiber length and width, wall thickness and lumen size have an effect on the bulk, burst, tear, fold and tensile strength of paper. It was reported that fiber characteristics are very important and course fibers have the same effect on paper as short fibers. It was established that cell length was often thought to be only academic importance for solid wood products; however, definite correlations between tracheid length and certain lumber mechanical properties existed (Bisset *et al.*, 1951).

In the present study, the fiber length and width of 11 provenances of four species of acacia exhibited significant variation between the provenances and species. The fiber length and fiber width expressed by the different provenances ranged from 0.2 0 to 0.92 and 0.02 to 0.05 microns, respectively. Zahner (1968) established that in hardwoods the growing conditions have profound effect on cellular components and proportion of fibers, vessels and rays. Singh *et al.* (1985) reported that fiber/vessel ratio varied within the trees of a locality and had a marked influence on paper strength and surface properties. Wu and Wang (1988) reported in his study that radial and a longitudinal variation in fiber length was more pronounced in *A. mangium* and *A. auriculiformis*.

Among the four species *A. auriculiformis* recorded the maximum fiber length. Species with higher fiber length are reported to be suitable for pulping. In the present study, it was observed that provenances of *A. auriculiformis* were having the higher fiber length. Hence, this species and provenances might be suitable for pulping. This characteristics may be the reason for using this species as one of the raw material in pulp and paper production.

Vessels are vertical series of cells with open ends placed one above the other, forming a continuous tube, like the section of a drain pipe, running in the direction of the long axis of the tree. Their function is to conduct sap (water and nutrients) from the soil and roots to the crown for which they are structurally well adapted. The size and distribution of rays and vessels in the hardwoods have major effects on wood quality and utility. The patterns of vessel production are of great importance in determining the utility of hardwoods for a given product (Guiher, 1965).

The dimensions of vessels of 11 provenances of four species of acacia were evaluated and it was found that significant variations existed. It was found that vessels of four species namely *A. mangium, A. auriculiformis, A. crassicarpa* and *A. aulacocarpa* were differed with a tendency to align in oblique lines; tyloses generally absent; gum like deposits present. Similar observations were recorded by Wu *et al.*, 1988; Moh Hamami *et al.*, 1992. The length and width of the vessels, varied from 0.09 to 0.93 microns and 0.08 to 0.12 microns, respectively. Provenances Balimo Aramia River and Claudie River of *A. mangium* recorded the maximum vessel length, while the minimum vessels width exhibited by the provenances of *A. auriculiformis.*

Rays are groups or plates of horizontally oriented parenchyma cells, which run in a radial direction from pith or centre of the log towards the bark or periphery.

An attempt to evaluate the dimensions of ray and axial parenchyma of 11 provenances and four species of acacia it has been found that they exhibited significant variation between the provenances and species. Provenances of *A. mangium* namely, Research Seed Orchard and 7KMSSE Mossman showed the maximum length for ray parenchyma of 0.40 to 0:41 microns respectively. Provenance *of A. auriculiformis* and *A. aulacocarpa* were at par.

The size and distribution of rays and vessels in the hardwood have a major effect on woods quality and utility (Guiher, 1965). Hardwoods possess more complex wood than conifers, having very short and large diameter vessel elements and rays with different types of cells (Mac Donald and Franklin, 1969). The decrease in the size of rays with phylogenetic advancement may have been brought about by changes that took place in the cambium (Barghoorn, 1941).

The rays found widely and uniformly distributed in all the four species and which was barely visible to the naked eye. The same observation was also reported by Wu *et al.*, 1988; Mohd Hamami *et al.*, 1992).

SUMMARY AND CONCLUSIONS

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The experiment was carried out at the experimental farm of College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur, during the period 1998 to 1999, with the basic objective of evaluating the performance of five provenances of *Acacia mangium*, two each for *A. auriculiformis, A. crassicarpa* and *A. aulacocarpa*. The provenances were selected from Queensland, Northern Territory and Papua New Guinea. The various characters studied included biometrical, physiological and anatomical characteristics. The salient results are summarized here under.

1. Among the provenances the best performance in terms of height growth were Balimo Aramia and Wipim to Oriomo from Papua New Guinea and Research Seed Orchard, Claudie River from Queensland.
2. *A. mangium, A. auriculiformis* and *A. crassicarpa* were at par and significantly superior to *A. aulacocarpa* in terms of height growth.
3. Provenances Balimo Aramia River, Wipim to Oriomo from Papua New Guinea and Research Seed Orchard and Claudie River from Queensland exhibited better performance in terms of collar girth.
4. Among the four species, *A. mangium* was the best performer in terms of collar girth, while *A. aulacocarpa* exhibited significantly low value for this character.
5. The maximum branch number was exhibited by the provenances of *A. auriculiformis*. Among the two, Orchard Melville-1 from Northern Territory recorded the maximum.

