KFRI Research Report 174

GROWTH AND WOOD CHARACTERISTICS OF ACACIA MANGIUM GROWN IN KERALA

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PEECHI, THRISSUR

November 1999 Pages: 60

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ABSTRACT

Acacia mangium in the recent years. has achieved wide popularity in the private sector plantation programmes in Kerala. India, as a multi-purpose fast growing species. As no data on growth and wood properties of Kerala grown *A. mangium* were available. a preliminary study was conducted during 1994-'96 to evaluate the performance of this species.

Trees of age 1 to 13 years available either singly or from plantations in different parts of the Kerala State were used for the study. Growth studies revealed an average girth at breast height (GBH)of 112 cm for trees of age 10 years. The mean annual increment (MAI) of GBH varied from 11 to 18 cm. The mean height of the trees varied from 4 m to 9 m at the age of 1 year, to 26.2 m at the age of 10 years: the corresponding MAI in height was in the range of 1.8-6.1 m. These values indicate that the species is fast- growing.

The wood properties of 8 to 10-year-old trees were evaluated. Basic density of stem wood was in the range of 425-575 kg/m^3. with the mean value of 500 kg/m^3. This value is comparable to that of Kerala grown rubber wood of age 30-35 years. Between the age 8 and 10 years. difference in wood density was not significant. Bark was found to be heavier than wood, mean bark density of stern wood was 570 kg/m^3 for 8-year-old trees and 625 kg/m^3 for 10-year-old trees. The bark constituted about 13 to 14 % by volume and about 10 to 11 % by weight. The average bark thickness was in the range of 0.4-0.6 cm. The mean heartwood content was about 50 percent. A softer corewood was found in all the trees studied which occupied **7** to 14 % of the wood volume: comparatively larger quantity than that of other common timbers grown in Kerala. This indicated the prevalence of reaction wood. The core wood gets detached from the heartwood while drying, which is an undesirable feature as far as many end-uses are concerned. The wood exhibited only normal shrinkage: in the range of 1.2% for radial and 2 to 4% for tangential directions from green to air-dry condition.

As far as the physical properties of the branch wood was concerned, it was found that branch wood was denser than stem wood, the mean value of branch wood density being 570 kg/m^3. Branch bark was slightly denser than that of stem bark. Thickness of branch bark was less than stem bark. The branch wood was found to have more soft central core portion. The effective heartwood content of commercially utilisable branches was about 28%. and this was lower than that of stem wood.

Values of the strength properties of the timber from 8-year-old trees are law. The mean value of the modulus of rupture (MOR) of air-dried wood is 66N/mm^2. modulus of elasticity (MOE). 6 kN/mm^2 and the maximum compressive stress (MCS). 30 N/mm^2. These values are below them that of rubber mood. The mean sawn timber recovery was 45 percent.

Casual observations indicated that the timber is non-durable: the sapwood is susceptible to insect borer attack and hearhvood to termite attack. It is advisable to treat the timber with preservatives.

The assessment of the potential of timber from 8 to 10 year-old trees indicated that for better physical and mechanical properties required for specific end-uses, it is advisable to harvest the trees at a later age. As trees of higher age group were not available for the present study. a study needs to bc undertaken in future to evaluate the potential of timber from older trees. The data lor physical and mechanical properties reveal that the timber is 'light to moderately heavy' and moderately strong. It appears to be suitable for all uses of general purpose.

Key words: *Acacia mangium.* Bark density. Bark percentage, Bark thickness. Growth, Girth, Hcight. Heartwood content, Mean annual increment. Maximum compressive stress. Modulus of rupture, Modulus of elasticity. Sawn timber output, Shrinkage.

1. INTRODUCTION

Acacia mangium is a promising. fast growing, evergreen. leguminous tree, native of tropical rainforests of Australia, Papua New Guinea and Indonesia. In 14 years it grows up to 30 m height and 40 cm in diameter (DBH) (NRC. 1983). This species is able to grow even in acidic soils with pH as low as 4.2. The trees are useful for shade, ornamental purpose. screening, demarcating boundaries and wind breaks as well as for use in agro-forestry and erosion control. It is also suitable for planting in areas heavily infested with weedy *Imperta* grass (Pinyopusarerk *et al.*. 1993). The leaves can serve as forage for livestock. The tree produces considerable amount of fallen branches and dead leaves that can be gathered for fuel.

The growth rate of *A. mangium* is remarkable. On good sites in Malaysia. for trees of 9 years age, a height of 23 m and an average increase in diameter of 2-3 cm per year are reported. Annual growth yield reported is 46 m^3 per hectare. Average stands of 4year-old-trees annually produce 27 m^3 wood per hectare (NRC. 1983).

Reports on the excellent growth of *A. mangium* generated wide interest. especially in the private sector, as a result of which schemes for raising plantations of this species were initiated. Even though *A. mangium* was introduced in Kerala in the early 1980s with the major initiative of His Grace Benedict Mar Gregorius. the then Archbishop of Thiruvananthapuram. it was only in the early 1990's that farmers started planting it. However. no information is available on the locations planted with *A. mangium* either interplanted with farm crops or as pure plots in Kerala. Although *A. mangium* is described as a multi-purpose fast-growing tree species for the humid tropics, the wide variability in growth rates and susceptibility to pests and diseases calls for evaluation of its growth performance and wood properties before large scale planting is done. In order to make wise investments in extensive plantation programmes of this species, information regarding its growth rate and wood properties are essential. This will be helpful for evaluating its potential for various end-uses. It is in this context that the present study was planned.

In brief, the objectives were to examine the status of *Acacia mangium* in Kerala as fast-growing plantation timber and to evaluate the wood properties of this species in order to assess its potential for various end-use applications.

2. REVIEW OF LITERATURE

A*cacia mangium.* formerly known as *Mangium montanum* and later as Racosperma mangium indigenous to north-eastern Australia. eastern Indonesia and western Papua New Guinea, is an evergreen. leguminous. tropical tree popular for its rapid early growth (Awang and Taylor, 1993;NRC. 1983). In Australia this timber is known as brown sal wood, black wattle and lickony wattle. Other attributes of the species include optimum wood quality (for pulp, sawn timber and fuel wood) and tolerance to a range of soil types and pH.

2.1. DISTRIBUTION AND GROWTH

Acacia mangium has a fragmented natural distribution which stretches from Indonesia (where it occurs on the islands of Sula. Ceram and Aru) to Iriyan Jaya. the Western Province of Papua New Guinea (PNG), and North-East Queensland in Australia (Fig. 1.). The latitudinal range is 1°-18°57'S and longitudinal range is 125°22'- 146°17'E. The mean altitudinal range is from just above sea level to about 100 m, with an upper limit of 780 m. Distribution is strongly influenced by rainfall patterns and soil drainage.

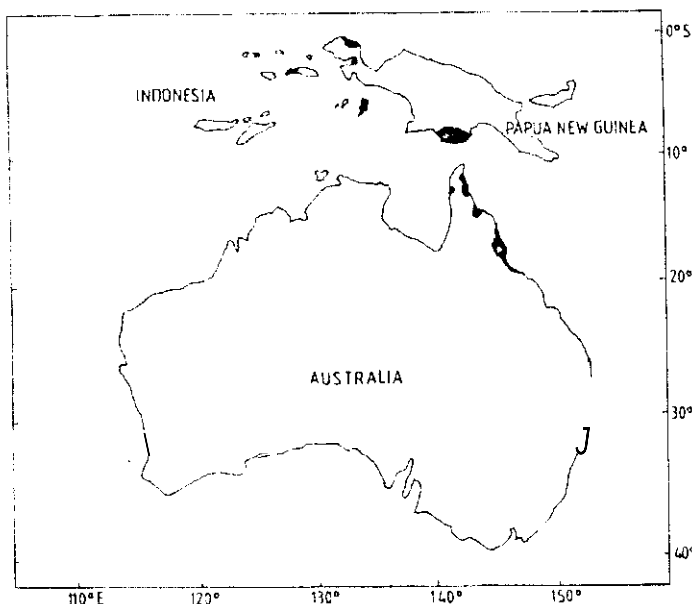

Fig. 1. Generalized range of natural distribution of *Acacia mangium*

A. mangium is a species of the humid. tropical lowland climatic zone characterised by a short winter dry season and high total annual rainfall. It prefers wet sites with an annual rainfall of 1,000-4,500 mm. Prolonged dry periods will slow down the tree growth (NRC. 19831. While the annual rainfall of over 2.500 mm in the Bengkoka/Kudat region of Sabah is considered adequate for *A. mangium* tree growth is still affected by seasonal conditions (Pinyopusarerk *et al..* 1993). During the dry season, when monthly rainfall is below 100 mm and the evaporation rate exceeds 130 mm per month. the trees are under moisture stress. Dieback due to a prolonged dry season (5-6 months) and high temperature has been observed in Thailand (Pinyopusarerk *et al.* 1993). It is typically a low elevation species associated chiefly with rainforest margins and disturbed sites on well-drained acid soils (pH 4.5-6.5) of low fertility. It also occurs behind mangroves. in seasonal swamps, along streams. and on well-drained flats. low ridges. and mountain foot hills (Pinyopusarerk *et al*, 1993).

A. mangium generally grows to a height of 25-35 m with straight bole which may be over half of the total height. and the diameter at breast height (dbh) of over 60 cm (Pinyopusarerk et al,.1993). On good sites, average increase in diameter commonly reaches 3-4 cm per year. It can attain a mean annual diameter increment at breast height up to 5 cm and mean annual height increment of 5 m in the first four to five years. However. growth declines rapidly after seven or eight years and except under very ideal conditions over long periods (above 20 years). the tree probably does not grow beyond 35 cm in dbh and 35 m in height. A tree of 20 cm dbh can give a volume of 0.185 m^3 to 0.220 m^3 with a biomass of 160 to 183 kg (Lim. 1993).

About 80 insect species are reportcd to feed on *A. mangium*: however. only a few are described as serious pests. Root feeders (*Sternocera aequisignata*) and termites. branch and stem borers (*Sinoxylon* sp.). and the red coffee borer (*Zeuzera coffeae*) can cause death. deformity. or reduced biomass production (Hutacharern. 1993). Boa and Lcnne (1994) have listed 19 diseases on *A. mangium* Of them, three (root disease and canker caused by *Botryodiplodia theobromae*, leaf spot caused by *Cylindrocladium quinqueseptatum.* sooty mould caused by *Meliola* sp.) have been reported from India (Boa and Lenne. 1994). As the plants grow older. it is increasingly susceptible to several diseases. most notably heart rot and root rot. Control of both these diseases is difficult (Lee. 1993).

Because of its fast growth and suitability for areas heavily infested by weeds *(Immperata* grass) in the tropical Asian region and due to its ability to control soil erosion. *Acacia mangium* has become one of the major tropical plantation forestry species in Asia, primarily in Indonesia. Malaysia, Philippines and Thailand. Its successful introduction to Malaysia in 1976 led to its introduction to China, Figi. Laos. Philippines, Sri Lanka. Thailand. Vietnam and some countries in Africa. Even though the current worldwide extent of *A. mangium* is around 1,50,000 ha only, Indonesia alone is reported to aim at establishing about 4.4 million ha forest plantation by 2000 AD using mangium as the principal species (Awang and Taylor, 1993). Mangium is one of the most widely planted *Acacia* species in the humid and suh-humid tropics. Many countries have introduced this species for trial and revegetation and rehabilitation programmes.

