SCREENING OF TREE SPECIES FOR GROWTH BEHAVIOUR, BIOMASS AND WOOD PROPERTIES

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled " **Screening of Tree Species for Growth behaviour, Biomass and Wood properties** " is a bonafide record of research done by me during the research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society to me.

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Dedicated to my parents, sisters, maternal uncles and their family.

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Introduction

INTRODUCTION

The state of Kerala is endowed with high rainfall and most favourable humidity conditions which makes the way for growth of numerous tree species. Tropical rain forests with maximum species diversity of flora and fauna are in abundance in the state. Natural forests are highly depleting due to forest fires, encroachments, unscientific management, soil erosion, developmental activities, human interference and other man made activities. Even when so many methods are being developed to improve the natural forests, it would not be possible to meet the increasing demand for food, fuel, fibre and timber. To meet this demand, the degraded forest, marginal land, village common land, strips on sides of roads, canals, railway, rivers and peripheries of agricultural fields could be utilized for planting of trees. For this purpose choice of species is an important criteria. The proper choice of tree species at a particular place which can yield enormous benefits is the need of the hour.

Planting of quick growing multipurpose tree species which can meet the various needs of the community, is of great importance in social/farm forestry system. Trees will also help in arresting the deterioration of the environment and improving the quality of life of people. To achieve the above objectives, a thorough knowledge of growth habit of various tree species is inevitable. Biomass produced by tree species is also important for carbon sequestration and these trees should be useful for small timber purpose also. So the wood properties and biomass production should be given importance in the choice of species. In addition to fodder values, leaf biomass of tree species are rich sources of nutrients which are essential for plant growth. Incorporation of leaf litters will improve the nutrient status of the soil without any deleterious effects on physical or chemical properties. Hence, selection of tree species with leaf biomass rich in nutrients is another need of the day.

Much studies are not done on this aspect in Kerala, particularly with regard to tropical forest tree species. At the same time, this information is very essential for the proper selection of forest tree species for extensive planting programme under social/agroforestry programmes. Fast growing species could be further multiplied for general afforestation programmes also.

With this objective, the present series of studies were undertaken in the College of Forestry, Kerala Agricultural University, Vellanikkara to generate some valuable data based on which fast growing species having better wood qualities and leaf nutrient content could be screened among the various tree species already planted and maintained in the College arboretum. These species could be further multiplied in the college nursery for large scale production of seedlings for distribution to farmers for farm forestry and general afforestation programmes.

Review of Literature

REVIEW OF LITERATURE

It is a very well known fact that for commercial extensive planting, good quality planting materials have to be produced at an economic rate. This can be achieved by considering several factors. Selection of species is the priority factor which needs to be considered besides soil characters, climate and so on. Hence, there is a need to study the performance of different species at different sites. Some of the important studies done to evaluate tree species under various agro-ecological conditions are reviewed here under :

2. 1. Evaluation of tree species for growth behaviour

The superiority of *Michelia champaca* and *Grevillea robusta* under Dehradun condition in terms of height and biomass production was reported by Art and Mark (1971). The annual increment in height, girth and branching of *Leucaena leucocephala* was evaluated in Kanpur by Mishra and Srinivasa (1980) and this species was identified as a fast growing multipurpose tree species based on the growth rate compared to other types.

Yadav (1981) observed that Casuarina recorded a height of 6.9 m and a diameter of 4 cm by the end of third year, while by the end of fourth year the respective figures were 9.1 m and 36 cm. Eucalyptus is found suitable for planting because of fast growing nature and suitability to poor sites. In this species, the height growth in early stages varied from 1 m to 2.6 m per year. The overall average mean annual increment recorded in India was 10 m/ha/year depending on site quality. The adaptive character and species choice in planting of trees in the farm land shelter belt of Pearl river delta revealed that the main factors affecting the growth of the species were soil acidity, salt content and water level. The optimum pH of soil was between 7 to 8 (Long and Xu, 1983).

Lahiri (1984) conducted studies on the growth behaviour of *Acacia mangium, Eucalyptus camaldulensis* and *Albizia falcataria* as influenced by soil nitrogen and phosphorous. Phosphorous significantly influenced the height growth of all the species, but nitrogen in general, was found to have no significant effect. Lahiri (1984) has reported that *Acacia mangium* possessed a height and girth of 2 m and 4 cm respectively within one year when planted on the lateritic tract.

Hocking and Ramprakash (1986) reported that growth of Casuarina in lateritic soils is poor and it prefers a soil with high organic matter, nitrogen and phosphorous. Potash in the soil is less important compared to the nitrogen level. Casuarina is a light demanding evergreen tree susceptible to drought and fire in the sapling stage.

Pandey *et al.* (1987) conducted some studies in *Eucalyptus sp.* and *Acacia auriculiformis* plantation in Bihar. Eucalyptus proved to be superior to Acacia. At the end of third year, it recorded a dbh of 34 cm and a height of 3.7 m only. However, with regard to biomass production, Acacia produced 16.4 mt from 1355 trees/ha, while Eucalyptus yielded only 11.9 mt from 1120 trees/ha. The average above ground biomass for Eucalyptus was reported to be 19 to 22 mt/ha in Karnataka.

A detailed study on the soil properties and their relationship with the growth of sandal in three areas of Karnataka has shown that physical and chemical properties of soil affected the height, girth and growth of seedlings. The maximum increment in height and girth of sandal was observed in alkaline soil compared to acidic soils (Jain and Rangaswamy, 1988).

Swaminathan (1988) conducted a study on the biomass production of the fast growing forestry species. Irrigation was provided twice a week by flooding. Among the 13 species studied in the experiment, *Albizia falcataria* has recorded maximum biomass while *Acacia auriculiformis* the minimum. He emphasized the fact that the forestry species have inherent potentiality in farm forestry planting programmes.

Bahuguna and Dhawan (1990) stated that tree species have to be selected according to climate and soil conditions prevalent in a particular area for social/ agroforestry planting programmes. They studied the growth performance of *Dalbergia* *sissoo, Eucalyptus grandis, Michelia champaca, Grevillea robusta, Bauhinia variegata* and *Bauhinia purpurea. Eucalyptus grandis* was reported to be superior in rate of growth, particularly in terms of height and girth compared to other species. The biomass production was also found to be significantly high in this species. A study was also conducted to compare the performance of three exotic fast growing tree species viz., *Casuarina equisetifolia, Acacia auriculiformis* and *Eucalyptus tereticornis* planted under social forestry strip plantation programme. At the end of third year, *Acacia auriculiformis* recorded a dbh of 45.6 cm followed by *Eucalyptus tereticornis* (38 cm) and *Casuarina equisetifolia* (62 cm). *Acacia auriculiformis* has been recommended for extensive strip planting programmes.

Studies done by Mzoma (1990) in Malawi revealed the superiority of *Acacia adsargens, Acacia auriculiformis, Albizia guachepele, Gliricidia sepium, Leucaena leucocephala* and *Senna atomaria* seedlings in terms of survival, height and girth. Field studies were conducted to evaluate the performance of *Prosopis juliflora* grown under irrigated and rainfed conditions. After two years of growth, the mean plant height and diameter was found to be 2.8 m and 137 cm respectively under irrigated condition as reported by Singh *et al.* (1990).

Sharma and Geyar (1990) studied the growth behaviour of *Acacia mollissima, Albizia lebbek, Bauhinia variegata, Celtis australis, Eucalyptus* sp., *Grevillea robusta, Grevillea optiva, Leucaena leucocephala* and *Robina pseudoacacia* seedlings. The study has been done to compare fifteen species of Acacia, planted in a statistically designed experiment. The height, bark moisture content, stomatal resistance and transpiration rate were recorded three year after planting. *Acacia auriculiformis* recorded best transpiration rate. All other parameters were also found to be highest in this species. This study also revealed that height is positively associated with bark moisture content and total chlorophyll content and negatively with transpiration. The growth rate of nodal cuttings of *Acacia mangium* was found poor compared to seedlings.

Johnkutty (1992) studied the growth evaluation of various tree species planted in the arboretum. Based on the study, species like *Indigofera teysmanii, Ceiba pentandra, Delonix regia, Trema orientalis* etc. were identified as fast growing species, while species like *Artocarpus incisa, Mangifera indica, Hydnocarpus whightiana* etc. were considered as slow growing species in terms of height. Species like *Ceiba pentandra, Trema orientalis, Bauhinia purpurea, Indigofera teysmanii* etc. recorded the highest diameter growth, while *Harpullea arborea, Dalbergia latifolia* etc. recorded the minimum diameter growth. Most of the species recorded maximum height and diameter increment during October.

Trials were carried out with 19 multipurpose tree species under rainfed conditions in red gravelly soils from June 1988 to June 1993 in range land at the National Research Centre for Agroforestry, Jhansi, U.P. The trees were planted as one year old saplings at 8 x 4m spacing, and a grass legume mixture of *Cenchrus ciliaris and Stylosanthes hamata* sown in the interspaces. The trees were pruned starting in the year 1991 at 50 and 75 per cent height. Based on survival, growth, leaf production and fuelwood yield, species like *Leucaena leucocephala, Albizia procera, Emblica officianalis, Dichrostachus cinererea, Albizia amara, Acacia nilotica, Dalbergia sissoo* and *Terminalia arjuna* were found to be more suitable for introduction into range lands to improve their production. *Leucaena leucocephala* obtained maximum leaf fodder and fuel wood yield at pruning height. Due to its regeneration capacity through root suckers, *D. cinererea* was found suitable for development of ravine lands in addition to rangeland as reported by Rai *et al.* (1995).

During the period from 1982 to 1995, species and provenance trials for 73 provenances of *Acacia* species have been carried out at the Forest Science Institute of Vietnam and its research centres located across the whole country. Among the species tested, *A. auriculiformis, A. mangium* and *A. crassicarpa* were reported to be most promising while *A. aulacocarpa* and *A. uncinnata* were reported to be inferior (Kha *et al.* 1996).

Gera *et al.* (1996) conducted a field screening trial of 17 multipurpose tree species grown in an acid soil of pH 6.3 to 6.7 in the Barha experimental area, Jabalpur, with the objective of identifying the species for afforestation, agroforestry and social forestry programmes for the semi arid regions of Madhyapradesh. The species evaluated were *Azadirachta indica, Bauhinia variegata, Eucalyptus tereticornis, Albizia procera, Emblica ofiicianalis, Pongamia pinnata, Gmelina arborea, Tectona grandis, Acacia nilotica, Acacia catechu, Dalbergia sissoo, Dendrocalamus strictus, Albizia lebbek, Acacia auriculiformis, Acacia benthamii* and *Leucaena leucocephala.* Height, collar diameter and survival were recorded after 6 and 30 months. The results suggested that *Gmelina arborea, Azadirachta indica* and *Leucaena leucocephala* were among the fastest growing species with maximum mean annual increment. *Acacia catechu, Albizia procera, Bauhinia variegata, Tectona grandis* and *Acacia benthamii* showed slow growth. *Tectona grandis* and *Gmelina arborea* were promising species for maximum survival. *Acacia auriculiformis* and *Bauhinia variegata* were poor adapted to the region on the basis of survival.

Sun and Dickinson (1997) conducted a trial to examine the suitability of tree species for both non saline and saline soils in the lower Burdekin region of dry tropical areas of Queensland and found that *Azadirachta indica, Eucalyptus camaldulensis, E. citriodora, E. maculata, E. pellita, E. raveretiana, Khaya senegalensis* and *Paulownia fortunei* recorded high survival and fast growth in terms of height and DBH on the non-saline site while *E. camaldulensis, E. drepenophylla, E. moluccana* and *E. raveretiana* performed better on the saline soil.