6. Provenances did not differ significantly with respect to the leaf area index. However, significant variation existed among the species.
7. *A. mangium* and *A. aulacocarpa* showed maximum leaf area index and minimum was recorded by *A. auriculiformis*.
8. The maximum number of stomata per square centimeter on both upper and lower leaf surfaces was recorded by the provenances Orchard Melville-1 from Northern Territory and King's Plain Lake from Queensland of *A. auriculiformis*.
9. Almost all the provenances, irrespective of the species showed higher stomatal frequency on the lower leaf surface, *A. mangium* 38.91/cm^2 x 10^3, *A. auriculiformis* 40.37/cm^2 x 10^3, *A. crassicarpa* 20.93/cm^2 x 10^3 and *A. aulacocarpa* 35.44/cm^2 x 10^3.
10. Transpiration rate increased from predawn to afternoon hours in almost all the provenances.
11. Significant differences in the transpiration rate between the predawn and afternoon hours exhibited only during the month of April (20 MAP).
12. Significant differences in the transpiration rate between the species exhibited only at predawn hours during the month of April (20 MAP).
13. Transpiration rate and leaf water potential was negatively related in almost all the provenances.
14. Leaf temperature increased from predawn to afternoon in almost all the provenances.
15. Provenances and species exhibited no significant difference with respect to leaf temperature.

16. The maximum heartwood percentage was recorded by the provenances Balimo Aramia River of *A. mangium* as well as one each of *A. auriculiformis* and *A. crassicarpa*, namely, Orchard Melville and Bensbach WP.
17. Significant differences were noticed between the provenances with respect to moisture content at fresh weight and oven dry weight basis.
18. On oven dry weight basis, *A. aulacocarpa* recorded the maximum moisture content while *A. crassicarpa* was at minimum.
19. The provenance 7KMSSE Mossman of *A. mangium* recorded the maximum specific gravity at green condition, while the minimum was Kapal Oriomo of *A. crassicarpa*. Generally, provenances of *A. mangium* recorded higher specific gravity.
20. The higher fibre length was exhibited by the provenances Orchard Melville-1, Northern Territory and King's Plain Lake, Queensland of *A. auriculiformis* while, minimum was recorded by the provenances of *A. mangium*.
21. The maximum vessel length was recorded for the provenances of *A. mangium* while minimum for *A. auriculiformis*.
22. The maximum length of ray parenchyma was recorded by the provenances of *A. mangium*.
23. Provenances of *A. mangium* also recorded the maximum length as well as width for axial parenchyma.

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* Original not seen

ANATOMICAL AND PHYSIOLOGICAL VARIATIONS IN CERTAIN SELECTED SPECIES AND PROVENANCES OF *Acacia*

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ABSTRACT OF THE THESIS

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ABSTRACT

An experiment was carried out during 1998-99 with the objective of evaluating the anatomical and physiological variations among provenances and species of *Acacia* and to correlate this with their growth characteristics. The experimental materials consisted of 11 provenances which included five provenances of *Acacia mangium* Willd., and two each of *A. auriculiformis* Cunn. ex., Benth., *A. crassicarpa* Cunn ex., Benth and *A. aulacocarpa* Cunn. ex., Benth. They were planted in a randomized block design in the farms of the College of Forestry, Vellanikkara in 1996. The ultimate objective of the study was to identify the most suitable species/provenances from among these for the ecoclimatic conditions of Kerala.

At four years of growth, provenances Balimo Aramia and Wipim to Oriomo from Papua New Guinea and Research Seed Orchard from Queensland were significantly superior to the rest. Among the four species, except *A. aulacocarpa,* the other three species namely, *A. mangium, A. auriculiformis* and *A. crassicarpa* showed superiority over height and collar girth. The most important component of total biomass undoubtedly, was the bole volume. So in this regard, the superiority of the species on height and collar girth indicates good volume production in future. *A. auriculiformis* exhibited superiority over branch production throughout the study, indicating its suitability for fire wood production.

As far as leaf area is concerned the species exhibited significant variation while, provenances did not. *A. mangium* and *A. aulacocarpa* showed maximum leaf area index, compared to *A. auriculiformis* and *A. crassicarpa.*

Irrespective or the species, all the provenances showed higher stomatal frequency on the lower leaf surface. Almost in all the provenances, transpiration late was increased from predawn to afternoon hours. Significant differences in the transpiration rate among the provenances and species was noticed between the predawn and afternoon hours only during the month of April. Transpiration rate and leaf water potential was negatively related in almost all the provenances. Provenances and species exhibited no significant difference with respect to leaf temperature. However, leaf temperature increased from predawn to afternoon in almost all the provenances.

The provenance Balimo Aramia River of *A.. mangium* as well as one each of *A. auriculiformis* and *A. crassicarpa,* namely, Orchard Melville and Bensbach WP registered the maximum heartwood percentage. The moisture content exhibited significant differences between the provenances. The specific gravity was maximum for the provenance 7 KMSSE Mossman of *A. auriculiformis* while the minimum was shown by the provenance Kapal Oriomo of *A. crassicarpa.* Generally, provenances of *A. mangium* recorded higher specific gravity.

The length of fiber was maximum for provenances orchard Melville – 1, NT and Kings Plain Lake, Queensland of *A. auriculiformis* while, minimum registered by the provenances of *A. mangium.* The maximum length and width for vessel, ray and axial parenchyma was recorded by the provenances of *A. mangium.*