2.2. WOOD PROPERTIES

2.2.1. Anatomical, physical and mechanical properties

The sapwood of *Acacia mangium* is white and sharply defined from the darker brown heartwood. The wood has fine texture and straight or interlocked grain. Mohd. Hamami *et al* (1993) classified *A. mangium* as a short-fibred tropical species. The average values for fibre length, fibre diameter, fibre lumen diameter and fibre wall thickness are 934, 25. 18 and 3.3 µm for 4-year-old samples and 1017. 20. 12 and 4.3 µm for 8-year-old samples respectively. The fibre length increases from pith to bark and decreases with stem height. The vessel percentage decreases with increasing tree height. The wood is diffuse porous with mostly solitary vessels. The rays are uniseriate. The average percentage of fibres. vessels and rays are 85. 7-11 and 5-6 respectively. The fibre morphology of *A. mangium* wood was reported by Logan and Balodis (1982): Peh *et al.* (1982): Scharai and Budiarso (1988): Alloysius (1989) and Pensook (1990). The average fibre length is reported to be 1.0-1.2 mm (1000-1200 µm) (NRC, 19831. According to Scharai and Budiarso (1988), Acacia mangium has a comparatively low proportion of parenchymatous cells, a relatively high proportion of prosenchymatous cells and a low proportion of vessels indicating satisfactory strength properties. It is short fibred (870 µm), characterised with small fibre diameter (18.9 µm) and small wall thickness (2.7 µm). Wu *et al.*, (1988) studied the anatomical structure of mangium wood. They observed libriform fibres with inclusions. small longitudinal parenchyma with calcium crystals and vessels with silica crystals.

Although the mean value of specific gravity obtained for trees from natural stands is 0.56-0.60. plantation grown Umber is found to have a low range of specific gravity (0.40-0.45) (NRC. 1983). Peh and Khoo (1984) also reported a low density for mangium wood (380-480 kg/m3). Scharai and Kambey (1989). from Indonesia, reported about the properties and possible uses of the wood of mangium. They reported a wood density of 501 kg/m^3. Sulaiman and Lim (1993) studied the wood specific gravity of four 5-year-old mangium trees. The trees were 22-24 m in height. with a dbh range of 21.5-26.3 cm and clean bole height of 4-9 m. All the sample discs were reported to have discolouration and were hollow at the centre. due to heart rot. Specific gravity in the radial direction increased from the centre to the outer region near the bark. Wood density decreased with increasing tree height. They also reported that the low specific gravity of the juvenile wood reduced its utilization potential.

The moduius of elasticity (MOE) and hardness values were reported to be similar to those of black walnut (*Juglans nigra*) and modulus of rupture (MOR) and maximum compressive stress (MCS) values are somewhat higher than those of walnut (NRC, 1983). Ong (1985) reported the shrinkage. density. strength and hardness of wood from 12-year-old trees. There were considerable variations behveen and within trees. Scharai and Budiarso (1988) classified this as a species of medium strength properties. According to them its bending strength is 83.5 N/mm^2. crushing strength is 37.0 N/mm^2 and modulus of elasticity (MOE) is 10.6 kN/mm^2. The wood is reported to be moderately strong with an average bending strength value of 65 N/mm^2 in green condition (Sattar *et al.* 1993).The Bangladesh Standard Specification included this timber in the Group B timbers whose bending strength ranges from 63 lo 85 N/mm^2 (Anon.. 1973. c.f. Sattar *et al.* 1993). An investigation of the vaiation of wood density, fibre length and shrinkage within and between trees as well as between 3 provenances of 8- year-old *A. mangium* in Sabah by Sining (1989) showed that basic density ranged from 430 to 500 kg/m^3. Behveen provenances and behveen tree variations were less significant than the within tree variation of wood properties. Basic density and fibre length increased from pith to bark. shrinkage increased as basic density increased from pith to bark. However. among parameters. the shrinkage decreased as the basic density increased. Wu and Wang (1988) compared the wood properties of *A. mangium* with *Acacia auriculiformis* They found that shrinkage and its variation were generally less and strength properties were greater in *A. auriculiformis*. Scharai and Budiarso (1988) reported that *A. mangium* showed a high swelling anisotropy.

2.2.2. Chemical properties

The results of proximate chemical analysis of *A. mangium* were rcportcd by Khoo *et al.* (1991). Peh *et al.* (1982). Jagatheswaran (1989) and Alloysius (1989). Sukaton *et al.* (1985) made a study on the distribution of wood extractives and density of *A. mangium* along with some other Indonesian hardwood species. Mansor (1989) made a comparative study of simple wood sugars and proximate chemical components of sound and decayed wood of 8- year-old *A. mangium* trees. There were significantly higher percentages of mannitol and alkali solubles in decayed wood than in sound wood. A slight difference was observed in the amounts of alcohol-benzene and hot water solubles which were a little higher in decayed wood. Tomimura *et al.* (1989) studied the enzymatic hydrolysis of mangium wood along with some other Malaysian woods. They found that the yield of reducing sugars from trees such as *A. mangium* rubber wood and *Albizia falcataria* and *Gmelina arborea* was below 20% of the total fibre weight, while that from oil palm stem was about 50%. Choon and Roffael (1990) reported about the acidity of *A. mangium* wood. The amounts of chemical components were permissible for use in pulping, although the holocellulose. alpha cellulose and pentosan contents were slightly lower than average for temperate hardwoods (Khoo et *al.* 1991). Fuji *et al.* (1992) characterized the chemical nature of autohydrolyzed wood meal of *A. mangium* They found that the lignin content of *A. mangium* was higher than that in A. melanoxylon. The syringyl residue content of the lignin of *A. mangium* was lesser than that of *A. melanoxylon*

2.3. WOOD UTILIZATION

2.3.1. Preservative treatment

Acacia mangium is generally regarded as non-durable timber (Razali and Mohd. Hamami. 1993).It is quite amenable to preservative treatment (NRC. 1983: Peh and Khoo. 1984). Nilsson (1992)noted an uneven microdistribution of CCA preservative in its fibres. The treated wood may not give good performance in ground contact. Also he reported that it had a relatively narrow sapwood band and was not a suitable species to be used for exterior and outdoor purposes. Elias *et al.* (1993) reported that mangium could be easily treated by pressure method using CCA preservative. They also reported that the exent of pressure and duration of treatment did not have any significant effects on preservative retention. The retention decreased significantly from the outer surface to the core. Preservative treatment does not pose any serious problem of reduction in strength properties due to treatment (Kaber *et.al.*. 1994).

2.3.2. Seasoning

The wood seasons fairly rapidly without serious defects. Warping, end-splitting and surface checking are negligible. In the early stage of seasoning, however. heartwood areas can collapse, particularly on quarter sawn boards (NRC. 1983: Peh and Khoo, 1984). The timber kiln-dries well and fairly rapidly. without serious defects when suitable kiln schedules are used (Awang and Taylor. 1993).

2.3.3. The problem of heart-rot

Progressive decay of heartwood is termed heart-rot. Normally, fungi that decay the heartwood do not attack sapwood; such trees continue to grow to maturity and may outwardly appear healthy and vigorous. However. since heart-rot is progressive, there is no considerable decay cull at the end of a rotation.

Heart-rot in *A. mangium* was first reported in 1981. in Malaysia. It was reported that heart-rot was associated with fungal invasion of poorly healed wounds, especially those left by branch stubs left after self- pruning, singling and artificial pruning, broken branches and mechanical injuries. *A. mangium's* high susceptibility to heart-rot may be partially attributed to its mode of self-pruning. During self-pruning, the branch dies slowly allowing infection by decay fungi and entry of the fungi into the tree trunk before the branch stub has occluded (Lee *et al.* 1988: Ito, 1991 and Lee. 1993).The volume of heart-rot ranged from 2.7- 17.5% and 34- 100% of the length of the stem of the sample trees was found affected by heart-rot.

Pioneer micro-organisms such as *Certacystis funbriata. Chalara* spp. and Phialophora spp. found in discoloured heartwood (Lee, 1986 and Lee *et al.* 1988) breakdown the host defenses and invade the xylem. which then allows the decay fungi. with the ability to degrade cellulose and lignin of the cell walls, to become active.

The rot is often confined to small pockets in the heartwood. but is occasionally found throughout the length of the bole. especially in older trees. However. the overall volume of wood affected is normally small, about 10 percent. Chew (1987) also reported high percentage of heart-rot as a serious problem in the young stands. Mahmud Sudin *et al* (1993) reported that the average incidence of heart-rot was 35.3% and the volume of wood affected by heart-rot and discolouration ranged between 0.3 and 24 percent. According to them, the main infection courts were decayed branches while cankers. and less frequently, roots and branch stubs. were supplementary courts.

At present, there are no practical control measures against *A. mangium* heart-rot. Wound dressings that have long been used as a preventive measure are known to be ineffective and may infact create conditions favourabie for invasion of the wound by decay fungi (Lee. 1993).The high incidence of heart-rot in *A. mangium* trees in Peninsular Malaysia recently led the Ministry of Primary lndustries of Malaysia to place a temporary moratorium of planting these trees (Awang and Taylor, 1993).

2.3.4. Sawn timber recovery

Chan (1983) reported that sawn timber recovery ranges from 37 to 40%. The recovery is reported to be improved to the extent of around 50% by using 'modified live sawing', compared to the conventional live sawing (34.6%) (Winrock International and FAO. 1993).The low recovery may be due to small diameter of the sample logs, fluting. knots and heart-rot. The high incidence of knots (1 to 1.5 per meter length) causes considerable decrease in sawn timber recovery.

2.3.5. Multiple end-uses

A detailed review on processing quality. including seasoning, working, peeling, pulping and paper making properties. preservative treatment and its suitability for the manufacture of particle board was done by Peh and Khoo (1984). The timber is reported to be of general utility and is particularly suitable for pulping. Scharai and Kambey (1989) suggested it for uses such as, light indoor constructions and moldings, furniture, blockboards, veneer and plywood.

A. mangium wood makes attractive furniture and cabinets, molding and door and window components (NRC, 1983). The wood is also suitable for light structural works, agricultural implements, boxes and crates (Awang and Taylor, 1993).

Peh *et al.* (1982) and Peh and Khoo (1984) reported the suitability of *A. mangium* for pulping. Ku and Chen (1984) also produced high quality kraft and soda-AQ processed pulps and printing and writing paper from *A. mangium* Yantash *et al* (1985) and Yantash (1987) reported that this species displays very favourable pulping and paper making qualities. Logan (1987) obtained high yields of kraft and NSSC pulps and produced paper with good optical, physical and surface properties. Becker (1987) reported that *A. mangium* had the highest pulp yield and required the least cooking chemicals when compared with other species like *Eucalyptus deglupta* and *Gmelina arborea*. Udarbe (1987) reported about an integrated timber, pulp and paper project in Sabah which will rely heavily on plantation grown *A. mangium* Awang and Taylor (1993) stated that *A. mangium* is currently being grown with the primary use for pulp and paper in Sumatra, Sabah and Vietnam.

A. mangium is reported to be suitable for many re-constituted wood products. Its suitability for medium density fibre board (MDF) is reported by Tomimura *et al* (1987). Chew *et al* (1988 and 1990). Khoo and Matsuda (1990). Pensook (1990) and Pasaribu (1994). Its suitability for cement- bonded particle board (CBP) were reported by Tachi *et al.* (1988 and 1989). Jagatheswaran (1989). Rahim and Wan Asma (1989). Sulastiningsih *el al.*

(1990) and Rahim *et al* (1991). Methods for overcoming the inhibitory effects of extractives on CBP were reported by Chew *et al.* (1990).

Wood of *A. mangium* has been successfully utilized for the manufacture of particle boards (NRC. 1983: Chew and Jaafar. 1986; Chew *et al*. 1988 and 1991; Razali and Kuo, 1991). Particle boards meeting the specifications of Japanese Industrial Standards (JIS) were produced and the boards could easily be overlaid with veneer or other resin-impregnated papers.

A. mangium timber is reported to be easily peeled and the green veneers of tight, smooth and acceptable quality were obtained Wang *et al*, 1989: Chai. 1989 and Salim. 1992). However. the veneer recovery rate was low, 35- 45%. which could be due to the small diameter with fluted boles and numerous knot marks. The timber is also suitable for the production of decorative veneers. Wong *et al* (1988) and Chai (1989) found that phenol- formaldehyde (PF) resins would be more compatible with *A. mangium* for plywood manufacture. Similar results were obtained by Mohd. Hamami *et al* (1991a) and Salim (1992) on wood lamination and laminated veneer lumber (LVL) respectively. The LVL's bending and shear strengths were much greater than the minimum values required by the Japan Agricultural Standards for first-grade structural LVL. Wang *et al.* (1990) and Sasaki *et al*. (1990 and 1993) also reported potential of this species for LVL.