Gopikumar *et al.* (1998) studied the growth behaviour of forest tree species grown in the arboretum of Kerala Agricultural University, Vellanikkara with an objective of selecting fast growing species suitable for tropical area. About 50 tree species were included in this study. The results showed that *Albizia falcataria, Trema orientalis, Cassia renigera, Acacia auriculiformis, Macaranga indica, Delonix regia, Acacia mangium* and *Bridelia retusa* can be considered as fast growing in terms of height and girth. Hence, these species were recommended for intensive planting under agro/social forestry programmes.

Kumar *et al.* (1998) studied the biomass accumulation of nine multipurpose trees grown in Thiruvazhamkunnu, Kerala. Trees were felled at 8.8 years of age. Rate of biomass accumulation was highest for *Acacia auriculiformis* and least for *Leucaena leucocephala*

Tiwari *et al.* (1999) analyzed the growth behaviour of 39 species of multipurpose trees grown in the arboretum in Madhya Pradesh on sandy loam soil. Basal area and biomass were estimated from the height and gbh data. There was a wide range in growth among the species; the height varied from 5.04 to 16.4 m, gbh 22.67 to 89 cm; and mean annual increment for gbh from 1.13 to 4.70 cm. *Terminalia bellerica* and *Azadirachta indica* had a mean annual increment more than 4 cm and *Albizia lebbek, Anthocephalus chinensis, Terminalia arjuna* and *T.tomentosa* had a mean annual increment for gbh as 3 to 4 cm.

Girijapushpom (2000) conducted growth behaviour studies of 102 tree species planted in the arboretum of Kerala Agricultural University, Vellanikkara. Sixty percentage of the trees included in this study were found to be slow in growth in terms of height and girth increment. Species which were found as fast growing in terms of height were *Casuarina equisetifolia, Albizia falcataria, Delonix regia, Terminalia catappa* and *Cassia renigera* and in terms of girth were *Albizia falcataria, Delonix regia and Acacia mangium*. In general, based on the growth performance the species like *Albizia falcataria* and *Delonix regia* could be considered as the fast growing while *Dalbergia sissoo* and *Flourcourtia inermis* as the slow growing species under Vellanikkara condition.

Gopikumar (2000 a) conducted a study to compare the growth habit of four tree species and found that the total and monthly increment was maximum for *Albizia falcataria* compared to *Artocarpus hirsutus, Artocarpus heterophyllus* and *Erythrina indica*. A study was conducted in Gujarat by Jaimini and Tikka (2001) to evaluate the survival, growth and biomass production of 15 multipurpose tree species used for agroforestry in dryland agriculture. Results showed that *Azadirachta indica* had the highest survival rate. *Dalbergia sissoo* had the maximum height while collar diameter was maximum for *Acacia albida*. Crown spread was observed to be maximum for *Albizia lebbek*. *Azadirachta indica, Albizia lebbek, Acacia tortilis* and *Prosopis cineraria* were proved most promising multipurpose trees because of their growth and survival.

Maikhuri *et al.* (2000) conducted a study on the growth performances of ten, locally valued multipurpose species grown in district Chamoli of Uttaranchal. *Alnus nepalensis* and *Dalbergia sissoo* gave best growth performance in terms of survival, height, stem circumference, crown depth and width and number of branches.

Kumar *et al.* (2002) conducted a study on the growth rate convergence in teak trees from three sites in Karnataka. Results showed that growth rate compensation may not extend beyond the juvenile stage of tree. It also suggests that growth rates of similar aged trees were relatively constant beyond their juvenile stage. Naveed and Kumar (2003) assessed the performance of *Ailanthus triphysa* at different densities and fertilizer regimes in Kerala. and results showed that height, diameter, stand leaf area index, biomass production and volume yield were greater in 2m x 2m spacing. Repeated application of fertilizers at 1.2, 2.25 and 5.25 years after planting had little effect on biomass and volume yields.

An experiment was conducted in Faizabad, Uttar Pradesh to study the growth performance of 13 multipurpose tree species. Among the 13 species studied, *Casuarina equisetifolia, Eucalyptus hybrid, Dalbergia sissoo* and *Leucaena leucocephala* recorded conceivably better growth (Anon., 2002).

Goel and Behl (2004) studied the performance of three leguminous species viz., *Acacia farnesiana, A. nilotica* subspecies *cupressiformis* and *Cassia siamea* at three planting densities on a highly alkaline soil site. Study revealed that individual tree biomass was not affected by increasing plant density in case of *Acacia farnesiana* and *Cassia siamea. Acacia nilotica* subspecies *cupressiformis* on the other hand showed a negative response when planted in high density with respect to plant growth, survival and stand productivity. Jisha (2006) conducted a study to evaluate the growth performance of ten tree species under Vellanikkara conditions. The results revealed that species like *Casuarina equisetifolia, Terminalia tomentosa* and *Samanea saman* were found fast growing in terms of height and girth while *Pongamia pinnata* and *Tamarindus indica* showed lowest increment with regard to above growth parameters.

2.2. Evaluation of tree species for biomass production

Ponnammal and Gnanam (1988) evaluated the biomass production of seven tree species adapted to the semi arid conditions of south India. Greatest above-ground production was by *Leucaena leucocephala* (45.52 t/ha) followed by *Samanea saman, Erythrina variegata* and a local variety of *Leucaena leucocephala*, all of which produced about 30 t/ha while *Acacia auriculiformis, Adenanthera pavonina* and *Gliricidia maculata* produced much less than 30 t/ha. Biomass production potential of *Albizia lebbek* was evaluated by Roy (1988) under silvipasture system and found out average biomass production per tree was 164.8 kg, giving an annual production (at harvest) of 5.16 t/ha with a population of 300 trees/ha when sampled at nine year old.

A study was conducted for estimating biomass of eight species grown in Gujarat by Raj and Raj (1991). Maximum dry weight of biomass was recorded for *Albizia lebbek* (26.10t/ha) while the lowest was for *Tamarindus indica* (5.43 t/ha). Maximum mean dry weight of branch was observed for *Azadirachta indica* while the minimum was for *Tamarindus indica. Melia azedarach* was having the highest dry weight of twigs while *Cassia fistula* with the lowest. *Pithecellobium dulce* recorded the lowest stem bark weight. The highest extractable dry root biomass was produced by *Albizia lebbek* while *Cordia myxa* produced the lowest dry extractable root biomass. The maximum total mean dry biomass was recorded by *Albizia lebbek* and the poorest performance was observed for *Tamaridus indica* with respect to total dry biomass production.

Jha (1999) conducted studies on 18 month old seedlings of five fast growing tree species for evaluation of growth and biomass production in Bihar. The results indicated that on the basis of the maximum biomass production and growth, the most promising one to provide fuel wood and fodder in the region was *Leucaena leucocephala* followed by *Cassia siamea, Gliricidia sepium, Albizia lebbek* and *Millettia pinnata.* Biomass and net production were found to be best in *Azadirachta indica, Pongamia pinnata* and highest in *Dalbergia sissoo* when four species were planted at 2m x 2m spacing in a coalmine spoil in Madhya Pradesh (Singh and Singh, 1998).

Gopikumar (2000 a) conducted a study in Vellanikkara conditions to compare the biomass production of four multipurpose species. The results showed that *Albizia falcataria* produced highest biomass compared to *Artocarpus hirsutus, Artocarpus heterophyllus* and *Erythrina indica.* An experiment with 11 multipurpose tree species was conducted on red sandy loam soils in Andhra Pradesh by Rao *et al.* (2000). The results showed that *Dalbergia sissoo* yielded maximum biomass (214.6 t/ha) followed by *Leucaena leucocephala* (187.8 t/ha) and *Acacia auriculiformis* (162.4 t/ha). Maximum mean annual biomass production (MABP) was also maximum for *Dalbergia sissoo* (23.8 t/ha) followed by *Leucaena leucocephala* (20.9 t/ha) and *Acacia auriculiformis* (18.0 t/ha). Foliage yield was maximum for *Leucaena leucocephala* (16.8 t/ha) followed by *Acacia auriculiformis* (12.0 t/ha) and *Eucalyptus camaldulensis* (9.9 t/ha).

Jaimini and Tikka (2001) conducted a study to compare the biomass production of 15 multipurpose tree species grown in an agroforestry system in Gujarat. Among these, *Albizia lebbek* had the maximum trunk and branch weight while *Acacia nilotica* and *A. nilotica var. cupressiformis* had the minimum values for these attributes. The highest twig weight per tree was observed for *Dalbergia sissoo* while minimum for *Moringa oleifera.*

The clear felling of *Casuarina* at an age of 7 to 10 years yielded 120 tonnes ha^{-1} of firewood as reported by Hocking and Ramprakash (1986). Gurumurthi *et al.* (1984) observed a net primary production (NPP) of 30 tonnes ha^{-1} $year^{-1}$ for *Prosopis juliflora* and 38 tonnes ha^{-1} year for *Leucaena leucocephala.* In a comparative study of biomass productivity of *Acacia auriculiformis* and *Casuarina equisetifolia* in a five year old plantation, Kushalapa, (1987) found that *A. auriculiformis* gave a green yield of 81.05 t ha^{-1} while *Casuarina equisetifolia* yielded 68.9 t ha^{-1} .

Wang *et al.* (1991) assessed the biomass accumulation rates of five tropical tree species in a 5.5 year old plantation in Puerto Rico. *Casuarina equisetifolia* recorded the highest dry matter accumulation of 36.2 tonnes ha^{-1} $year^{-1}$. The respective figures for *Albizia procera, Eucalyptus robusta* , *Leucaena leucocephala* var.K8 and *L. leucocephala* var. Puerto Rico were 22.5, 12.18, 8.5 and 6 tonnes ha^{-1} $year^{-1}$ respectively. In another study, Singh and Gupta (1993) found that biomass production in *Eucalyptus hybrid* (26.74kg/plant), *Acacia auriculiformis* (6.49 kg/plant) at 7 years of age and *Emblica officinalis* (13.49 kg/plant) at nine years of age were higher compared to *Tectona grandis* (11.34 kg/plant) at 30 years of age.

Mishra and Nayak (2000) studied the biomass production in a nine year old energy plantation on bhabar tract of Himalayan foothills in Sirmour district of Himachal Pradesh. Above ground mean tree biomass estimated was highest for *Leucaena leucocephala* (34.76 kg) and lowest mean tree biomass per hectare for *Melia azedarach* was noticed (13.10 kg). Rana *et al.* (2001) assessed the biomass production in seven year old *Casuarina equisetifolia* plantations on sodic wasteland in Uttar Pradesh and found that the average stand biomass was 170.5 to 172 tonnes ha^{-1}.

Perez and Kanninen (2003) conducted a study on above ground biomass of *Tectona grandis* plantations in Costa Rica. Foliage dry biomass varied between 70 to 221 tonnes and total above ground biomass between 84 to 284 tonnes ha^{-1}. The studies conducted to estimate the biomass production in ten tree species under Vellanikkara conditions revealed that the maximum biomass was produced by *Terminalia tomentosa* (320 kg dry weight / tree) while minimum (15.92 kg / tree) by *Pterocarpus santalinus* .