Chew *et al.* (1990 and 1992) reported 18-39% tannin content in the bark of *A. mangium* This indicates possible commercial exploitation of tannins from the bark of *A. mangium* Further, the bark extracts had good reactivity towards formaldehyde. and therefore good adhesive properties. Plywood manufactured using the bark extract showed excellent bonding properties with failing loads twice the minimum failing load for boiling resistant type of adhesive. stipulated in the British Standards (Mohd. Nor Yusof *et al.* 1989).

The calorific value of the timber is also relatively high, 4800-4900 k cal per kg and the wood makes good fuel (Mohd. Hamami *et al*.. 1991b) and reasonably good quality charcoal and is suitable for the manufacture of charcoal briquettes and activated carbon (Awang and Taylor. 1993).

3. MATERIALS AND METHODS

3.1. EXTENT OF *ACACIA MANGIUM* PLANTING IN KERALA

A proforma (Appendix 1)was designed and sent to all the1065 Panchayat level Krishi Bhavans including Corporation/Municipality level Agricultural Units through the 14 District level Principal Agricultural Officers. The details of the number of offices contacted through the proforma survey are given in Appendix 2. Details such as presence, year of planting, number of block plantation of above 400 m^2 (10 cents) were asked in the proforma.

3.2. GROWTH RATE

As interest in planting *Acacia mangium* developed only very recently in Kerala. there were only very limited number of plantations. that too in the form of small blocks either interplanted with farm crops or as pure blocks. All of these are in private sector. There are no plantations of this species in the Government sector (Forest Department). As it was not possible to wait for the availability of plantations in a systematic way for the studies. a survey was conducted on whatever small scale plantations available. for identifying the locations where *A. mangium* was planted and for collecting the growth rate data of trees of different ages growing at various places (Fig. 2 and Table 1).

Girth at breast height (GBH) (1.37m above ground level) was recorded for all trees in selected sample plots. In each sample plot, height measurements were recorded on sample trees representing the height range. GBH was converted to diameter at breast height (DBH) and the corresponding mean annual diameter increments were worked out and diameter at breast height was co-related with tree height through regression analysis in order to develop statistical relationship between the hvo (Chaturvedi and Khanna. 1994).

The GBH and height data from a plot established in Nilambur in 1984 was used to study the seasonal growth pattern during the initial 3 year period of the crop.

3.3. BIOMASS MEASUREMENT

Three sample trees at the age of 10 years were harvested for the estimation of biomass. Green and oven-dry (OD) weights of different tree components were determined. Green weight was determined by weighing the different

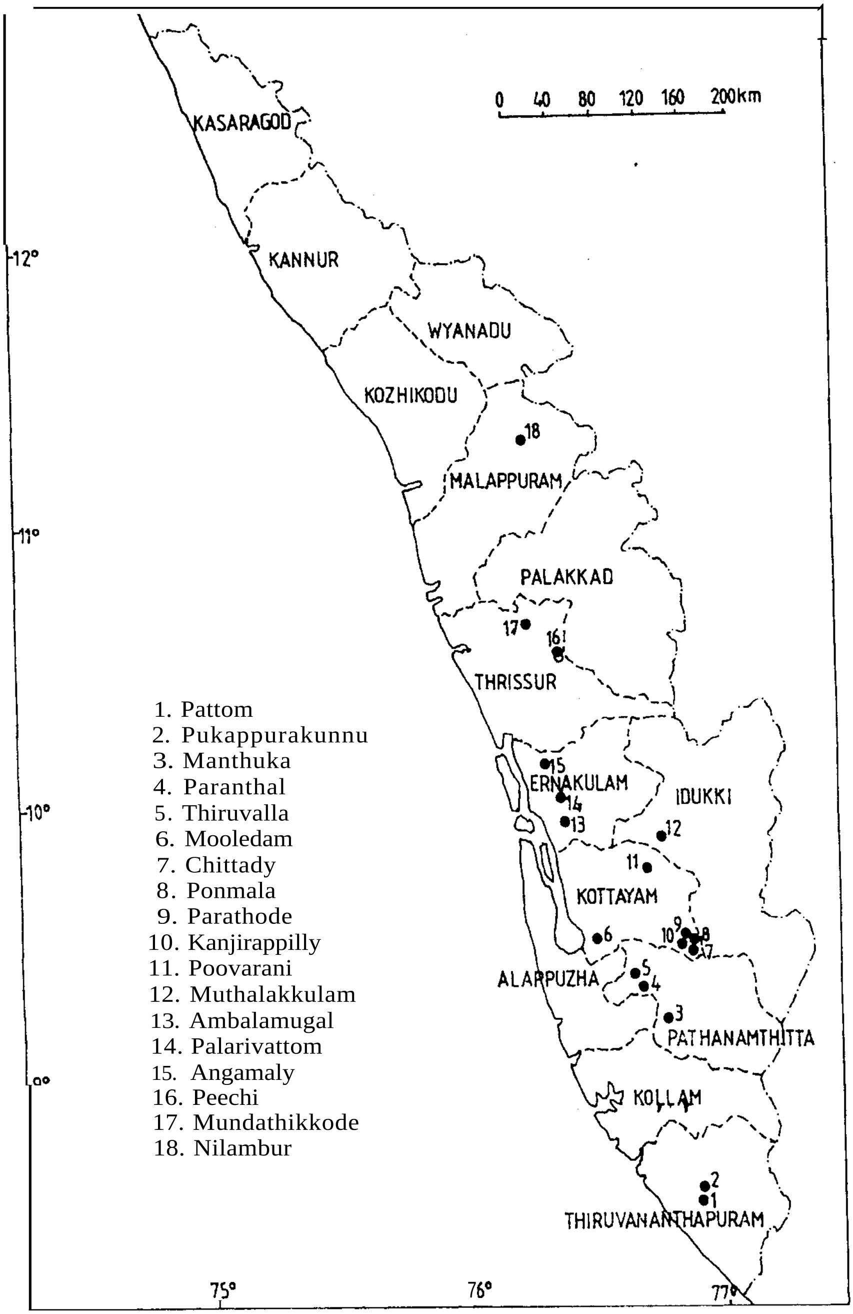

Fig.2. Map of Kerala and locations of sample plots of Acacia

Table 1. **Details of Acacia mangium plantations in Kerala taken up for growth measurements**

Sl. No.	Approx. Latitude	Approx. Longitude	Place	Year of Planting	No. of trees
1	8°34'	76°58'	Bishop Palace, Pattom (Trivandrum)	1984-94	83
2	8°34'	76°58'	Pukappurakunnu, Bethany Estate (Trivandrum)	1989-94	63
3	9°12'	76°42'	Manthuka (between Panthalam and Adoor)	1991-95	11
4	9°14'	76°43'	Paranthal (Panthalam)	1989-91	15
5	9°23'	76°34'	Thiruvalla	1988	8
6	9°33'	76°31'	Mooledam (Kottayam)	1993	24
7	9°33'	76°50'	Chittady (Kanjirappilly)	1993-95	55
8	9°33'	76°48'	Ponmala (Kanjirappilly)	1993	30
9	9°34'	76°49'	Parathode	1992	9
10	9°34'	76°48'	Kanjirappilly	1989	4
11	9°43'	76°37'	Poovarani (Palai)	1993	11
12	9°57'	76°45'	Muthalakkulam (Thodupuzha)	1995	38
13	9°57'	76°21'	Cochin Refineries (Ambalamugal)	1994	11
14	10°1'	76°20'	Palarivattom	1986	1
15	10°13'	76°22'	Angamaly	1994-95	286
16	10°32'	76°20'	Peechi	1982-93	31
17	10°36'	76°13'	Mundathikkode (Thrissur)	1991	40
18	11°16'	76°15'	KFRI Subcentre (Nilambur)	1984-95	164
19	11°16'	76°15'	Vallappuzha (Nilambur)	1994	264
20	11°16'	76°15'	Chandakkunnu (Nilambur)	1994	335

components such as phyllodes. stem below 7 cm girth over bark (GOB). between 7 cm and 10 cm. and those above 10 cm: roots below 6 cm GOB. For oven-dry weight determination. samples of different components were oven- dried at 105^{O}C to constant weight. Based on the relationship worked out between fresh weight and oven-dry weight, the biomass was estimated.

3.4. WOOD PROPERTIES

Any investigation on wood properties will be meaningful only if the studies are made on mature wood. as far as its commercial end-use applications are concerned. As there are no plantations of *A. mangium* with such mature wood available for felling, for the evaluation of wood properties. five trees of age 8 years and three trees of age 10 years were felled from KFRl campus. The characteristics of sample trees used for preparing samples for the estimation of wood properties are given in Table 2.

The wood properties were estimated as detailed in a previous report (Bhat *et a1* 1985). About 6 cm thick transverse discs were cut from various height levels (such as base. 25, 50 and 75 percent of the tree height as well as from the top portion) from the commercially utilizable portion of the stem wood of the trees. Each disc was again transversely divided into two halves. One half was used for the **estimation of bark percentage and heartwood.**

To estimate the **heartwood percentage,** the heartwood area and the disc area were calculated by measuring the four radii at right angles to one another and the four measurements were averaged for each disc and weigh- tage was given for the volume to estimate the heartwood percentage. As it was found that in all the samples collected, the central core portion is very distinct, with loose fibres and comparatively much larger than other common timber species growing in the region, the central core portion was also quantified in a way similar to the heartwood percentage.

The other half of the discs was used for the **determination of basic density and shrinkage** properties. A diametrical segment was cut and 3 x 3 x 3 cm blocks were prepared from the pith outwards on both radii. The distance from the pith to the outer margin of each block was noted.

Two bark samples from opposite radii were available for the **estimation of bark density** of the discs. The density of wood and bark was measured on oven dry (OD) weight to green volume basis. The green volume was measured by water displacement method, using top pan balance.

After determining the initial weight and green volume of the samples. two points were marked on their opposite faces in the tangential and radial

Table 2. Characteristics of sample trees used for preparing test samples for estimation of wood properties

Tree No.	Height of commercially utilizable stem wood (m)	Girth at base (cm)	GBH (cm)	Girth at 25% of height (cm)	Girth at 50% of height (cm)	Girth at 75% of height (cm)	Girth at top portion of commercially utilizable stem wood (cm)
Age : 8 years							
1	6.7	67.0	54.5	48.5	48.5	44.0	43.5
2	10.4	136.0	118.0	112.0	92.0	75.0	65.0
3	7.5	85.0	69.1	58.0	39.0	22.0	8.0
4	8.9	45.0	39.0	38.0	35.0	32.0	29.0
5	7.9	25.0	23.0	22.0	18.5	16.5	14.0
Age : 10 years							
6	5.3	57.0	55.0	55.0	44.0	41.0	35.0
7	9.4	65.0	63.0	55.0	44.0	39.0	25.0
8	8.9	44.0	42.0	41.0	39.0	34.0	28.0

directions and the distance between the points were measured accurately using a digital vernier. The samples were allowed to air-dry and the distance between the points was measured once in a week. After allowing for an air-drying period of about two months. the samples were oven-dried and weighed and again the shrinkage measurements are repeated. From these data the **density and shrinkage** were calculated.

Only four trees were available for complete conversion into the sizes required for testing the **mechanical properties.** The logs were sawn into sizes of 3 x 3 x 30 cm and air-dried. From the air-dried material the maximum number of clear specimen available for each tree were selected randomly and re-sized into 2 x 2 x 30 cm for **static bending test** and 2 x 2 x 8 cm for compression test. Static bending test and **compression parallel to grain tests** were conducted in a 'Zwick' Universal Testing Machine. Tests were limited to those two as **modulus of rupture (MOR). modulus of elasticity (MOE) and maximum compressive stress (MCS)** will give a fairly good indication of the utilization potential. The tests were conducted as per the Indian Standard procedure,IS:l708 (BIS.1986).

For estimating the **sawn timber recovery.** the trees were cross-cut into convenient lengths for further sawing: The cross-cuts were made in such a way that crooks (bends) were eliminated in the logs. Depending upon the diameter of the logs, scantlings of maximum thickness were cut in such a way that the pith (soft core portion) was avoided. From every piece of sawn timber, maximum sizes that could be recovered were sawn out to estimate the recovery.

Wherever available. samples from the basal portion of all the **branches** were collected for determining the physical properties such as basic density of wood and bark, bark percentage, bark thickness and heartwood content of branches. As there were not many defect-free samples recoverable from the branch wood. testing the mechanical properties of branch wovd was not attempted.

4. RESULTS AND DISCUSSION

4.1. EXTENT OF *ACACIA MANGIUM IN KFRALA*

Of the total 1065 agricultural offices contacted through the proforma survey, 155 responded (Table 3).The results presented in Table 3, based on 14.6% returns (district-wise returns vary between 2.2% and 48.7%) provide a rough picture about the extent of *A. mangium* plantations in Kerala.

In India, this low elevation species was probably introduced in the eighties. However, it was only in the early 1990's that farmers had started planting them, either interplanted with farm crops or as pure plots. In 1997, trees up to an age of 13 years are present in some plots. Mangium timber has not yet reached the market. Unfortunately, data on the extent of planting in Kerala is not available. There is no plantation of this species at State Government level, particularly by the Kerala Forest Department. Mature trees are available in the State only in a private plantation at the Trivandrum Archbishop's Palace and in Bethany Estate, near to the Mar Ivanios College, Trivandrum. The extent of both these plantations amounts to a few hectares only.

District-wise data show that *A. mangium* has been introduced in all the districts of Kerala. The state average shows presence of *A. mangium* in 43% of the Panchayats. Farmers have taken up plantations of above 400 m^2 in 8 districts. The largest block has an area of 3.24 ha. Even though block planting is not reported from Malappuram District, we are aware of cultivation of the species in plots above 400 m^2 in Nilambur of Malappuram.

Our dependence on 155 returns is certainly a limitation of this survey, and therefore the data on block planting of *A. mangium* may be understood within this limitation.

4.2. GROWTH RATE

Table 4 and Appendix 3 gives the details of variation of GBH with age as recorded from various plantations. It can be seen that the mean annual increment (MAI) of GBH vanes from 11.1 to 17.9 cm. The GBH gradually increased as the age increased and reached a mean value of 100.0 cm at the age of 7 years. The slightly low value of GBH observed for the 8-year-old trees may be due to the limited number of trees available for measurement and that too, from only one plantation. The influence of soil factors on growth may be another reason for the slightly low growth observed in this case. After 8 years, again the mean GBH was found increasing. A GBH of around 111 cm

Table 3. District-wise details of *A. mangium* cultivation in Kerala as revealed through proforma survey

Name of District	No. of Krishi Bhavans approached through Proforma	No. of Krishi Bhavans returning Proforma	No. of returns with Acacia *mangium* cultivation	No. of returns showing Acacia *mangium* cultivation in more than 10 cents ($400 m^2$)	No. of plots more than 10 cents ($400 m^2$)
1	2	3	4	5	6
Kasargode	39	19 (48.7%)	8 (42.1%)	4 (21%)	18
Kannur	87	32 (37.9%)	12 (37.5%)	4 (12.5%)	8
Wayanad	25	2 (8.0%)	1 (50%)	1 (50%)	1
Kozhikode	79	21 (26.6%)	5 (23.8%)	1 (4.7%)	1
Malappuram	99	16 (16.2%)	3 (18.7%)	-	-
Palakkad	94	6 (6.4%)	3 (50%)	1 (16.6%)	2
Thrissur	105	13 (12.4%)	6 (46.1%)	-	-
Ernakulam	94	13 (13.8%)	4 (30.7%)	3 (23%)	4
Idukki	52	5 (9.6%)	4 (80%)	-	-
Kottayam	77	7 (9.1%)	5 (71.4%)	4 (57.1%)	6
Alappuzha	78	2 (2.6%)	2 (100%)	1 (50%)	1
Pathanamthitta	61	3 (4.9%)	3 (100%)	3 (100%)	4
Kollam	86	14 (16.3%)	10 (71.4%)	7 (50%)	15
Thiruvananthapuram	89	2 (2.2%)	1 (50%)	1 (50%)	1
Total 14 Districts	1065	155 (14.6%)	67 (43.2%)	30 (19.3%)	

Figures in parenthesis in Column 3 indicates percentage offices returning the proforma.
Figures in parenthesis in Column 4 indicates percentage of returns with *A. mangium* cultivation.
Figures in parenthesis in Column 5 indicates percentage of returns with *A. mangium* in plots of 10 cents or more ($400 m^2$).

Table 4. Mean value of GBH (cm), DBH (cm) and estimated height(m) of *A. mangium* grown in Kerala (summary of Appendix 3)*

Age (years)	No. of localities sampled	No. of trees observed	Mean GBH (cm)	Mean MAI in GBH (cm)	Mean DBH (cm)	Mean MAI in DBH (cm)
1	5	218	17.9	17.9	5.7	5.7
2	5	271	26.7	13.4	8.5	4.3
3	8	178	43.7	14.6	13.9	4.6
4	5	96	50.7	12.7	16.1	4.0
5	6	146	61.1	12.2	19.5	3.9
6	4	28	94.7	15.8	29.8	5.0
7	4	19	100.0	14.3	31.8	4.5
8	1	8	94.4	11.8	30.0	3.8
9	1	4	107.3	11.9	34.1	3.8
10	1	4	111.2	11.1	35.6	3.6
11	1	1	150.5	13.7	47.9	4.4
12	1	1	160.0	13.3	50.9	4.2

*see Appendix 3

was observed in trees of 10 years age. A GBH of 160 cm was observed in a tree with 12 years of age. Taking a mean GBH value of 111 cm for 10-year-old trees, the MAI of GBH will be around 11.1 cm. This value is found falling in comparatively good range with other fast growing species.

The variation of estimated tree height with age is shown in Table 5. It can be seen that at the age of 1 year the mean height of the trees is about 4-9 m. This slowly increases to an average value of around 23-26 m at the age of 7 years. For 8 years a low value is observed, may be due to the limited number of samples and that too representing only one plantation. A single tree of age 10 years was available for measurements, which showed an estimated height growth of 26.2 m. The MAI of height growth is in the range of 1.8-6.1 m during the first 7 years, then slowly stabilizes in the range of 2.6-2.9 m during the age of 8-12 years. Taking a value of around 32.4 m as the average height of 11 year-old trees, the MAI of height will be around 3 m.

Awang and Taylor (1993) reported that this species can achieve a MAI in GBH of up to 15.7 cm and MAI in height up to 5 m in the first four or five years. Height growth rate is reported to decline rapidly after 7 or 8 years and except for very ideal conditions or over long periods of more than 20 years, the trees probably will not grow beyond 110 cm GBH and 35 m in height.

Table 5. Diameter growth and estimated height of *A. mangium* trees growing in Kerala

Age (years)	Range of mean values of GBH		Range of mean values of DBH		MAI in DBH		Estimated height (m)**	MAI in height	No. of plantations
	Mean lower value	Mean upper value	Mean lower value	Mean upper value	Mean lower value	Mean upper value			
1	7.6	25.4	2.4	8.1	2.41	8.1	3.8-9.1	3.8-3.1	5
2	10.9	38.5	3.5	12.3	1.68	6.13	5.0-12.2	2.5-6.1	5
3	26.4	51.7	8.4	16.5	2.80	5.49	9.3-15.1	3.1-5.03	8
4	29.6	64.3	9.4	20.5	2.36	5.12	10.1-17.6	2.5-4.4	5
5	24.9	85.2	7.9	26.2	1.58	5.23	8.9-21.0	1.8-4.2	6
6	87.5	102.1	27.9	32.5	4.64	5.41	22.0-24.5	3.7-4.1	3
7	91.7	109.8	29.2	35.0	4.17	4.99	22.7-25.9	3.2-3.7	4
8	94.4*		30.0*		3.76*		23.2*	2.9	1
9	107.3*		34.1*		3.79*		25.4*	2.8	1
10	111.8*		35.6*		3.56*		26.2*	2.6	1
11	150.5*		47.9*		4.36*		32.4*	2.9	1
12	160.0*		50.9*		4.24*		33.8*	2.8	1

Note: *Data for 8 to 12 years have come from single plantation and therefore, the range of mean values is not available.
**The height was estimated using the equation developed, Log (Height)= 0.708 + 0.716 Log (DBH).

4.2.1. Height-diameter relationship

The measured values of DBH and height (Appendix 4) are subjected to simple linear regression (SLR) analysis and a highly significant height-diameter relationship was developed (Appendix 5). Accordingly, the diameter and height growth of trees are related by the fo1lowing equation with an R^2 value of 92.4 percent.

Log (Height)= 0.708 + 0.716 Log (DBH)

This equation can be utilised for arriving at an estimated figure for height of the tree from DBH value. DBH values for different age groups and the corresponding estimated tree height values calculated by using the above equation are given in Table 5.

4.2.2. Seasonal growth trend

Seasonal height growth curves for initial three years (204 to 1299 days after planting (DAP)) is presented in Fig. 3. The graph clearly shows continuous height and diameter growth irrespective of season. The growth rate is related to soil moisture, associated with monsoon giving rise to two different rates of growth during a vear.

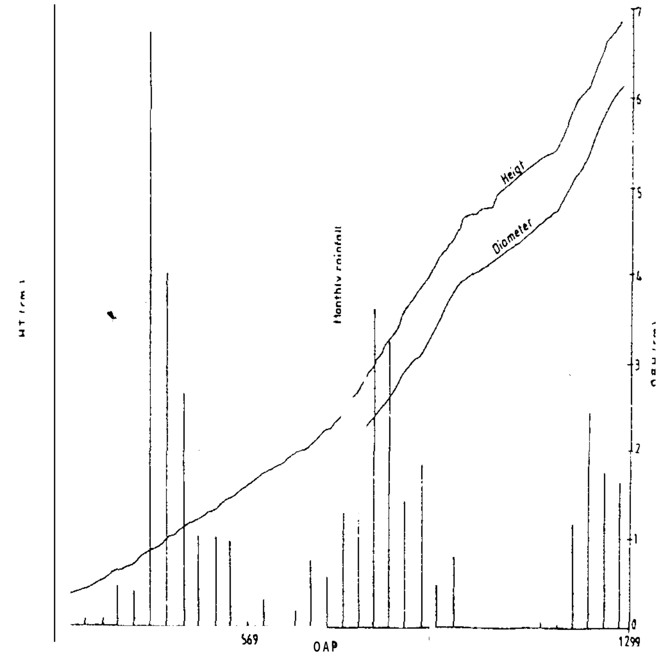

Fig.3. Height and diameter growth trend in Acacia mangium during initial three years at

4.3. BIOMASS MEASUREMENT

Ratio of green weight to oven-dry (OD) weight is presented in Table 6. This can be used as a factor for conversion of green weight to OD weight.

Table 6. Factor of conversion of fresh weight to oven-dry weight for different parts of *A. mangium* tree

Tree component	Green weight OD weight conversion factor
Phyllode	0.2702
Dry branches of < 7cm	0.7827
Green branches of < 7cm	0.4853
Green branches of 7-10cm	0.6242
Stem > 10cm	0.5953
Root collar region	0.5698
Roots > 10cm	0.6571
Roots< 10cm	0.3275

Biomass of various components of three 10-year-old trees of different diameter and height, grown in a single location at Nilambur, is provided in Table 7. Although data from three trees are not adequate for any generalisation, the value of this data lies in the fact that generation of such data is laborious, time consuming and hence, not easily available.