2.2.1 Partitioning of biomass

The relative allocation of biomass or energy to various above ground parts is a decisive factor that reflects the success of an organism in an environment (Gadgil and Solbrig, 1972). The partitioning of dry matter between different components namely, leaf, reproductive parts, bole, branchwood and root is a matter of considerable importance in agroforestry too. This is important in a multipurpose tree production system, as some of these components are harvested, periodically or at a stretch, and some others are returned to the system. In this context, Maghembe *et al.* (1986) reported values ranging from 14.8 per cent (foliage) and 50.4 per cent (bole) in *Leucaena leucocephala.* They did not observe any significant difference between intercropped and monoculture situations.

Total dry matter recorded including roots of *Acacia nilotica* (5264 plants ha^{-1}) after one year and five years of age were 16 and 154 tonnes ha^{-1} respectively (Gurumurti *et al.*, 1986). Out of these, the utilisable biomass (bole, bark, branch) was 10.9 and 110.1 t dry matter ha^{-1} respectively. Stemwood contributes 30 per cent and branches 35 per cent.

Tree biomass production and its relative allocation to various components in a central Himalayan forest revealed striking variability. For example, in *Shorea robusta,* 61.3 per cent biomass was allocated to the bole, 10.5 per cent to the branches, 4.7 per cent to the twigs, 2.6 per cent to leaves and 20.5 per cent to the roots. While in a mixed oak forest, the bole, branch, twig, leaf and the root contributions in the biomass were 43.9, 26.9, 10.5, 3.5 and 15.2 per cent respectively (Rana *et al.*,1989).

Wang *et al.* (1991) studied the biomass partitioning in five tropical tree taxa in a 5.5 year old plantation in Puerto Rico. *Casuarina equisetifolia* accumulated 70.8 per cent biomass in its bole, 17.4 per cent in the branch and 10.9 per cent in the leaves. In *Leucaena leucocephala* var. Puerto Rico, the respective values were 72.7, 15.4 and 11.5 per cent and for var. K8, 78.7, 17.4 and 5.1 per cent respectively. From a four year old *Acacia auriculiformis* stand, Osman *et al.* (1992) found that the percentage of biomass allocation to the system was to the tune of 72 to 76 per cent and that to the leaves was 9 to 12 per cent in four multipurpose tree species. George (1993) observed that the foliage had the least biomass yields to the level of 5.2 per cent in Leucaena to 8.5 per cent in Casuarina .

Naveed and Kumar (2003) assessed the performance of *Ailanthus triphysa* grown at different densities and fertilizer regimes in Kerala. At 8.8 years of age, results showed that height, diameter, stand leaf area index, biomass production and volume yield were greater in 2m x 2m spacing. Ninety six randomly selected average sized trees were felled at 8.8 years of age for assessment. Stem wood represented the principal component (77 %), while foliage contributed the least (< 7 %).

Above ground and below ground biomass and its allocation pattern were studied in six year old trees of nine species viz., *Acacia catechu, A nilotica* subspecies *indica, Albizia lebbek, Azadirachta indica, Dalbergia sissoo, Melia azedarach, Morus alba, Prosopis cineraria* and *Ziziphus mauritiana* from arid North-West India. Maximum biomass of 39 to 65 per cent was allocated to boles and a lesser amount of 22 to 40 per cent to branches and 9 to 29 per cent to roots.

A chronosequence of *Gmelina arborea* stands ranging from one to six years old was measured to document changes in growth, biomass and nutrient contents for three red lateritic sites in Chhattisgarh. The stand's density, survival and growth parameters varied significantly with age and site. The number of stems was highest (789 trees/ ha) in a one year old plantation at site 3 (Kusumi) and lowest (724 trees/ ha) in a 6 year old stand at site 2 (Anandgaon). The stem wood contributed from 55.3 per cent (site 3) to 56.3 per cent (site 1), branch wood from 18.3 per cent (site 2) to 19.8 per cent (site 3), roots from 17.9 per cent (site 3) to 18.5 per cent (site 2) and foliage from 6.6 per cent (site 2) to 7 per cent (site 3) of the total biomass (Swamy *et al.*, 2004).

Das and Chaturvedi (2003) estimated biomass production and nutrient distribution of three to seven year old plantation of *Dalbergia sissoo* in Pusa, Bihar, India. Leaf, bole, branch and root constituted 1, 58 to 61, 24 to 26 and 13 to 15 per cent of total tree biomass respectively.

2.3 Evaluation of tree species for wood properties

Although wood density does not always directly relate to the variation of strength properties within and among trees, it is still very useful for predicting strength (Littleford, 1961). Mottet (1965) stated that, of all the physical properties in tropical woods, density is by far the most important and most well known. Vanbuijtenan (1982) stated that, of all the wood properties, density is the most significant in determining the end use.

Variation of specific gravity from pith to periphery is noticed for many species. The specific gravity *of Eucalyptus grandis* increased from 0.419 in the central segment to 0.472 in the outer segment along radial direction (Hans *et al.,* 1972). By studying the fuel wood characteristics of thirteen firewood species, Singh and Khanduja (1984) reported that the ash content of wood generally lowers the heat of combustion of fuel wood. From the same study, they also interpreted that the ash per cent in thirteen firewood species showed wide variations ranging from 0.87 per cent to 5.20 per cent.

Ong (1986) analysed the moisture content, density, shrinkage and strength properties of wood from nine year old trees of *Albizia falcataria.* There were considerable differences in density between sites and trees and within trees. Regression equations derived for predicting changes in strength properties in relation to wood density and moisture content were reliable. Moisture content of wood is reported to have negative correlation with fuel wood value. This was confirmed by Haufa and Wojciechowska (1986) from their studies in Norway spruce, oak and beech, where the average calorific value changed from13.2 KJ g^{-1} to15.675 KJ g^{-1} from green condition to air dry condition. Tissue position and stem diameter are two key factors affecting moisture content of wood.

Physico-mechanical properties and possible uses of eleven plantation grown timber species were studied in Philippines by Tamolang and Rocafort (1987). The properties studied included relative density, shrinkage, bending, shear parallel to grain, compression parallel and perpendicular to grain, hardness and toughness. Based on the classification of the species in accordance with the five physico-mechanical property groupings devised by FPRDI, the following use recommendations were made: (1) *Leucaena leucocephala, Pinus kesiya, Swietenia macrophylla, Gmelina arborea* and *Tectona grandis* were recommended for medium construction purposes; (2) *Hevea brasiliensis* for moderately light construction; and (3) *Anthocephalus chinensis, Albizia falcataria, Endospermum peltatum, Eucalyptus deglupta* and *Aleurites moluccana* for light construction purposes where strength and durability are not critical requirements.

Chapola and Ngulube (1990) studied the wood density of 18 species sampled at five to eight year old from nine sites in Malawi, with a view to the selection of tree species suitable for particular end uses. The species studied include *Eucalyptus*, *Albizia lebbek, Cassia siamea, Gmelina arborea* and *Melia azedarach.* Density varied significantly between species and ranged from 300 to 700 kg/m3. Radial wood density showed a general increase from pith outwards. No specific pattern in axial variation was observed, although density values at tree mid height were generally greater than values at breast height and at 75 per cent height.

In another study conducted by Robert and Espen (1992), it was found that the wood specific gravity of *Cieba pentandra* from four Costa Rican life zones and a moist tropical forest in West Africa exhibited marked variability. Tree age is another factor, which influences specific gravity. It was reported that with increase in tree age, the specific gravity increased from 0.47 to 0.56 in case *of Acacia mangium* (Siagian *et al.,* 1999) but in some species like teak and *Gmelina arborea,* age have no influence on specific gravity (Siagian and Komarayati, 1998 and Bhat *et al.,* 1999).

Studies on oak revealed that the ash content of oak wood changed along tree height with the highest ash content recorded at the top and lowest at the butt end (Krutul, 1997). Mazurkin *et al.* (1998) and Siagian *et al.* (1999) from their findings on *Acacia* *mangium* and *Abies sibirica* stated that ash content varied with tree age and wood density. Wood density changes according to position in the tree was also reported by Chen *et al.*, (1998) and Damodaran and Chacko (1999).

Variation in specific gravity with topographic differences was confirmed when it was noticed that the specific gravity of wood of *Grevillia robusta* from Uttar Pradesh was much higher than the specific gravity from Karnataka (Khanduri *et al.*, 2000). A study carried out in College of Forestry, Vellanikkara revealed that basic density is decreasing along the heights and also from pith to bark (Lisha, 2004). Bark and wood samples of 45 multipurpose tree species in the home gardens of Kerala were studied to assess their fuel wood characteristics by Shanavas and Kumar (2003). They reported large variations in calorific values of species and tissue types. It was also evident from these studies that ash content had a negative correlation with heat of combustion but specific gravity exerted a positive influence.

Sahu (2005) from his studies conducted in College of Forestry, Vellanikkara reported that the heartwood calorific value was highest for *Dalbergia latifolia* followed by *Samanea saman* and *Albizia odoratissima.* Heartwood calorific value of *D. latifolia* showed slight difference compared to *Samanea saman.* The heartwoods of *Albizia odoratissima* and *Samanea saman* possessed significantly greater moisture content than sapwoods at green condition whereas, at air dry condition sapwoods of both these species possessed significantly higher moisture content than heartwoods. The differences between specific gravities of sapwood and heartwood were not significant.

2.4 Fuelwood values of trees

Calorific value of wood is a variable parameter. Important determinants of calorific value include ash content, wood density, moisture content, species, locality, seasonal changes and tissue types. Ash content of wood generally lowers the heat of combustion of fuelwood (Singh and Khanduja, 1984). Ash content is a variable parameter and may change with species, tree age, tissue-position and wood density. In general, tropical taxa have high ash percentage than that of temperate taxa (Bhatt and Todaria, 1990). Chemical analyses *of Acacia mangium* wood of several age groups suggests that ash content increased from 0.31 per cent to 0.83 per cent depending on the age (Siagian *et al.,* 1999). Within trees, variation of ash content was also noticed.

One of the most important determinants of fuelwood value is the dry matter content (density) of wood. Wood specific gravity is a variable parameter and changes with positions in a tree. Wood density decreased from bottom to top along the tree height in eight year old *Acacia mangium* (Dhamodaran and Chacko,1999). Sulaiman (1993) reported similar results for five year old *Acacia mangium* trees and Choudhary (1997) for *Cassia siamea.* Vale and Nogueira (1998) also reported that the basic density of *Dalbergia miscolobium* wood decreased from bottom to top. However, contrary to the expectations, *Cryptomeria japonica* showed an opposite trend where wood specific gravity increased from bottom to top along tree height (Chen *et al.*,1998). In general, twigs had lower dry matter content than branches which, in turn was lower than stemwood (Neenan and Steinbeck,1979) and the higher density species took longer time to ignite and burnt more slowly but produced hot embers, which continued to give off a steady heat long after the flame had died down (Groves *et al.*,1989).

Moisture content of the wood has a negative correlation with fuelwood value. The calorific value per unit volume of wood changes with change in moisture content and the calorific value of wood with equilibrium moisture content (air-dry condition) is greater than the calorific value of wood with higher moisture content (Skrinska *et al.,* 1999). Haufa and Wojciechowska (1986) observed similar results in Norway spruce, oak and beech where the average calorific value changed from 13.2 cal. g^{-1} to 15.675 cal. g^{-1} from green condition to air-dry condition. In general, moisture content reduces the calorific value of fuel up to 20 per cent (Rongjunchen *et al.,* 1997). Moisture content increased significantly with increasing tree height in the case of Scots pine *(Pinus sylvestris)* with the highest moisture content in the branches (Uzunovic and Dickinson, 1998) and with increasing stem diameter in *Elaeagnus umbellata* (Thakur and Thakur, 1998).