Of the total tree biomass (which includes the whole of above-ground biomass and the root biomass down to 6 cm girth over bark) in a moderately well-grown tree of 10 years, the above-ground biomass formed 84.1% and below-ground biomass 15.9%. Various constituents of the above-ground biomass are: main stem 71.02%. branchwood 26.2% and phyllodes 2.87 percent. The quarter girth volume (commercial volume) of timber above 30 cm girth over bark (gob)worked out to 0.201 m3,

4.4. WOOD PROPERTIES

From utilization point of view, wood properties need to be estimated on mature trees. There were not many mature trees available for felling and collection of samples because this species achieved wide popularity in Kerala

Table 7. Biomass of three sample trees of *Acacia mangium* of 10 years age, grown in KFRI Subcentre campus at Nilambur, Kerala

Parameter	Tree No. 1		Tree No.2		Tree No.3	
TREE MEASUREMENTS Height of the tree (m)	20.4		15.2		10.4	
Girth at breast height (cm)	69.8		39.0		21.0	
Diameter at breast height (cm)	22.2		12.4		6.7	
Volume (quarter girth formula) of timber above 30 cm gob (m^3)	0.201		0.047		Nil	
BIOMASS MEASUREMENTS	Fresh weight (kg)	Oven dry weight (kg)	Fresh weight (kg)	Oven dry weight (kg)	Fresh weight (kg)	Oven dry weight (kg)
Phyllodes	32.040	8.683 (2.87)	11.600	3.134 (4.73)	2.100	0.567 (4.69)
Branches Dry twigs < 7 cm gob	21.910	17.149 (5.67)	5.900	4.618 (6.97)	0.400	0.313 (2.59)
Green twigs < 7 cm gob	29.100	14.122 (4.67)	13.600	6.600 (9.97)	2.600	1.262 (10.44)
Green twigs 7-10 cm gob	23.630	14.750 (4.88)	10.500	6.554 (9.90)	Nil	Nil (0)
Green twigs 10-30 cm gob	55.800	33.218 (10.98)	Nil	Nil (0)	Nil	Nil (0)
Main stem Up to 30 cm gob	21.800	12.978 (4.29)	14.500	8.632 (13.04)	16.700	9.942 (82.27)
> 30 cm gob	338.660	201.602 (66.73)	61.600	36.670 (55.39)	Nil	Nil (0)
Biomass Above ground total	522.940	302.502 (100)	117.700	66.208 (100)	21.800	12.084 (100)
Below ground total up to 6 cm gob and up to a depth of 108 cm	87.200	57.299	NA	NA	NA	NA
Whole tree	554.34	359.801	NA	NA	NA	NA

NA - Not available

Figures in parenthesis indicate percentage of total above-ground biomass (oven-dry weight).

only in the recent years and hence not many plantations have been raised so far. As timber being highly heterogeneous in properties, more number of samples have to be used for the estimation of wood properties. Further, in order to account for the variation of properties within trees, the entire trees need to be felled and sampled from various height levels. Many of the plantations are in the private sector, the owners were reluctant for felling the trees which are in an immature stage. Collection of samples from such plots was not possible. Hence, five trees of 8 year- old age and three trees of 10 year age grown in the KFRI campus were felled and samples collected for the estimation of the wood properties.

Table 2 gives the details of the sample trees felled and used for preparing samples for evaluation of wood properties. The physical properties of the wood of trees of age 8 years and 10 years were determined. Trees of only these two age groups were available for felling and conversion for sampling. Out of these, only two trees of age 8 years were available for estimating the branch wood properties.

The timber has distinct heartwood and sapwood. Heartwood is brownish when first exposed which turns to dark brown during drying. Corewood portion is distinct and is found comparatively large, weak and with loose fibres.

4.4.1. Wood density

Table 8 gives the variation in basic density of stemwood with respect to height levels. The mean values of the basic density of stemwood at various height levels indicates that it decreases with increasing height level in trees of age 8 years. Such a trend is not observed in trees of 10 years age. This may be due to the limited number of sample trees of 10-year-old available for the study. The values of basic density range from 422.5-572.5 kg/m^3; the mean value obtained is around 500 kg/m^3 for the 8-year-old trees. The between-tree-variation in basic density of the trees of age 10 years is also covered by the same range mentioned earlier, the mean value obtained is 508 kg/m^3, not much different from the mean value obtained for trees of age 8 years. The wood density reported in an earlier study is also in the same range, 500 kg/m^3 (NRC. 1983). This timber is lighter than teak wood, whose wood density (at 12% MC) is reported as 650 kg/m^3 (Nazma *et al.,* 1981).

Even though variation in wood properties significantly affects utilization, studies on provenance variation in terms of wood characteristics are scarce. Pipatwattanakul (1989) examined provenance variation in wood density of 6-year-old *A. mangium* trial plantation and got values of 0.3-0.4 for the wood specific gravity, differences among the 16 provenances studied were not

Table 8. Variation of basic density of stem wood with tree height

Tree No.	Basic density (kg/m^3)					CV (%)
	Height level					
	25%	50%	75%	Top	Mean	
Age : 8 years						
1	437.7	424.9	435.0	392.2	422.5	4.9
2	591.2	552.1	522.4	543.7	552.4	5.2
3	599.2	567.4	571.1	551.2	572.2	3.5
4	564.5	495.0	475.6	488.3	505.9	7.9
5	518.8	486.2	425.2	418.6	462.2	10.5
Mean	542.3	505.1	485.9	478.8	503.0	
CV(%)	12.2	11.8	12.6	15.0	12.3	
Pooled mean MC = 80%						
Age : 10 years						
6	476.4	454.0	556.8	458.0	486.3	9.9
7	569.6	543.4	622.8	539.1	568.7	6.8
8	459.4	473.1	448.9	495.8	469.3	4.3
Mean	501.8	490.2	542.8	497.6	508.1	
CV(%)	11.8	9.6	16.2	8.2	10.5	
Pooled mean MC = 70%						

significant. However, values obtained at the generally drier sites (0.6) were substantially higher than those at wetter sites (0.4) (Awang and Taylor, 19931.

4.4.2. Bark density

The variation of bark density is shown in Table 9. No specific trend is observed with regard to the variation of bark density with respect to height levels within the tree. The bark is found to be heavier than wood, the mean value of the bark density of the five trees examined is 570 kg/m^3 for 8-year-old trees and 624 kg/m^3 for 10-year-old trees. The density of stem bark increases with age. The density of branch bark of 8-year-old trees is found to be slightly higher than that of the stem. The mean value obtained for the density of branch bark of 8-year-old trees is around 628 kg/m^3 (Table 15).

4.4.3. Bark percentage

Table 10 illustrates the variation of bark percentage by volume with respect to height level in the trees and Table 11, the variation of bark percentage by weight in the stems. The bark percentage by volume gradually increases up to 75% of the tree height. The mean value of bark percentage by volume is 13.9 for the 8-year-old material and 12.9 for the 10-year-old sample (Table 10).The bark percentage by weight decreases up to 75% of the tree height in the 8-year-old samples. The mean value of bark percentage by weight is 10.8 for the 8-year-old trees and was 10.4 for the 10-year-old trees (Table 11). Hence, between ages 8 and 10 years, bark percentage by weight value is not much different. The mean bark percentage by volume of branch in 8-year-old trees is around 18.5, whereas that of the main stem is 13.9 (Table 10 and 15). The mean value of the bark percentage by weight of the branches of 8-year-old trees is 13.5 (Table 11 and 15) and that of stem is 10.8. In general. the bark content of branches is higher than that of stem.

The variation of mean bark thickness of stem with height level is found negligible up to 75% of the tree height in the case of trees of both the age groups. Between trees bark thickness is found to vary in the range of 0.25-1.12 cm (Table 12). The thickest bark is found in the tree with more vigorous growth (Tree No. 2). The thickness of bark in branches is found to be lower than that of the stem. The 8-year-old trees have been found to have an average bark thickness of around 0.6 cm in stem whereas the average branch bark thickness for the same age group is around 0.4 cm (Table 12 and Table 15).

Table 9. Variation of bark density with tree height

Tree No.	Bark density (kg/m^3)					CV(%)
	Height level					
	25%	50%	75%	Top	Mean	
Age : 8 years						
1	638.9	633.2	600.0	591.0	615.8	3.9
2	606.1	666.6	575.7	626.5	618.7	6.2
3	500.0	495.0	455.2	465.0	478.8	4.6
4	516.2	566.2	550.6	553.1	546.5	3.9
5	509.8	608.7	613.4	633.1	591.3	9.4
Mean	554.2	593.9	559.0	573.7	570.2	
CV(%)	11.5	11.2	11.2	12.0	10.3	
Pooled mean MC = 70%						
Age : 10 years						
6	627.5	589.1	612.6	684.5	628.4	6.5
7	640.7	557.4	632.9	721.2	638.1	10.5
8	596.5	555.6	676.6	589.0	604.4	8.5
Mean	621.6	567.4	640.7	664.9	623.6	
CV(%)	3.7	3.3	5.1	10.3	2.8	
Pooled mean MC = 60%						

Tree No.	Bark % by volume					CV(%)
	Height level					
	25%	50%	75%	Top	Mean	
Age : 8 years						
1	6.9	9.6	9.7	12.5	9.7	23.6
2	13.5	12.7	14.9	13.4	13.6	6.8
3	10.7	17.4	18.2	16.4	15.7	21.6
4	*14.0*	11.6	13.9	13.4	13.2	8.4
5	14.9	17.3	18.0	19.2	17.4	10.4
Mean	12.0	13.7	15.3	13.9	13.9	
CV(%)	27.1	25.5	18.6	12.3	20.9	
Age : 10 years						
6	11.0	9.8	8.9	13.2	10.7	17.4
7	16.2	13.1	17.5	13.1	15.0	14.9
8	8.4	13.6	14.2	15.7	13.0	24.4
Mean	11.9	12.2	13.5	14.0	12.9	
CV(%)	33.4	16.9	32.1	10.5	16.7	

Table 11. Variation of bark percentage by weight with tree height

Tree No.	Bark % by weight					CV(%)
	Height level					
	25%	50%	75%	Top	Mean	
Age : 8 years						
1	8.4	8.9	8.6	8.4	8.6	2.7
2	12.2	10.3	8.5	9.5	10.1	15.5
3	11.3	11.1	7.9	9.5	10.0	15.9
4	12.4	9.6	9.1	9.2	10.1	15.5
5	18.2	12.1	14.3	16.1	15.2	17.1
Mean	12.5	10.4	9.7	10.5	10.8	
CV(%)	28.5	12.0	27.0	29.9	23.5	
Age : 10 years						
6	10.2	9.3	9.7	12.0	10.3	11.6
7	9.4	9.8	10.1	11.9	10.3	10.7
8	8.3	9.2	10.6	14.5	10.7	25.6
Mean	9.3	9.4	10.1	12.8	10.4	
CV(%)	10.3	3.4	4.5	11.5	2.2	

Table 12. Variation of bark thickness with tree height

Tree No.	Bark thickness (cm)					CV(%)
	Height level					
	25%	50%	75%	Top	Mean	
Age : 8 years						
1	0.28	0.38	0.40	0.43	0.37	17.6
2	1.43	1.13	1.05	0.85	1.12	21.5
3	0.63	0.95	0.95	0.78	0.83	18.6
4	0.44	0.33	0.34	0.31	0.36	16.1
5	0.25	0.27	0.24	0.23	0.25	6.8
Mean	0.61	0.61	0.60	0.52	0.59	
CV(%)	79.5	65.2	62.5	53.8	63.2	
Age : 10 years						
6	0.35	0.28	0.23	0.30	0.29	17.1
7	0.60	0.45	0.53	0.25	0.46	32.9
8	0.33	0.48	0.40	0.40	0.40	15.3
Mean	0.43	0.40	0.39	0.32	0.38	
CV(%)	35.0	27.0	38.6	23.9	22.7	

4.4.4. Heartwood percentage

The heartwood content of stemwood is given in Table 13. The incidence of 'heart-rot'. is more severe in this species and this in turn can affect the wood quality. In the heartwood, a soft inner core of wood is found (Fig. 4a) which often got detached from the rest of wood while drying (Fig. 4b). This portion is found amounting to around 7-14% of the wood volume. The mean heartwood content excluding the soft core portion is found to be around 50% for both the age groups.

For *Eucalyptus grandis*, another fast growing tropical plantation species in Kerala, an average heartwood percentage of 52.5 is reported for 7-years-old and 66.4 for 9-year-old trees (Bhat *et al.* 1987).The variation of soft corewood content with height level is not uniform in all the trees studied. It showed no specific trend with height level in both the age groups (Table 13). It may depend upon other factors like heartrot, injury or decay etc. Bhumibhamon *et al.* (1992) found significant variation among 5-year-old trees of *A. mangium* from 7 seed sources. The branchwood was found to have more soft core portion. The effective heartwood content of branch wood is found to be lower than that in the stem wood, the average value is around 28% (Table 15).

4.4.5. Shrinkage

The variation in the mean values of shrinkage with tree height was not very large and did not show any uniform trend (Fig. 5), whereas between tree variations are large (Tables 14. 16. 17 and 18).Table 19 gives the consolidated picture of shrinkage in the radial as well as tangential direction from green to air-dry, air dry to oven-dry and from green to oven-dry conditions. The tangential shrinkage is found to be higher than radial shrinkage in both the age groups in all the three moisture conditions. Material from older trees had high radial shrinkage compared to younger trees whereas tangential shrinkage was low for the former (Table 19).Shrinkage in the green to air-dry condition in the radial direction is in the range of 0.6-2.0%, whereas that in the tangential direction is 0.6-7.8%; the mean values are 1.1 and 3.7% respectively. Salleh and Wong (1991)reported a green to air-dry shrinkage of 6.4% (tangential)and 2.7% (radial).Slightly lower values are recorded by Ong (1985). 2.6% for tangential and 1.4% for radial directions in the case of green to air-dry shrinkage. The green to oven-dry shrinkage values reported for teak wood are 2.3% (radial) and 4.8% (tangential) (Nazma *et al*, 1981). whereas the corresponding values for mangium wood of 10 years age, as is revealed from Table 19 are 3.2% (radial)and 4.7% (tangential).The shrinkage values for both the species are in a comparable range. The present data shows that the wood exhibits only normal shrinkage and is a fairly stable timber when compared with the shrinkage values of other common tropical trees grown in this region (Nazma *et al*, 1981).

Table 13. Variation of heartwood percentage with tree height

Tree No.	Heartwood % including pith						Pith %						Effective heartwood % excluding pith
	Height level						Height level						
	25%	50%	75%	Top	Mean	CV(%)	25%	50%	75%	Top	Mean	CV(%)	
Age : 8 years													
1	58.8	55.5	58.5	61.1	58.5	3.9	10.6	8.2	8.0	6.5	8.3	20.4	50.2
2	75.6	73.6	71.9	58.0	69.8	11.5	2.5	1.6	5.0	1.8	2.7	58.0	67.1
3	72.1	70.4	70.0	66.5	69.8	3.4	2.0	3.5	7.9	5.8	4.8	54.0	65.0
4	54.0	54.2	52.2	47.3	51.9	6.2	3.7	15.7	24.2	20.4	16.0	55.7	35.9
5	63.7	60.0	64.5	64.3	63.1	3.3	10.5	35.5	43.1	53.9	35.8	51.5	27.3
Mean	64.8	62.7	63.4	59.4	62.6		5.9	12.9	17.6	17.7	13.5		49.1
CV(%)	13.9	14.0	12.9	12.6	12.3		73.3	106.6	91.6	121.1	99.6		35.7
Age : 10 years													
6	62.5	58.4	45.5	41.5	52.0	19.3	7.5	6.5	6.0	3.9	6.0	25.3	46.0
7	66.0	58.1	47.9	56.5	52.1	13.0	3.9	8.7	7.5	9.4	7.4	23.1	49.8
8	61.8	54.9	55.0	62.9	58.7	7.3	2.5	11.5	9.5	8.8	8.1	48.0	50.6
Mean	63.4	57.1	49.5	53.6	54.3	-	4.6	8.9	7.7	7.4	7.2	32.1	48.8
CV(%)	3.5	3.4	10.0	20.5	7.1	-	56.1	28.2	22.9	40.8	14.9	42.9	5.0

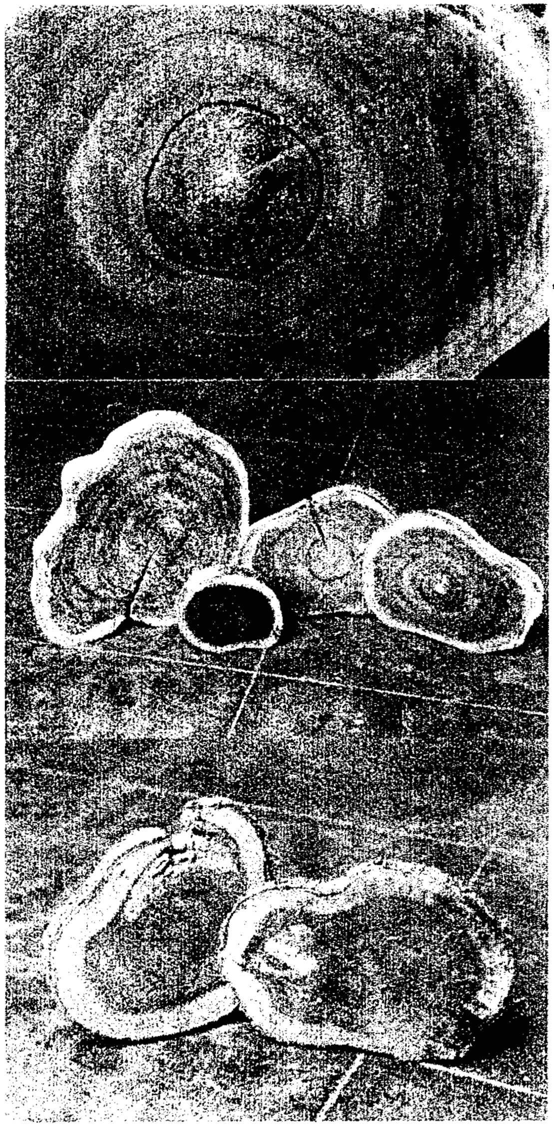

Fig. 4. A

Fig. 4. B

Fig. 4.A & B Cross sectional discs of *Acacia mangium* wood

Fig. 4 A. Showing the sap wood, heart wood and the soft central portion

Fig. 4 B. Showing the portion of the soft central core detached while drying. Note the termite attack within heart wood

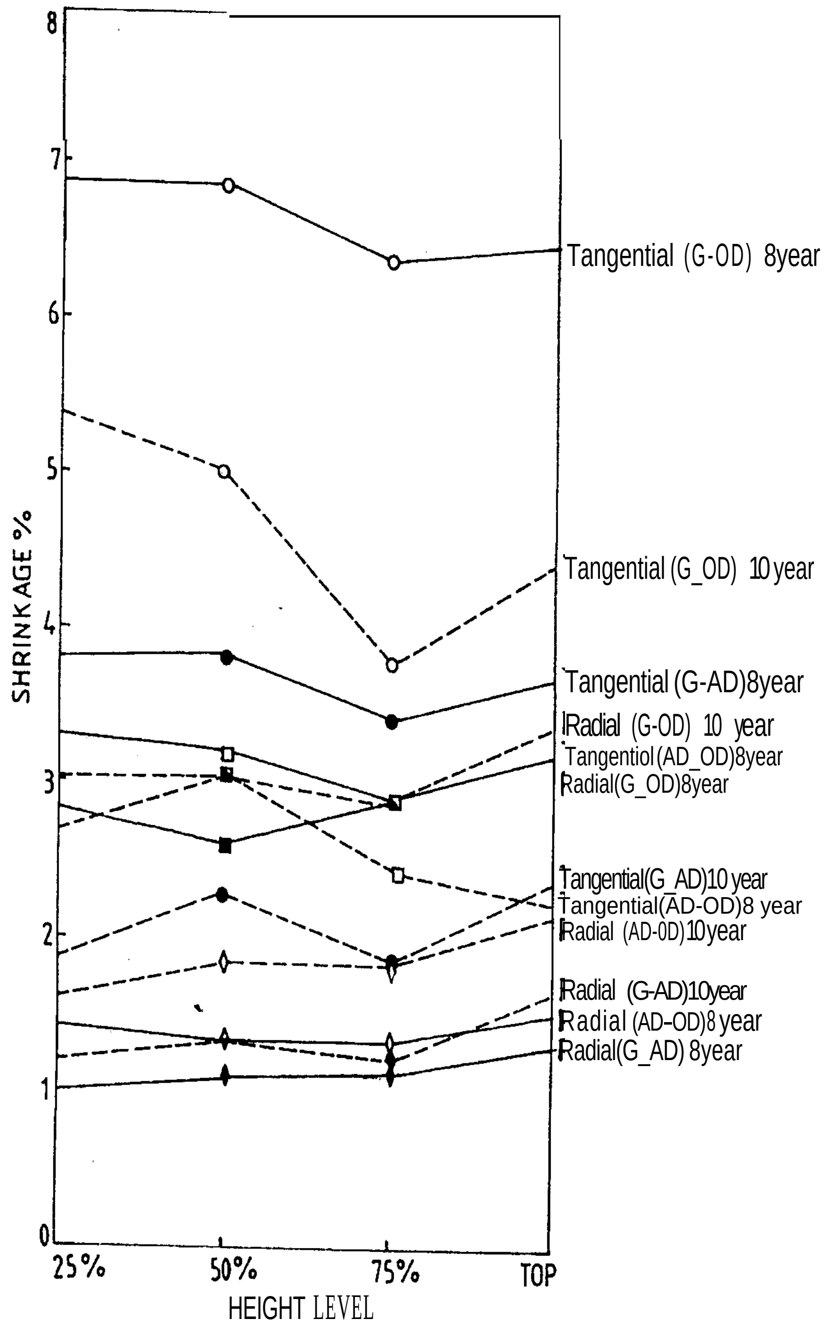

Fig.5. Variation of shrinkage **with** height level

Table 14. Within tree variation of shrinkage (%) of 8 and 10 years old *Acacia mangium* trees

Height level	Green-Air dry		Air dry-Oven dry		Green-Oven dry	
	Radial	Tangential	Radial	Tangential	Radial	Tangential
Age : 8 pears'						
25%	1.0	3.8	1.4	3.3	2.8	6.9
50%	1.1	3.8	1.3	3.2	2.6	6.9
75%	1.1	3.4	1.3	2.9	2.9	6.4
TQP	1.3	3.7	1.5	3.2	3.2	6.5
Mean	1.1	3.7	1.4	3.2	2.9	6.7
CV(%)	11.4	5.1	6.8	5.4	8.6	3.9
Age : 10 years**						
25%	1.1	1.6	1.9	2.8	3.0	5.4
50%	1.2	1.8	2.2	3.0	3.0	5.0
75%	1.1	1.9	1.7	2.7	2.8	3.8
Top	1.4	2.4	2.1	2.3	3.5	4.5
Mean	1.2	1.9	2.0	2.7	3.1	4.7
CV(%)	11.8	17.9	11.1	10.9	9.6	14.7

*Mean of 5 trees
**Mean of 3 trees

Table 15. Physical properties of branch wood and branch bark of 8-year-old *Acacia mangium* wood (CV(%) values are given in brackets)