Tree species with high wood specific gravity, low ash content and moisture fractions, high biomass to ash ratio and low nitrogen were considered to be good fuelwood species (Bhatt and Todaria, 1990). In general, indigenous tree species are better suited as fuelwood species as they manifest high wood density, low ash content and low nitrogen percentage as compared to exotics (Puri *et al.*, 1994). Furthermore, calorific value of coniferous species are higher than that of broad leaved species (Wang *et al.*, 1999). Presence of resins in most of the coniferous species is a reason for the high calorific value. Goel *et al.* (1992) estimated the calorific values and burning properties of eighteen shrubs commonly occurring in tropical and temperate areas adjoining Dehra Dun and classified them into two categories based on their calorific value and burning properties as more suitable and less suitable.

The edaphic and climatic factors will affect the specific gravity, moisture content and ash content of wood that in turn will influence the calorific value of wood. Variations in calorific value among trees of same species between different localities were reported in six indegenous species by Puri *et al.* (1994). Mean calorific value ranged from 18.7 to 21.77 MJ /kg. Calorific value varies with seasonal change and the seasonal variation of calorific value is due to the change in the ratio between low and high energy components in the tissue due to the change in the intensity of physiological and growth processes (Ivask, 1999).

2.5 Factors affecting physical and mechanical properties of timber

Variations in specific gravity in 27 month old plantations of *Eucalyptus teriticornis, Leucaena leucocephala* and *Melia azedarach* grown at various densities, (5000, 10000, 15000 and 20000 plants ha^{-1}) were studied by Sharma *et al.* (1992) in Himachal Pradesh and found that *Leucaena leucocephala* had significantly higher specific gravity compared to other species.

Kroll *et al.* (1992) studied anatomical and physical properties of balsam poplar in Minnesota and found that heart wood had higher moisture content than sapwood.

Bhat and Todaria (1990) studied the wood specific gravity in stem and branches of eleven timbers from Kerala. Four of the timbers viz., *Erythrina stricta, Anacardium occidentale, Lagerstroemia microcarpa* and *Hevea brasiliensis* were classified as light to very light (specific gravity < 0.550) and the remaining seven timbers (*Dipterocarpus indicus, Terminalia paniculata, Dillenia pentagyna, Tectona grandis, Grewia tiliaefolia, Stereospermum chelonoides* and *Xylia xylocarpa*) were classified as moderately heavy to heavy where specific gravity ranges from 0.550 to 0.750.

Rao and Sampathrajan (2001) carried out proximate and ultimate analysis to characterize 11 dryland wood species namely *Eucalyptus hybrid, Prosopis juliflora, Tamarindus indica, Acacia leucopholea, Leucaena leucocephala, Peltoforum ferungienum, Acacia nilotica, Delonix regia, Syzygium cumini, Albizia amara, Casuarina equsetifolia* for effective classification. The density of wood species was low for *Leucaena leucocephala* (630 kg/ m^3) and high for *T. indicus* and *A. amara* species (850 kg/ m^3). The moisture content of the wood species varied from 7.0 per cent to 11.7 per cent.

Sahu (2005) from his studies reported that the heartwoods of *Albizia odoratissima* and *Samanea saman* possessed significantly greater moisture content than sapwoods at green condition, whereas, at air dry condition sapwoods of both these species possessed significantly higher moisture content than heartwoods. The differences between specific gravities of sapwoods and heartwood were non significant.

Sahri *et al.*(1998) conducted research on physical and mechanical properties of *Acacia mangium* and *A. auriculiformis.* Three healthy trees of each species or provenance were sampled from sites in Indonesia (Bogor), Malaysia (Serdang) and Thailand. The specific gravity and mechanical properties were affected by species, provenance and site.

The Indonesian samples exhibited the best results in terms of both physical and chemical properties and *Acacia auriculiformis* had better properties than *A. mangium.* Tree species also demonstrate a high degree of variability with respect to physical and mechanical properties from provenance to provenance. For instance, the physical and mechanical properties of teak showed wide variations among different parts of the country (Rajput and Gulati, 1983). The average specific gravity for teak from Mizoram, Orissa, Tamil Nadu and Kerala were 0.606, 0.539, 0.639 and 0.604 respectively (Shukla and Lal, 1994). Similarly the wood density of oak and ash changed from provenance to provenance with an increasing trend from North latitude to South latitude (Patlai, 1982) and that of *Sterculia apetala* provenance from Colombia (0.216) were significantly higher than that from central America in wood specific gravity (Dvorak *et al.*,1998).

An investigation on variations in wood density of eight year old *Acacia mangium* provenances in Sabah by Sining (1989) showed that the basic density ranged from 430 kg m^{-3} to 500 kg m^{-3} and the physical and mechanical properties of *Acacia mangium and Acacia auriculiformis* from Indonesia were superior to that of Papua New Guinea, Australia, Malaysia and Thailand provenances (Hamami *et al* 1998). Variation in wood density among genotypes of poplar (Gruss and Becker, 1993) and Dougles fir (Veveries, 1982) were also reported. However, despite the high growth rate of oak from Mazandaran territory of Iran, their mechanical properties were superior to the oak from Noushahr territory in Iran (Ebrahimi *et al.,* 1997).

Another factor that influences the physical and mechanical properties of wood is the site characteristics. Edaphic, climatic and topographic factors profoundly influence the physical and mechanical properties of wood. Soil fertility influences the rate of growth of trees that, in turn, influence the physical and mechanical properties of wood. Specific gravity of 35 central Amazonian tree species grown on soils with low nutrient status was generally higher than that of wood grown on soils with high nutrient status (Parolin and Ferriera, 1998).

Variations in physical and mechanical properties among trees grown under different climatic conditions were reported in loblolly pine by Mcalister and Clark (1991). Wood specific gravity of *Ceiba pentandra* from four Costa Rican life zones and a moist tropical forest in West Africa exhibited marked variability (Robert and Espen, 1992). Shukla *et al.* (1990) reported that the surface hardness values of *Acacia auriculiformis* from Karnataka was almost twice than that of Bihar. Altitude influences the physical and mechanical properties of wood. For instance, the air-dry density of *Eucalyptus grandis* varied between high altitudes and low altitudes (Benny and Bhat, 1996). The average static modulus of elasticity and average density of spruce timber grown under non-polluted atmosphere is found to be greater than those grown under polluted conditions (Hantsch, 1983).

Seasonal changes in weather exert a profound influence on wood moisture content, density and shrinkage. The moisture content of green sapwood and heartwood was found to be greatest in February and lowest in summer and November in the case of larch (Burmester and Ranke, 1982). In the same study, it was found that density was greatest in February and lowest in April and shrinkage was lowest in February-March and greatest in July. This was due to the changes in the intensity of physiological and growth processes depending upon the season. Chafe (1994) reported that the bending stress encountered through wind action at the time of wood formation has an influence on the specific gravity of the wood.

Increase in age increased the wood specific gravity from 0.47 to 0.56 in the case of *Acacia mangium* (Siagian *et al.,* 1999). Dhamodharan and Chacko (1999) obtained a basic density value of 500 kg m^{-3} for eight year old *Acacia mangium* trees and 508 kg m^{-3} for 10 year old mangium trees. In *Cassia siamea,* increase in age increased specific gravity and shrinkage and this increase was spectacular between six and nine years of age (Choudhury, 1997). Specific gravity, modulus of rupture and modulus of elasticity of red pine *(Pinus resinosa)* was 22 to 90 per cent greater in mature wood than in green wood (Shepard and Schottafer, 1992). But age did not have any influence on the physical and mechanical properties of teak wood and *Gmelina arborea* wood.

Materials and Methods

MATERIALS AND METHODS

The present investigations were carried out at the instructional farm, College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur, Kerala, in a 15 year old arboretum during the period 2004 to 2006. The details about the experimental site, materials used and methodology adopted are furnished below:

3.1 Location

The experimental site has an elevation of 40.29 m above sea level and located at 10°13' N latitude and 76°13'E longitude.

3.1.1 Climate

The study site experiences a warm humid climate, having a mean annual rainfall of 2899 mm, most of which is received during the south west monsoon (June to August). The mean maximum temperature recorded at Vellanikkara varied from 28.4°C in June to 34.9°C in March. The mean minimum temperature varied from 21.9°C in July to 24.7°C in April.

3.1.2 Soil

The soil of the experimental site is an Ultisol having a pH of 5 to 6, relatively rich in organic matter.

3.2 Field experiment

The experimental materials consist of 10 trees each of 10 tree species planted in the instructional farm at a spacing of 4 x 4 m. Uniform seedlings were planted during 1991-92 and are being maintained. Proper watering and weeding were done during the initial stages of establishment. Plant protection measures were taken up whenever necessary.
The species included in the study are:

1. *Acacia auriculiformis* A.Cunn.Ex Benth (Acacia)
2. *Acacia mangium* Willd. (Mangium)
3. *Ailanthus triphysa* (Dennst.) Alston (Matti)
4. *Artocarpus hirsutus* Lamk. (Anjali)
5. *Grevillea robusta* A.Cunn. (Silver oak)
6. *Swietenia macrophylla* King. (Mahogany)
7. *Tectona grandis* L.f. (Teak)
8. *Terminalia bellerica* (Gaertn.) Roxb. (Thanni)
9. *Terminalia tomentosa* W. and A. (Karimaruthu)
10. *Xylia xylocarpa* (Roxb.) Taub. (Irul)

A brief description of the tree species is given below:

1. *Acacia auriculiformis* A. Cunn. Ex Benth (Family – Mimosoideae)

It is a tall straight evergreen tree with dull green, thick crown, reaching a maximum height of 15 m in about 30 years. The tree is a native of north Australia and Queensland, but is now frequently planted in various parts of India as an exotic suitable for introduction in dry regions. The bark of the tree is smooth and white, contains 12 to 16 per cent tannin. This species has been found useful for paper making. It is reasonably good firewood and can also be used for making low cost furniture. It is used for planting as an avenue tree also.

2. *Acacia mangium* Willd. (Family – Mimosoideae)

Acacia mangium, formerly known as *Mangium montanum* and later as *Racosperma mangium*, is indigenous to north-eastern Australia, eastern Indonesia and western Papua New Guinea. It is an evergreen, leguminous tropical tree popular for its rapid early growth. *Acacia mangium* generally grows to a height of 25 to 35 m with straight bole which may be over half of the total height with a diameter at breast height (dbh) of over 60 cm .The sapwood is white and sharply defined from the darker brown heartwood. The timber is reported to be of general utility and is particularly suitable for pulping. It is recommended for extensive planting under agro forestry system as it fixes nitrogen.

3. *Ailanthus triphysa* (Dennst.) Alston. (Family Simaroubaceae)

It is a medium sized deciduous tree with cylindrical bole and narrow crown, reaching a maximum height of 30 m . The tree is a strong light demander, especially during initial stages of growth. Ailanthus is a dominant woody perennial component in the homesteads of Kerala. This fast growing multipurpose tree species is used in matchwood, packing case, paper and pulp industries and is suitable for intercropping. It is a recommended standard for black pepper.

4. *Artocarpus hirsutus* Lamk. (Family - Moraceae)

A very tall, handsome evergreen tree, attaining a height of 45 m and a girth of 4.5 m or more with a straight clean stem and dense foliage. It is distributed in the evergreen forests of Western Ghats from the Konkan southwards. The wood is moderately hard, yellowish brown, durable, very coarse and even textured. The timber is used for furniture making, house building and boat building. It is common in homegardens of Kerala. It is a good ornamental foliage tree used for landscaping.

5. *Grevillea robusta* A. Cunn. (Family - Proteaceae)

It is a fast growing tree species, native to Australia and introduced to the Indian sub continent during the early 1860s as shade tree for tea gardens in the high ranges. It is widely grown in the indogangetic alluvial plains and humid/subhumid regions. On good soils with suitable climate, annual increment of 2 m in height and 2 cm in diameter at breast height has been reported over the first 5 to 10 years and this species is widely used in agroforestry. It is easy to propagate and provides good poles and fuelwood and does not compete strongly with adjacent food and cash crops. The bark is rough and silvery blue in colour. The sapwood is reddish brown and heartwood is darker than sapwood. Its timber is easy to work and behaves satisfactorily in planning, mortising and turning. It is also recommended for planting along the road side, rail side and canal banks.

6. *Swietenia macrophylla* King. (Family - Meliaceae)

A beautiful, lofty, evergreen tree native to north America and now widely planted throughout south India. Mahogany plantations have been established in over 40 countries of the world outside its natural habitat. Mahogany timber is priced particularly for its colour and workability. It is primarily valued for construction of high value furniture and interior fittings. The bark is greyish brown, smooth and rough and the wood is lustrous, light red, moderately hard and heavy. The timber is used for jetty-piles, furniture making and plywood. This evergreen ornamental tree is also used for landscaping.

7. *Tectona grandis* L. f. (Family Verbenaceae)

A large deciduous tree with a rounded crown and under favourable conditions, a tall clear cylindrical bole is produced, which is often buttressed at the base and some times fluted. It is the most important timber tree species of India. It is indigenous throughout the greater part of Burma and the Indian Peninsula, in Siam and in Java and other islands of the Indian Archipelago. Teak thrives best and reaches its largest dimensions in a fairly moist, warm, tropical climate. It occurs normally in mixed deciduous forests, but occasionally teak trees are found standing in dense evergreen forests. Teak is a pronounced light demander. It grows on variety of soils and geological formations but requires good drainage. Teak is considered as one of the most important standard timber trees of the world.

8. *Terminalia bellerica* (Gaertn.) Roxb. (Family Combretaceae)

It is commonly known as bahera. A large, deciduous tree attaining a height of 40 m and a girth of 3.3 m or more is usually with a straight tall bole. The tree is found in deciduous forests throughout the greater part of India and Burma but not in arid regions. In the Indian peninsula, it occurs most frequently in arid regions. It is a light demander. It is sensitive to frost. It coppices fairly well. Wood is yellowish grey, hard, not durable, but lasts fairly well under water, used for planking, packing cases, boats and other purposes. Fruits of the tree are used for various pharmaceutical preparations.

9. *Terminalia tomentosa* W. and A . (Family Combretaceae)

It is a large deciduous tree with a long clean bole and a full crown, bark grey to black, with deep longitudinal fissures and transverse cracks dividing it into oblong scales, red inside. Wood is dark brown, of variable durability used for building, carts, mine props and other purposes. It lasts well under water. The tree is distributed throughout the sub-Himalayan tract from the river Ravi eastwards. It is common throughout the greater part of Indian peninsula. The tree attains its largest dimensions on deep rich alluvial soil. It is proved to be a good tree for boundary planting in Kerala homesteads.

10. *Xylia xylocarpa* (Roxb.) Taub. (Family - Mimosoideae)

It is a large deciduous tree occcuring in the Indian peninsula extending from Maharashtra to Kerala. The bark is reddish grey and exfoliating in large irregular flakes. The sapwood is brownish or pinkish white and the heartwood is reddish brown to brown. The wood is very hard and heavy. The timber is used for making railway sleepers, bridge, piles and railway wagon, floor boards and is also widely used as a fuel . It is also used as a shade tree for home gardens and public parks.

All the tree species included in the study are depicted in plates 1 a and 1 b. The growth observations from 1992 to 2004 were taken from the department register.

3.3 Growth performance of the tree species grown in the arboretum

3.3.1 Height

Height of the individual tree was measured from ground level using a standard pole. The mean height was worked out.

Plate 1a. Experimental tree species grown in the arboretum

Plate 1b. Experimental tree species grown in the arboretum

3.3.2 Commercial bole height

Commercial bole height of individual tree was measured separately using a standard pole.

3.3.3 Girth

Girth of individual tree was measured at breast height using a measuring tape. Average girth was worked out.

3.3.4 Number of primary branches

Number of primary branches was also found out and average was estimated.

3.4 Estimation of fresh and dry biomass of the tree species grown in the arboretum

For biomass estimation, one average sized tree, from each species was felled at the ground level at the end of study using a mechanical chain saw (Poulan/Pro, USA).
The felled trees were then partitioned into:

1. Stem wood (main shoot, if the main shoot forked below the breast height level then such branches were also treated as stem wood) .
2. Branch wood (all branches differentiating from the trunk) above breast height level.
3. Twigs (secondaries, tertiaries and laterals were included).
4. Foliage

Fresh weights of all the above ground components were recorded tree wise using appropriate spring scales. Moisture percentage of each portions of the felled trees was found out separately. Samples of the felled trees viz., stem wood, branch wood, foliage and twigs were weighed in green condition to note their fresh weight. There after, they were placed in oven at 70°C till their constant weights were realized. The moisture percentage was calculated as follows:

$$\text{Moisture percentage} = \frac{\text{Fresh weight (g)} - \text{Dry weight (g)}}{\text{Fresh weight (g)}} \times 100$$

The total dry weight of the biomass was estimated after finding out the moisture content.

3.5 Estimation of physical properties of wood of the tree species

Stem discs of approximately 2 cm in width were cut at the breast height level, at the middle and at the top of stem from a randomly selected tree of each species of felled trees for estimation of sapwood percentage, heartwood percentage, bark percentage and other properties as discussed below:

3.5.1 Heartwood percentage

With the help of a trace paper, the heartwood portion in discs of each tree species was traced. This area was then laid on a graph paper. Using the graph paper, the area inscribed by the heartwood was calculated. Following similar method, total area of the disc was also calculated. The heartwood percentage was found out using the following formula:-

$$\text{Heartwood percentage} = \frac{\text{Area of heartwood (square cm)}}{\text{Total area (square cm)}} \times 100$$

3.5.2 Sapwood percentage of the tree species

Similar method as that used for heartwood percentage was followed to calculate sapwood percentage also.

3.5.3 Heartwood: sapwood ratio

This was estimated by using following formula:-

$$\text{Heartwood: sapwood} = \frac{\text{Percentage of heartwood (\%)}}{\text{Percentage of sapwood (\%)}}$$

3.5.4 Bark percentage

The bark percentage was worked out by using the following formula:-

$$\text{Bark percentage} = \frac{\text{Area of bark (square cm)}}{\text{Total area (square cm)}} \times 100$$

3.5.5 Calorific value

Samples of wood after drying in an electric oven at 103±2°C were chipped separately using a chisel to smaller sizes of approximately 0.3-0.4 cm thickness. The sample chips were then ground in an electric mill. The ground samples were stored in double sealed polythene covers. One gram of the ground material from each sample was accurately weighed and the calorific value was estimated using an Oxygen Bomb Calorimeter. A measured quantity of sample was burnt by supplying high voltage current through the electric terminals in the presence of oxygen and the heat absorbed by the water in the bucket was recorded. This rise in temperature is proportional to the gross energy value of the substance which is burnt. The calorific value was estimated by using the following formula.

$$\text{Calorific value (H)} = \frac{TW - (a + b + c)}{m}$$

Where

H = heat of combustion of sample (cal.)

T = difference in initial and final bucket temperature (°C)

W = energy equivalent of bomb calorimeter (cal.°C)

a = acid correction

b = calories liberated during the ignition of tungsten wire (cal.)

c = calories liberated during the ignition of cotton thread (cal.)

m = weight of the sample (g)

3.5.6 Specific gravity

Specific gravity of heartwood and sapwood of each species was estimated separately. A beaker filled with water was taken. It was then placed in another beaker of slightly bigger size. A known quantity of heartwood or sapwood after properly drying in hot air oven(at 70 ^{o}C) was fully immersed in water by using a needle. The volume of water displaced due to immersion of wood piece was noted. Then the specific gravity of wood was calculated by using the following formula:-

$$\text{Specific gravity} = \frac{\text{Dry weight of wood (g)}}{\text{Volume of water displaced (ml)}}$$

Mean specific gravity was also worked out.

3.6 Estimation of tissue nutrient content

The samples of leaves of each of the tree species were dried and powdered. The ground samples were analysed for the major nutrient elements viz., N, P and K using the following standard procedures.

3.6.1 Nitrogen

Nitrogen content in the powdered sample was determined by digesting 0.1 g of samples in 5 ml of concentrated sulphuric acid using the digestion mixture (potassium sulphate : copper sulphate in ratio of 10: 4) and the nitrogen in the digest was determined by Kjeldhal's method (Jackson, 1958).

3.6.2 Phosphorus

One gram of the powdered leaf sample was digested with diacid mixture (nitric acid ; perchloric acid in the ratio of 3:1) and a known aliquot was used to determine the phosphorus content using the vanadomolybdophosphoric yellow colour method (Jackson, 1958). The colour was read in the UV photospectrometer at 410 nm.

3.6.3 Potassium

A known quantity of aliquot from the diacid extract was taken to read potassium concentration using flame photometer (Jackson, 1958).

3.7 Statistical analysis

The observations recorded on vegetative growth parameters of the tree species were analysed with analysis of variance technique as per the methods suggested by Panse and Sukhatme (1978).

Results

RESULTS

4.1 Growth performance of tree species grown in the arboretum

The observations recorded on various growth parameters of tree species viz., height, commercial bole height, girth and number of branches produced by experimental tree species for the period from 1992 to 2006 are furnished in tables 1 to 4. The important findings are summarised here under:

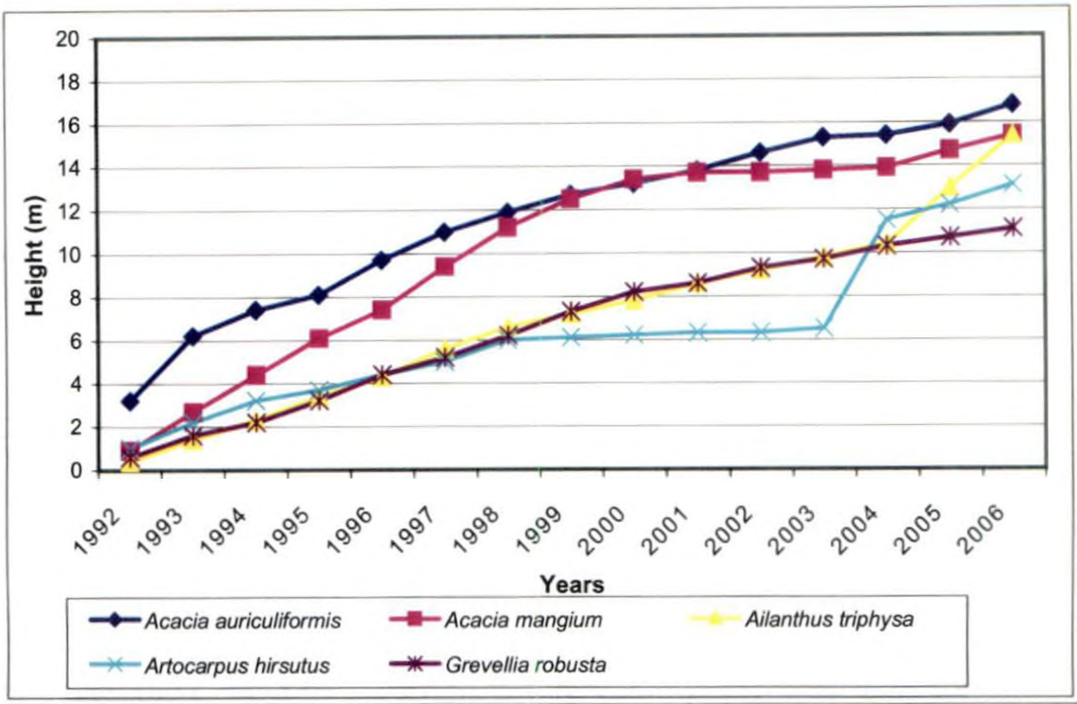
4.1.1 Height

The average height of tree species grown in the arboretum during the period from 1992 to 2006 along with total increment is tabulated in Table 1 and illustrated in Figure 1. From the data, it is evident that the total height increment was maximum for *Terminalia bellerica* (17.9 m) followed by *Terminalia tomentosa* (16.3) and *Tectona grandis* (15.5 m). The lowest height increment was recorded for *Grevellia robusta* (10.5) while *Artocarpus hirsutus* and *Swietenia macrophylla* recorded a height increment of 12.1 m each. *Ailanthus triphysa* recorded a total height increment of 15.5 m, while *Xylia xylocarpa* recorded 13.2 m. It could also be seen from the table and figure that *Acacia auriculiformis* has grown from the initial height of 3.2 m to 16.8 m while *Acacia mangium* from 0.9 m to 15.4 m and *Ailanthus triphysa* from 0.5 m to 15.4 m. A uniform height increment during the last 15 years was observed for *Terminalia tomentosa, Terminalia bellerica and Ailanthus triphysa* while the height increment was highly erratic in most of the other species especially, *Xylia xylocarpa* which showed a slow height growth during the initial stages which was stabilized in the last years of height growth. The height recorded at the end of the study was maximum for *Terminalia bellerica* (18.2) which was followed by *Acacia auriculiformis*, *Tectona grandis* and *Terminalia tomentosa*, all having a total height of 16.8 m followed by *Swietenia macrophylla* (15.5 m). However, the difference between these species with regard to height in 2006 was statistically not significant.

Table 1. Height (m) of tree species grown in the arboretum at yearly intervals

Tree species	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Total increment
Acacia auriculiformis	3.2	6.2	7.4	8.1	9.7	11.0	11.9	12.7	13.2	13.8	14.6	15.3	15.4	15.9	16.8	13.6
Acacia mangium	0.9	2.7	4.4	6.1	7.4	9.4	11.2	12.5	13.4	13.7	13.7	13.8	13.9	14.7	15.4	14.5
Ailanthus triphysa	0.4	1.4	2.3	3.4	4.3	5.6	6.6	7.2	7.8	8.6	9.2	9.8	10.4	13.0	15.4	15.0
Artocarpus hirsutus	1.0	2.2	3.2	3.7	4.4	5.0	6.0	6.1	6.2	6.3	6.3	6.5	11.5	12.2	13.1	12.1
Grevellia robusta	0.6	1.6	2.2	3.2	4.4	5.2	6.2	7.3	8.2	8.6	9.3	9.7	10.3	10.7	11.1	10.5
Swietenia macrophylla	2.7	3.9	5.3	6.3	7.0	7.7	8.8	9.5	10.4	10.5	10.5	12.3	13.2	13.7	15.5	12.1
Tectona grandis	1.3	3.3	5.1	5.9	7.6	8.7	10.2	11.3	11.7	12.2	12.6	13.7	13.7	16.8	16.8	15.5
Terminalia bellerica	0.3	1.8	3.3	4.8	6.3	7.8	9.3	11.2	11.5	12.6	13.6	14.1	15.1	17.7	18.2	17.9
Terminalia tomentosa	0.5	1.7	3.3	4.3	5.8	7.2	8.3	9.8	11.3	12.4	13.4	14.9	15.9	16.5	16.8	16.3
Xylia xylocarpa	0.5	0.5	0.8	1.1	1.5	3.6	5.0	7.5	7.4	8.6	9.3	10.3	11.2	12.7	13.7	13.2
F	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	
CD (0.05)	0.33	0.58	0.63	0.47	0.46	0.46	0.39	047	0.16	0.47	0.44	0.24	0.34	0.31	5.26	
S.Em ±	0.16	0.28	0.30	0.22	0.22	0.22	0.19	0.22	0.08	0.22	0.21	0.11	0.16	0.15	2.50	

** Significant at 1 per cent level



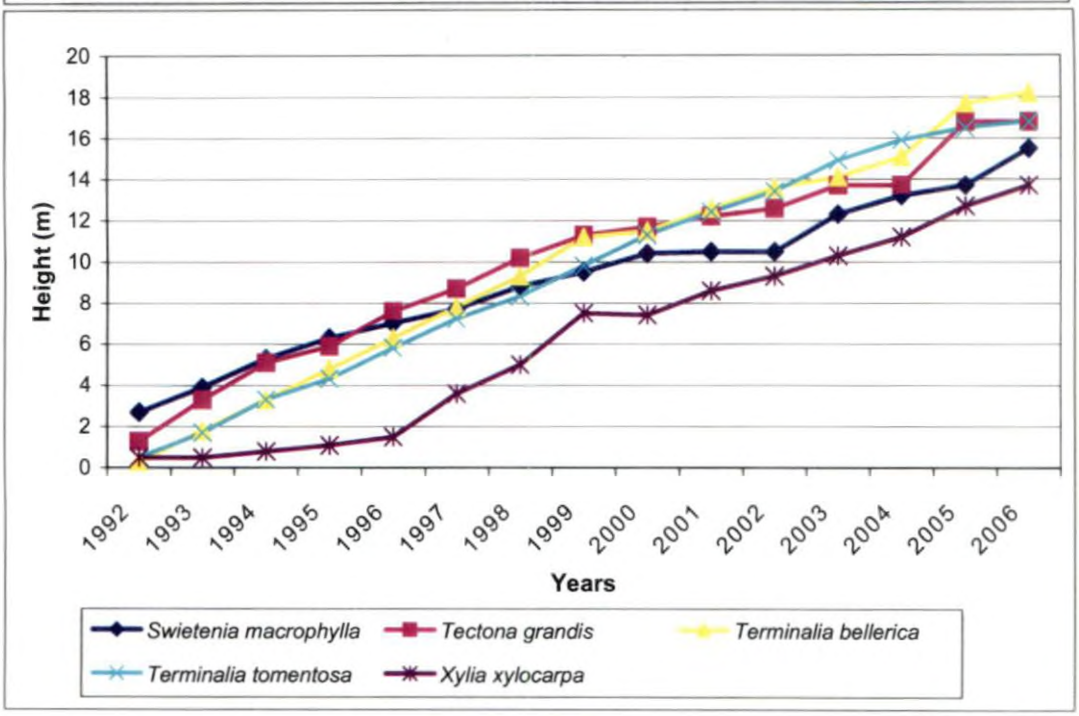


Figure 1. Height of tree species grown in the arboretum at yearly intervals

4.1.2 Commericial bole height

The commercial bole heights of all the ten tree species showed wide variation. The observations recorded in 2006 showed that maximum commericial bole height was recorded for *Terminalia tomentosa* (14.1 m) followed by *Tectona grandis* (13.5 m) and *Acacia auriculiformis* (12 m). However, the difference between these species with regard to this parameter was not significant. *Grevellia robusta* yielded the lowest commercial bole height (6.9 m) followed by *Artocarpus hirsutus* (7.9 m). *Terminalia bellerica* and *Acacia mangium* also yielded a relatively good commercial bole where it was respectively 11.7 m and 10 m and the difference between these two species was not significant. *Ailanthus triphysa, Xylia xylocarpa* and *Swietenia macrophylla* were poor with regard to commercial bole height. *Tectona grandis* recorded maximum total increment with regard to commercial bole height (8.5 m) while the minimum was noticed for *Grevellia robusta* (2.8 m) (Table 2 and Figure 2).

4.1.3 Girth

The observations taken on the girth of tree species are tabulated in Table 3 and presented in Figure 3. From the data it is clear that the highest total girth increment was recorded for *Acacia auriculiformis* (88.2 cm) which was followed by *Terminalia bellerica* (85.4 cm) and *Acacia mangium* (84.1 cm). On the other hand, the lowest girth increment was recorded by *Grevellia robusta* followed by *Swietenia macrophylla* and *Xylia xylocarpa* where the total increments were 40.2 cm, 56.7 cm and 57.5 cm respectively. *Terminalia tomentosa* showed a fast and steady increase in girth during the course of experiment. *Ailanthus triphysa* showed almost steady increase in girth up to 2004. It could also be seen from the table that during the second year, *Terminalia tomentosa* had a girth increase of more than three times of the first year. *Artocarpus hirsutus* also had a large increment in 2006 compared to 2005. With regard to total girth increment, the trees decreased in the order: *Acacia auriculiformis* > *Terminalia bellerica* > *Acacia mangium* > *Terminalia tomentosa* > *Ailanthus triphysa* > *Artocarpus hirsutus* > *Tectona grandis*> *Swietenia macrophylla* > *Xylia xylocarpa* and *Grevellia robusta*. At

Table 2. Commercial bole height (m) of tree species grown in the arboretum at yearly intervals

Tree species	2000	2001	2002	2003	2004	2005	2006	Total Increment
Acacia auriculiformis	5.4	6.2	7.2	8.2	8.3	10.7	12.0	6.6
Acacia mangium	5.9	6.7	6.7	8.0	8.0	9.6	10.0	4.1
Ailanthus triphysa	4.0	5.2	5.8	7.1	7.5	8.0	8.8	4.8
Artocarpus hirsutus	2.6	3.1	3.3	3.5	6.2	7.6	7.9	5.3
Grevellia robusta	4.1	3.9	4.8	5.2	5.5	5.9	6.9	2.8
Swietenia macrophylla	4.3	4.7	4.8	5.6	6.0	6.4	9.3	5.0
Tectona grandis	5.0	5.4	6.5	7.6	7.8	13.0	13.5	8.5
Terminalia bellerica	6.3	6.8	8.3	9.2	9.8	11.5	11.7	5.4
Terminalia tomentosa	8.0	9.2	10.5	12.7	13.6	13.8	14.1	6.1
Xylia xylocarpa	2.9	3.8	4.1	5.2	5.8	8.0	9.2	6.3
F	**	**	**	**	**	**	**	
CD (0.05)	3.92	5.22	4.46	4.40	4.81	4.38	5.56	
S.Em ±	1.86	2.53	2.12	2.09	2.29	2.08	2.18	