Property	Tree No.1		Tree No.2		Pooled Mean
	Mean*	Range	Mean**	Range	
Wood density(kg/m^3)	547.5 (9.5)	479.2-667.2	593.3 (5.0)	542.4-648.8	570.4
Bark density (kg/m^3)	628.2 (9.3)	515.2-733.3	622.4 (5.0)	573.0-673.6	625.3
Heartwood % including the soft core portion	53.8 (26.1)	36.9-82.9	38.9 (36.8)	12.0-63.4	46.4
Pith % (soft central core portion)	17.9 (41.2)	6.0-31.9	18.8 (36.5)	6.6-26.7	18.4
Effective heartwood % excluding the soft core portion	35.9 (38.1)	17.3-60.2	20.1 (48.2)	0.0-37.4	28.0
Bark thickness (cm)	0.38 (16.5)	0.28-0.50	0.29 (25.5)	0.20-0.40	0.34
Bark % by volume	14.3 (17.0)	9.6-18.7	22.6 (13.7)	17.2-27.2	18.5
Bark % by weight	11.9 (11.2)	9.8-19.2	15.0 (13.1)	11.6-18.2	13.5
MC of wood (%) at test condition	57.8 (11.5)	45.1-70.5	61.1 (4.7)	57.0-64.6	59.5
MC of bark (%) at test condition	50.1 (28.2)	33.3-87.5	46.1 (34.1)	37.1-63.8	48.1

*n=18
**n=13

Table 16. Green to air-dry shrinkage (%) - Variation between trees

Tree No.	Radial shrinkage (%)			Tangential shrinkage (%)		
	Mean	Range	CV (%)	Mean	Range	CV (%)
Age : 8 years						
1	1.56	1.12-2.01	23.9	6.64	5.57-7.78	13.7
2	1.31	1.10-1.52	13.5	4.30	3.91-5.09	12.4
3	1.20	1.09-1.28	7.7	3.44	2.97-3.86	11.6
4	0.87	0.77-1.03	13.4	2.98	2.64-3.54	13.4
5	0.68	0.64-0.71	4.6	0.92	0.64-1.18	24.0
Mean	1.12	0.64-2.03		3.66	0.64-7.78	
CV(%)	31.3			56.8		
Age : 10 years						
6	1.22	1.16-1.27	3.7	1.80	1.21-2.27	24.4
7	0.91	0.66-1.30	30.7	1.90	1.67-2.36	16.4
8	1.43	1.09-1.71	17.9	1.96	1.40-3.06	38.2
Mean	1.19	0.66-1.71		1.89	1.21-3.06	
CV(%)	22.0			4.3		

Table 17. Air-dry to oven-dry shrinkage (%) Variation between trees

Tree No.	Radial shrinkage (%)			Tangential shrinkage (%)		
	Mean	Range	CV(%)	Mean	Range	CV(%)
Age : 8 years						
1	1.15	0.99-1.38	14.4	2.69	2.39-3.60	10.3
2	0.96	0.77-1.31	26.0	2.85	2.60-3.30	10.9
3	1.37	1.14-1.65	13.6	3.95	3.58-4.12	6.3
4	1.31	1.16-1.58	14.3	3.61	2.81-4.03	15.8
5	2.19	1.89-2.55	12.5	2.63	2.37-2.83	7.3
Mean	1.43	0.77-2.55		3.15	2.37-4.12	
CV(%)	34.9			18.9		
Age : 10 years						
6	2.06	1.50-2.79	26.1	2.78	2.56-3.03	8.2
7	1.89	1.61-2.28	16.0	2.91	2.51-3.25	10.9
8	1.91	1.55-2.41	19.7	2.38	1.55-3.48	33.8
Mean	1.95	1.50-2.79		2.69	1.55-3.48	
CV(%)	4.8			10.3		

Table 18. Green to oven-dry shrinkage (%)- Variation between trees

Tree No.	Radial shrinkage (%)			Tangential shrinkage (%)		
	Mean	Range	CV(%)	Mean	Range	CV(%)
Age : 8 years						
1	2.70	2.47-3.12	11.1	9.12	8.06-9.97	8.7
2	2.25	2.03-2.82	16.9	7.03	6.73-7.60	5.5
3	2.55	2.41-2.78	5.5	7.25	6.84-7.60	4.3
4	2.17	1.95-2.59	13.8	6.48	5.37-7.39	12.9
5	2.86	2.58-3.17	8.3	3.53	3.46-3.59	1.6
Mean	2.51	1.95-3.16		6.68	3.46-9.97	
CV(%)	11.7			30.3		
Age : 10 years						
6	3.34	3.08-3.49	5.3	4.16	3.44-5.75	26.3
7	2.93	2.44-3.64	17.4	4.51	4.00-5.00	11.1
8	2.97	2.51-3.59	15.5	5.41	3.20-7.69	34.0
Mean	3.08	2.44-3.64		4.69	3.20-7.69	
CV(%)	7.3			13.7		

Table 19. Mean values of shrinkage (%) of *Acacia mangium* wood

Condition of wood	Radial shrinkage (%)	Range	CV (%)	Tangential shrinkage (%)	Range	CV (%)
Age : 8 years						
Green to air-dry	1.1	0.64-2.03	31.3	3.7	0.64-7.78	56.8
Air-dry to oven-dry	1.4	0.77-2.55	34.9	3.2	2.37-4.12	18.9
Green to oven-dry	2.5	1.95-3.17	11.7	6.7	3.46-9.97	30.3
Age : 10 years						
Green to air-dry	1.2	0.66-1.71	22.0	1.9	1.21-3.06	4.3
Air-dry to oven-dry	2.0	1.50-2.79	4.8	2.7	1.55-3.88	10.3
Green to oven-dry	3.2	2.44-4.98	14.2	4.7	3.20-7.69	13.7

4.4.6. Mechanical properties

Table 20 shows the variation of MOR, MOE and MCS with tree height. As can be seen from the table, within tree variation of MOR ranges from 77-130 N/mm^2. whereas MOE ranges from 7-13kN/mm^2. MCS has a range of 26-64 N/mm^2. All these values are for the material tested at 8% MC. The mean value of wood density at test condition was around 600 kg/m^3.

Table 21 shows the variation of mechanical properties between trees when samples tested at a mean moisture content of 8% and density around 540 kg/m^3. The mean value of MOR, 99 N/mm^2 obtained at 8% MC, when corrected for air-dry moisture content (12%),by applying the formula suggested by Sekhar and Rajput (1968). MOR will be around 66 N/mm^2. Similarly the mean MOE value after applying the correction will be 6.1 kN/mm^2 and MCS 30.4 N/mm^2. Wang *et al*(1989) reported MOR value of 74.5 N/mm^2 and 9.9 kN/mm^2 MOE for mangium trees of lower age (lower than 12 years). For 12-year-old trees, Razali and Hamami (1993) reported a mean MCS 43.4 N/mm2. All the values of mechanical properties obtained in the present study are in a lower range as compared to teak as well as rubber wood; may be due to a lower age of 8 years.

The average values of the mechanical properties reported for teak wood in air-dried condition is 96 N/mm^2 for MOR. 12 kN/mm2 for MOE and 53 N/mm^2 for MCS (Nazma *et al.,* 1981).

The strength values of rubber wood at 12% MC, as reported by Gnanaharan and Dhamodaran (1993) are in a much higher range; the average values are 98.4 N/mm^2. 15.7 kN/mm^2 and 52.7 N/mm^2 for MOR, MOE and MCS respectively. The comparison shows that mechanical properties of lower aged *Acacia mangium* are inferior to that of rubber wood of age around 35 years. However, Mohd. Zin *et al*(1991) indicated that the strength properties of *A. mangium* are not seriously affected by tree age.

4.4.7. Sawn timber recovery

It can seen from Table 22 that the sawn timber recovery varies from 16 to 80.5%. The pooled mean sawn timber recovery is around 45%. Chan (1983) reported a low recovery rate of 37-40°/o for the sawn timber of *A. mangium* The low recovery rate obtained in the present study may be due to the presence of comparatively large soft core portion and heart rot. According to Peh and Khoo (1984). no problems were associated with the sawing of the wood.

Table 20. Variation of mechanical properties of 8-year-old *Acacia mangium* wood (at 8%MC) with tree height

Position	Mean MOR (N/mm^2)	Range	CV (%)	Mean MOE (kN/mm^2)	Range	CV (%)	n	Mean MCS (N/mm^2)	Range	CV (%)	n	Mean density (kg/m^2)
Base	115.8	95.8-129.9	9.9	10.1	8.8-11.6	11.5	9	56.2	51.9-64.3	7.8	9	680.4
Middle	103.1	86.6-123.1	12.7	10.7	7.9-12.6	15.3	9	45.7	40.0-53.3	10.2	10	548.8
Top	107.6	76.8-125.5	14.5	10.0	7.1-12.0	15.4	10	44.9	26.1-53.8	21.6	6	575.8
Mean	108.8	76.8-129.9		10.3	7.1-12.6		28	48.9	26.1-64.3		25	601.7
CV(%)	5.9			3.7				12.9				11.6

Table 21. Between tree variation of mechanical properties of 8-year-old *Acacia mangium* wood (at 8%MC)

Position	Mean MOR (N/mm^2)	Range	CV (%)	Mean MOE (kN/mm^2)	Range	CV (%)	n	Mean MCS (N/mm^2)	Range	CV (%)	n	Mean density (kg/m^2)
1	77.2	59.9-101.8	24.2	6.9	4.9-9.7	29.8	5	39.1	35.0-46.1	11.2	9	482.3
2	107.9	74.4-145.4	16.9	9.6	6.4-15.0	24.5	27	47.0	29.3-61.7	15.8	27	587.2
3	108.8	76.8-129.9	13.0	10.2	7.1-12.6	14.1	28	49.3		16.0	25	601.7
4	100.3	82.6-118.4	13.9	9.5	7.6-10.8	13.8	6	46.8	37.8-58.9	13.2	11	484.4
Mean	98.6	59.9-145.4		9.1	4.9-15.0		66	45.6	26.7-64.3		72	538.9
CV(%)	14.9			16.1				9.8				12.0

Table 22. Sawn timber recovery (%)

Tree No.	Volume of utilizable timber obtained (m^3)	Volume of sawn timber obtained (m^3)	Sawn timber recovery (%)
Age : 8 years			
1	0.1474	0.0525	35.6
2	0.7212	0.4413	61.2
3	0.1938	0.1560	80.5
4	0.0780	0.0281	36.0
5	0.0226	0.0036	15.9
Mean	0.2326	0.1363	45.9
CV(%)	120.7	132.1	54.8
Age : 10 years			
6	0.0561	0.0250	44.5
7	0.1587	0.0653	41.2
8	0.1420	0.0571	41.2
Mean	0.1189	0.0491	42.3
CV(%)	46.3	43.4	4.5
		Pooled mean recovery %= 44.5	
		CV(%) = 43.0	

4.4.8. Observations on biodegradation

Even though detailed studies on the biodegradation of this wood are not carried out in the present study, samples of heartwood and sapwood were exposed to outdoor conditions for about more than six months to observe their performance. Termites were found to attack the heartwood (Fig. 4b). The sapwood was found attacked by insect borers. More severe fungal problems like, sapstain or decay were not found. *Mangium* timber is generally regarded as non-durable (Awang and Taylor, 1993). Hence it is advisable to treat the timber with preservative chemical.

5. CONCLUSIONS

Acacia mangium has been planted in most districts of Kerala in private farms either in conjunction with other farm crops or as pure plantations of varying sizes. In forest land this has not been raised as an important species.

The tree grows continuously throughout the year and the growth rate is related to soil moisture. The growth rate varies widely with locality. Mean annual diameter at breast height (DBH)increment varies between 3.6-5.7 cm and the mean annual height increment between 1.8-6.1 m.

A relationship between diameter and tree height is arrived at, which can be used to predict the height of trees from DBH values. The relationship is:

Log (Height) = 0.708 + 0.716 Log (DBH)

The mean GBH is in the range of 18 cm at the age of 1 year to 111 cm at the age of 10 years. The MAI in GBH is around 11 cm at the age of 10 years and the MAI in height at this age is around 2.6 m. The mean height growth vaned from 3.8-9.1 m at the age of 1 year to 33.8 m at the age of 12 years. The MAI in GBH and height growth shows that the species is fast growing in good sites and slow growing in poor infertile sites.

The wood is light, the average basic density is around 500 kg/m^3. The bark proportion is found around 13-14% by volume and 10-11% by weight. Bark is found heavier than wood. All these properties are more or less in the same range as those reported for other common Kerala grown timbers. The effective heartwood content, excluding its soft core was found to be around 50%. The central core portion which occupies comparatively larger extent (7-14% of the wood volume) was found to contain reaction wood, often getting detached from the rest of the wood while drying. As inclusion of such portion of wood is undesirable for many utilisation purposes, mean sawn timber recovery obtained is only around 45%. The wood exhibits only normal shrinkage and is fairly stable when compared with other species growing in Kerala. The timber possesses moderate strength properties. However, for comparison purpose, the timber from 8-year-old trees is found inferior to rubber wood in its strength properties. These points with regard to the wood properties may be carefully considered while planning for its extensive or large scale plantation programmes. Except in the case of its growth, it appears to be not at all a 'wonder wood, as claimed by many of the private sector planting tions.

From the assessment of the potential of the timber from 8 and 10-year-old trees it becomes clear that for better physical and mechanical properties required for specific end-uses, it is advisable to harvest the trees at a later age. As trees of higher age group are not currently available in Kerala. studies are needed in the future in order to assess the potential of this timber including the heart-rot problem.

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Appendix 1

Proforma for collection of details of Acacia rnangium plantations in different Panchayaths of Kerala

KERALA FOREST RESEARCH INSTITUTE, PEECHI-680 653

DETAILS OF 'MANGIUM' CULTIVATION IN DIFFERENT PANCHAYATS OF KERALA

This information is needed for an ongoing research project. In some cases you may not be in a position to provide accurate information. Therefore provide whatever information that can be provided by you and your staff.

1. Name and Address of the Krishibhavan

   PIN :

2. Name of the Panchayat in which : the office is located

3. District in which located

4. Details of Acacia mangium ('Mangium')(For Project KFRI 228/94: 'Status of Acacia mangium in Kerala')

4.1. Is Acacia mangium ('MANGIUM') : (Please tick mark) grown within your Krishibhavan area YES / NO

4.2. If 'YES',when was it first planted (Please round off)
1980/1981/1982/1983/1984/1985/1986/1987/1988/1989/1990/
1991/1992/1993/1994/1995/1996

4.3. If you are aware of cultivation of Acacia mangium in plantations of atleast 10 cents, kindly provide details

Location	Year of planting	Total area (acre, cents)	Name and Address of the owner

Name
Designation :
Signature :

Date:

Appendix 2. District-wise number of Krishi Bhavans and Agricultural Units in

Sl. No.	Districts	No. of Krishi Bhavans	No. of Agricultural Units		Total	Remark
		Panchayat	Municipality	Corporation		
1.	Kasargode	37	2	-	39	
2.	Kannur	85	2	-	87	
3.	Wayanad	25	-	-	25	
4.	Kozhikkode	77	1	1	79	
5.	Malappuram	95	4	-	99	
6.	Palakkad	91	3	-	94	
7.	Thrissur	98	7	-	105	
8.	Ernakulam	86	7	1	94	
9.	Idukki	51	1	-	52	
10.	Kottayam	73	4	-	77	
11.	Alappuzha	73	5	-	78	Including 6 offices in Kallada Irrigation Project
12.	Pathanamthitta	59	2	-	61	Including 15 offices in Kallada Irrigation Project
13.	Kollam	83	3	-	86	Including 6 offices in Kallada Irrigation Project
14.	Thiruvananthapuram	84	4	1	89	
	Total	1017	45	3	1065	

Appendix 3. Measurements of girth at breast height (GBH) and diameter at breast height (DBH) of *A. mangium* trees sampled .

Age at measurement	Growth period		No. of trees obaserved	Mean GBH (cm)	Mean DBH (cm)	MAI in DBH (cm)	Locality
	Planting year	Observation year					
1	1995	1996	66	7.56	2.41	2.41	Angamali
1	1994	1995	1	28.00	8.91	8.91	Arch Bishop House, Pattom
1	1995	1996	110	13.86	4.41	4.41	Parathode
1	1995	1996	4	14.50	4.62	4.62	Manthuka
1	1995	1996	37	25.44	8.10	8.10	Thodupuzha (Muthalakodam)
2	1994	1996	221	10.85	3.45	1.68	Angamali
2	1993	1995	1	38.50	12.25	6.13	Arch Bishop House, Pattom
2	1994	1996	1	34.00	10.82	5.41	Arch Bishop House, Pattom
2	1993	1995	16	31.88	10.15	5.08	Bathany's Estate,Tvm.
2	1994	1996	32	18.16	5.78	2.89	CRL, Kochi
3	1992	1995	18	35.36	11.26	3.75	Arch Bishop House, Pattom
3	1993	1996	1	48.80	15.53	5.18	Arch Bishop House, Pattom
3	1992	1995	2	51.50	16.39	5.46	Bathany's Estate, Tvm.
3	1993	1996	16	44.38	14.13	4.71	Bathany's Estate, Tvm.
3	1993	1996	60	44.91	14.30	4.76	Kanjirappilly
3	1993	1996	10	46.60	14.83	4.94	Mooledam
3	1993	1996	60	51.70	16.46	5.49	Parathode
3	1993	1996	11	26.35	8.39	2.80	Poovarany (Pala)
4	1991	1995	45	51.80	16.49	4.12	Arch Bishop House, Pattom
4	1992	1996	18	47.28	15.05	5.02	Arch Bishop House, Pattom
4	1991	1995	22	60.34	19.10	4.78	Bethany's Estate, Tvm.

Appendu 3 contd....

Appendix 3 contd ....

Age at measurement	Growth period		No. of trees obaserved	Mean GBH (cm)	Mean DBH (cm)	MAI in DBH (cm)	Locality
	Planting year	Observation year					
4	1992	1996	2	64.30	20.47	5.12	Bethany's Estate, Tvm.
4	1992	1996	9	29.61	9.43	2.36	Kanjirappilly
5	1991	1996*	45	56.98	18.14	3.63	Arch Bishop House, Pattom
5	1990	1995	19	82.18	26.16	5.23	Bethany's Estate, Tvm.
5	1991	1996	22	68.69	21.86	4.37	Bethany's Estate, Tvm.
5	1991	1996	12	70.96	22.59	4.52	Paranthal
5	1991	1996	7	63.00	20.05	4.01	Manthuka
5	1991	1996	41	24.85	7.91	1.58	Mundathikode
6	1989	1995	5	102.10	32.50	5.41	Arch Bishop House, Pattom
6	1989	1995	3	90.83	28.91	4.82	Bethany's Estate, Tvm.
6	1990	1996	19	87.51	27.86	4.64	Bethany's Estate, Tvm.
6	1991	1997	1	98.30	-	-	Multitier KFRI Type II Quarters
7	1989	1996	5	109.80	34.95	4.99	Arch Bishop House, Pattom
7	1989	1996	3	99.00	31.51	4.50	Bethany's Estate, Tvm.
7	1989	1996	8	91.63	29.17	4.17	Kanjirappilly
7	1989	1996	3	99.67	31.76	4.54	Paranthal
8	1988	1996	8	94.38	30.04	3.76	Thiruvalla
9	1986	1995	4	107.25	34.06	3.79	Arch Bishop House, Pattom
10	1986	1996	4	111.78	35.58	3.56	Arch Bishop House, Pattom
11	1984	1995	1	150.50	47.91	4.36	Arch Bishop House, Pattom
12	1984	1996	1	160.00	50.93	4.24	Arch Bishop House, Pattom
15	1982	1997	1	146.50			KFRI Type III Quarters

* see Table 4 also

Appendix 4. Diameter at breast height (DBH) (cm) and height (m) data subjected to Simple Linear Regression (SLR) analysis

Sl. No.	DBH	Ht	Sl. No.	DBH	Height
1	11.2955	14.0	44	19.5682	22.1
2	14.6364	14.0	45	21.1591	20.6
3	24.1818	22.5	46	8.4636	8.4
4	21.4773	21.5	47	7.9545	8.4
5	23.7045	21.5	48	6.2364	7.8
6	25.7727	24.5	49	5.5682	7.0
7	47.8864	31.5	50	4.7409	8.4
8	33.5682	21.0	51	6.2364	7.2
9	33.5682	21.0	52	4.9000	7.1
10	15.1136	15.0	53	5.4091	8.1
11	13.8409	14.6	54	2.4500	4.4
12	28.4773	20.5	55	3.1818	5.4
13	8.9091	12.0	56	5.4091	8.0
14	11.4545	9.5	57	7.1273	8.0
15	20.5227	13.5	58	4.7727	5.9
16	14.6364	12.5	59	4.4545	5.3
17	8.7500	8.0	60	3.5955	4.3
18	25.9318	15.5	61	2.6727	4.3
19	30.7045	19.0	62	2.8000	4.5
20	29.1136	18.0	63	3.5000	4.6
21	7.1591	7.0	64	2.9909	4.7
22	7.4773	6.5	65	3.0227	4.5
23	22.4318	18.0	66	1.5909	3.2
24	12.2500	15.0	67	2.9909	4.4
25	23.5455	19.0	68	4.8364	5.3
26	19.4091	21.0	69	3.3091	4.2
27	30.7045	21.0	70	2.6409	3.5
28	20.6818	18.0	71	2.8955	3.5
29	11.1364	11.5	72	1.6227	2.8
30	34.5227	21.0	73	2.0682	3.2
31	31.5000	26.5	74	2.1000	3.3
32	18.9318	23.0	75	2.1636	3.3
33	39.7727	29.0	76	1.6864	2.7
34	15.2727	13.0	77	1.8136	2.8
35	28.3182	15.5	78	3.4045	4.5
36	34.3636	14.0	79	22.2091	20.4
37	11.9318	13.6	80	48.7000	33.0
38	13.6818	16.6	81	35.3000	26.0
39	19.8864	17.1	82	38.2000	21.6
40	17.6591	17.1	83	41.1000	19.1
41	15.3682	21.6	84	31.5000	47.9
42	20.8409	22.6	85	21.0000	34.5
43	28.9545	27.1			

Appendix 5

Simple linear regression (SLR) analysis of DBH and height data

The regression equation is
LOGDBH = 0.708 + 0 .71 6 LOGDBH

Predictor	Coef	Stdev	t-ratio	p
Constant	0.70849	0.05707	12.41	0.000
LOGDBH	0.71629	0.02240	31.98	0.000

s = 0.2043 R-sq = 92.5% R-sq(adj) = 92.4%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	1	42.671	42.671	1022.68	0.000
Error	83	3.463	0.042		
Total	84	46.134			

Unusual Observations

Obs.	LOGDBH	LOGHT	Fit	Stdev.Fit	Residual	St.Resid
36	3.54	2.6391	3.2420	0.0346	-0.6029	-3.00R
41	2.73	3.0727	2.6656	0.0238	0.4071	2.01R
83	3.72	2.9497	3.3702	0.0378	-0.4205	-2.09R
84	3.45	3.8691	3.1797	0.0332	0.6894	3.42R
85	3.04	3.5410	2.8892	0.0271	0.6517	3.22R

R denotes an obs. with a large st. resid.

MTB > PLOT C13 Cl4

```
      4.0+
         -                                                *
 LOGHT   -                                          *
         -                                                    * **
         -                                         **  2 ** *
      3.0+                                      *  2 32  *22***
         -                                   ** * * 2*  *2
         -                                  2  3*   *       *
         -                              *  *
         -                     *       **   *
      2.0+                      *2*2 2  *
         -                     *      *
         -              *2*2  * *
         -            ** ***
         -      *  *2  **
      1.0+      2 *
         -
           --------+---------+---------+---------+---------+--------LOGD
                 0.70      1.40      2.10      2.80      3.50
```