** Significant at 1 per cent level

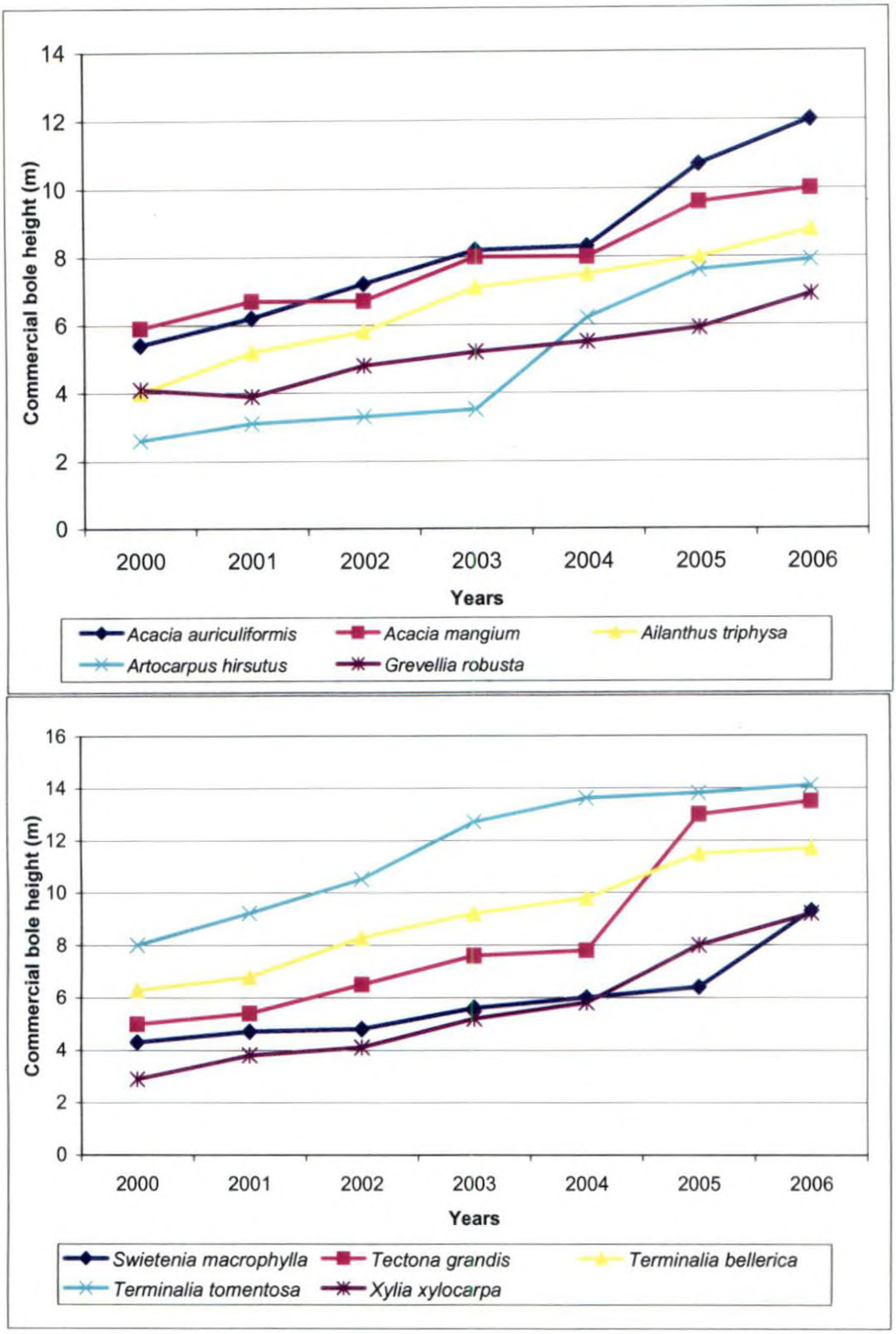
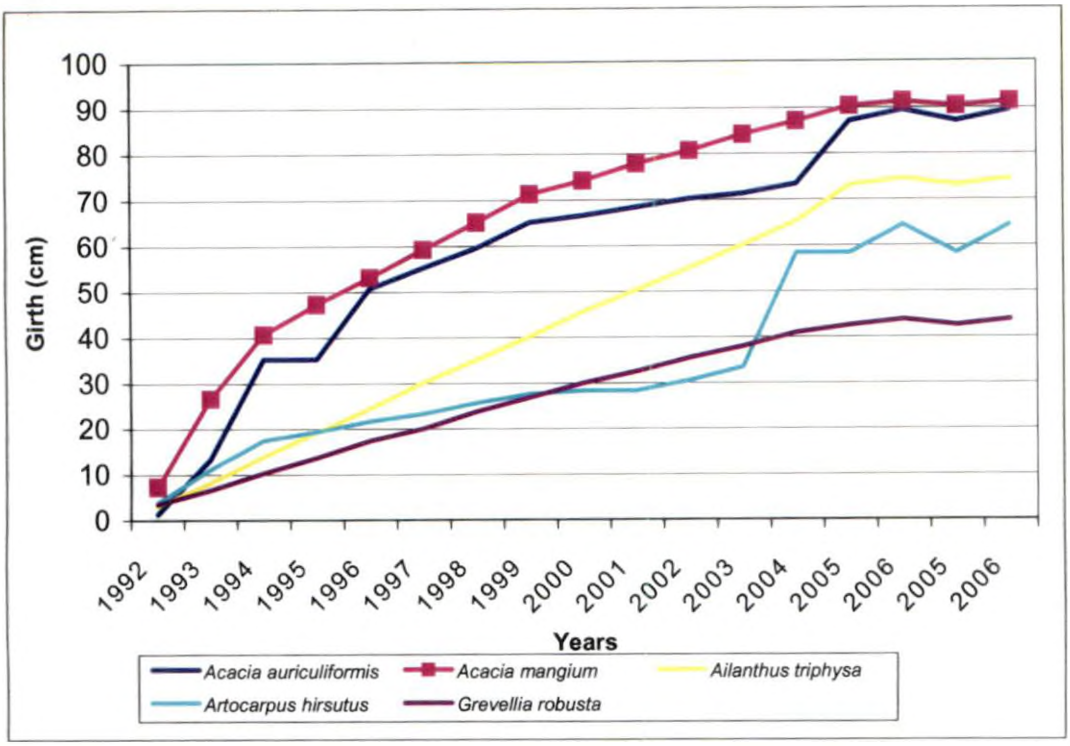


Figure 2.Commercial bole height of the tree species grown in the arboretum at yearly intervals

Table 3. Girth (cm) of tree species grown in the arboretum at yearly intervals

Tree species	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Total increment
Acacia auriculiformis	1.3	13.3	35.3	35.3	50.7	55.2	59.6	65.1	66.6	68.4	70.2	71.3	73.4	87.1	89.5	88.2
Acacia mangium	7.3	26.7	40.7	47.2	53.1	59.3	65.2	71.3	74.2	77.9	80.7	84.2	87.1	90.4	91.4	84.1
Ailanthus triphysa	3.1	8.2	13.9	19.2	24.5	30.2	35.2	40.2	45.6	50.3	55.2	60.2	65.3	73.2	74.5	71.4
Artocarpus hirsutus	3.8	11.1	17.4	19.3	21.6	23.2	25.6	27.6	28.3	28.3	30.5	33.4	58.3	58.3	64.4	60.6
Grevellia robusta	3.5	6.6	10.3	13.6	17.3	20.0	23.8	26.9	30.0	32.5	35.5	38.0	40.9	42.5	43.7	40.2
Swietenia macrophylla	10.4	18.6	22.7	25.3	27.6	30.2	32.9	35.5	41.1	46.5	52.0	57.5	62.2	65.6	67.9	57.5
Tectona grandis	6.6	18.4	21.3	24.1	26.6	29.5	32.1	34.4	39.4	43.6	48.9	53.6	58.5	64.3	64.8	58.2
Terminalia bellerica	3.0	8.9	14.9	22.0	28.2	34.2	41.0	47.3	59.4	62.0	69.2	76.3	83.2	83.2	88.4	85.4
Terminalia tomentosa	2.4	8.4	14.4	20.4	27.0	33.2	39.0	45.5	50.7	55.9	61.9	67.7	72.0	72.0	78.2	75.8
Xylia xylocarpa	1.9	4.9	7.0	9.0	14.2	17.5	20.7	23.6	28.6	32.9	37.7	42.2	42.2	53.6	58.6	56.7
F	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	
CD (0.05)	0.13	0.20	0.68	0.54	0.49	0.53	0.54	0.59	0.67	0.60	0.58	0.53	0.50	0.41	0.54	
S.Em ±	0.06	0.10	0.32	0.26	0.23	0.25	0.26	0.28	0.32	0.29	0.28	0.25	0.24	0.19	0.26	

** Significant at 1 per cent level



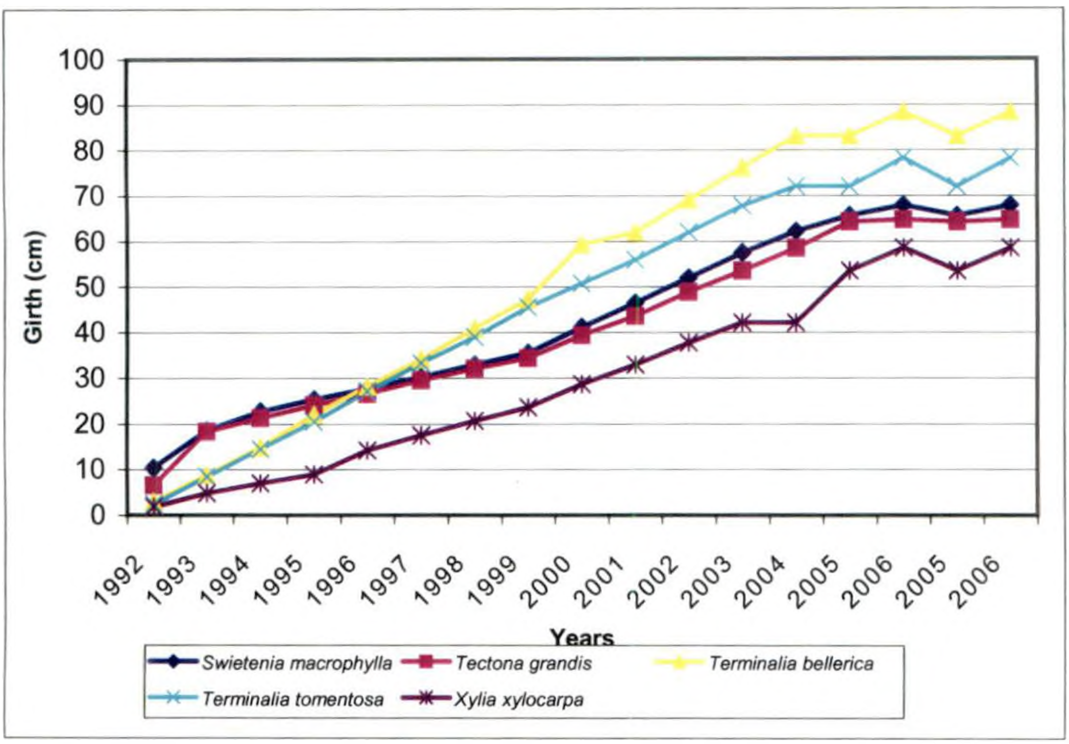


Figure 3. Girth of the tree species grown in the arboretum at yearly intervals

the end of the study *i.e* in 2006, *Acacia mangium* recorded maximum girth of 91.4 cm which was significantly superior to all other species. The lowest girth of 43.7 cm was recorded by *Grevellia robusta*. The difference between *Tectona grandis* and *Artocarpus hirsutus* with regard to girth during the year 2006 was not statistically significant.

4.1.4 Number of primary branches

Data furnished in Table 4 give an account on the number of primary branches produced by tree species in each year from 1992 onwards along with total increment. At the end of the study, maximum number of primary branches was produced by *Artocarpus hirsutus* (35.6) followed by *Grevellia robusta* (30.0) and the lowest by *Acacia auriculiformis* (16.4) followed by *Terminalia tomentosa* (17.3). The total number of branches produced by *Acacia mangium* and *Terminalia bellerica* at the end of study was 20.1 and 19.3 respectively. The difference was not statistically significant. In the first year, *Acacia auriculiformis* produced highest number of primary branches (9.3) followed by *Acacia mangium* (8.4) while *Swietenia macrophylla* produced only 0.4 branches which increased to 22.6 during the last year . Total increment in primary branches was also maximum in *Artocarpus hirsutus* (31.1) and minimum in *Acacia auriculiformis* (7.1). *Acacia mangium* started with a fair number of branches (8.4) in the first year. *Grevellia robusta* had quick increase in number of branches during the first few years but later on, the rate of increase was slow (Table 4 and Figure 4).

4.2 Biomass production of tree species grown in the arboretum

The biomass produced by tree species in terms of fresh and dry weight is tabulated in Table 5. The percentage contribution of various components in total biomass production is illustrated in Figures 5 and 6.

Table 4. Number of primary branches produced by tree species grown in the arboretum at yearly intervals

Tree species	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Total increment
Acacia auriculiformis	9.3	9.5	9.5	10.0	10.4	10.8	10.8	10.9	10.9	11.3	11.3	11.3	11.3	11.4	16.4	7.1
Acacia mangium	8.4	8.5	9.0	9.5	9.6	10.4	10.5	11.0	11.5	12.4	12.4	12.4	12.5	13.6	20.1	11.7
Ailanthus triphysa	1.4	2.5	4.0	5.4	6.5	8.0	9.4	10.6	11.7	13.5	15.2	15.3	16.4	19.5	21.5	20.1
Artocarpus hirsutus	4.5	5.5	5.4	6.7	8.0	8.5	9.1	9.6	10.3	12.1	12.1	11.8	22.7	27.6	35.6	31.1
Grevellia robusta	4.4	8.6	13.4	19.3	19.8	20.2	20.4	20.8	21.2	21.2	21.2	21.3	21.3	21.9	30.0	25.6
Swietenia macrophylla	0.4	2.6	4.7	6.8	8.4	8.9	9.4	9.9	10.4	10.9	11.4	11.9	12.6	13.3	22.6	22.2
Tectona grandis	1.5	3.4	5.4	8.8	12.5	14.6	15.5	16.4	16.4	16.6	17.5	17.3	20.0	23.0	24.3	22.8
Terminalia bellerica	5.3	5.9	6.6	7.5	8.4	9.0	9.7	10.9	11.6	12.5	12.5	12.6	12.6	13.0	19.3	14.0
Terminalia tomentosa	4.4	4.7	5.6	6.5	7.5	8.4	9.0	9.0	10.6	11.0	11.4	11.5	12.0	12.0	17.3	12.9
Xylia xylocarpa	0.4	1.4	1.6	2.3	2.5	4.0	5.4	6.9	8.0	9.5	11.0	12.5	16.0	17.4	20.1	19.7
F	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	
CD (0.05)	0.20	0.37	0.58	0.63	0.84	0.67	0.51	0.55	0.86	0.57	0.97	0.76	0.90	0.90	0.83	
S.Em ±	0.09	0.18	0.28	0.30	0.40	0.32	0.24	0.26	0.41	0.27	0.46	0.36	0.43	0.43	0.40	

** Significant at 1 per cent level

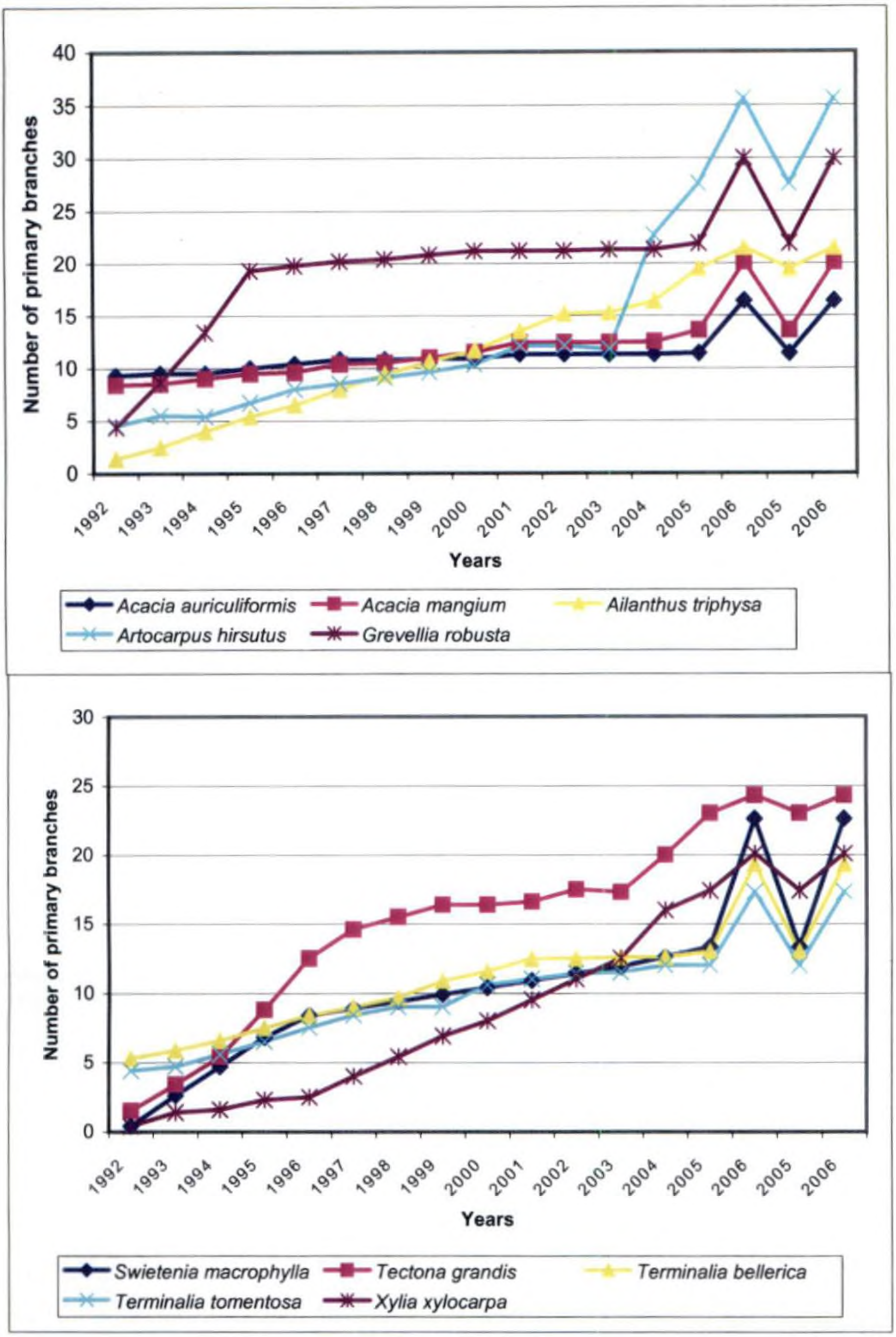


Figure 4.Number of primary branches produced by tree species grown in the arboretum at yearly interval

4.2.1 Fresh weight

The total fresh weight of the whole trees ranged from 94.5 kg in *Swietenia macrophylla* to 522.4 kg in *Terminalia tomentosa*. The trunk biomass was maximum for *Terminalia tomentosa* where it was 321.9 kg, followed by *Acacia auriculiformis* (233.0). The least fresh weight for trunk was recorded for *Swietenia macrophylla* (52.0 kg) followed by *Artocarpus hirsutus* (71.3 kg). Maximum weight for branches was recorded by *Terminalia tomentosa* (112.6 kg). All other species recorded the branch fresh weight less than 30 kg while the least was for *Tectona grandis* (4.5 kg) followed by *Grevellia robusta* (8.5 kg) and *Terminalia bellerica* (9.5 kg). In the case of twigs also, fresh weight was more for *Terminalia tomentos*a (44.0 kg) which was followed by *Grevellia robusta* (20.5 kg). The least fresh weight for twigs was for *Tectona grandis* and *Artocarpus hirsutus* (7.5 kg each). Among all the species studied, the maximum leaf biomass was accumulated by *Terminalia bellerica* (45.0 kg) and minimum by *Terminalia tomentosa* (8.5 kg).

The data illustrated in Figure 5 indicate that in all the species, trunk contributed maximum towards the total fresh biomass. The percentage contribution of trunk ranged from 55 per cent in *Swietenia macrophylla* to 86 per cent in *Tectona grandis*. The contribution of trunk was followed by branches in all the tree species except *Grevellia robusta, Tectona grandis and Terminalia bellerica* where the fresh weight of twigs was more than that of branches. The percentage contribution of branches towards total fresh weight in *Grevellia robusta*, *Tectona grandis* and *Terminalia bellerica* was 4 per cent, 3 per cent and 5 per cent respectively whereas that of twigs was 11 per cent, 5 per cent and 9 per cent respectively. In all other tree species, percentage contribution of branches was more than twigs and leaves. The percentage contribution of leaves ranged from 6 per cent in *Tectona grandis* to 23 per cent in *Artocarpus hirsutus*. The percentage contribution of the twigs to the total fresh weight was the least in all the species except *Terminalia bellerica* where the contribution of twigs was 9 per cent compared to that of leaves (7%).

Table 5. Biomass Production (kg) of the tree species grown in the arboretum

	Trunk			Branch			Twigs			Leaves			Total		
Tree species	Fresh weight	Dry weight	Moisture %	Fresh weight	Dry weight	Moisture %	Fresh weight	Dry weight	Moisture %	Fresh weight	Dry weight	Moisture %	Fresh weight	Dry weight	Moisture %
Acacia auriculiformis	233.0	125. 8	46.3	19.5	11.4	41.3	16.5	8.1	50.6	23.5	9.6	59.1	292.5	155.0	47.6
Acacia mangium	150.4	82.7	45.1	21.0	12.8	38.7	12.0	7.3	38.7	16.5	5.1	69.0	199.9	108.0	47.9
Ailanthus triphysa	119.0	50.0	58.6	25.0	12.2	55.0	19.5	6.5	66.6	41.0	11.2	57.9	204.5	79. 9	59.4
Artocarpus hirsutus	71.3	34.5	53.6	17.1	9.1	53.6	7.5	3.5	53.0	30.1	11.0	63.0	126.0	58.1	55.8
Grevellia robusta	125. 0	58.9	53.1	8.0	6.8	19.7	20.5	8.7	57.5	40.3	16.0	60.0	194.3	90.4	47.5
Swietenia macrophylla	52.0	29.1	44.8	19.0	10.1	46.4	8.5	4.5	46.4	15.0	4.1	72.4	94.5	47.9	52.5
Tectona grandis	113. 8	45.5	60.1	4.5	5.8	59.7	7.5	3.0	59.5	8.5	2.8	66.3	144.3	57.2	61.4
Terminalia bellerica	166. 9	80.1	52.6	9.5	4.1	56.1	18.5	8.1	56.2	15.5	3.4	77.9	210.4	95.8	60.7
Terminalia tomentosa	321. 9	211. 8	34.3	112.6	68.5	37.7	44.0	27.4	37.7	45.0	12.2	71.6	522.4	319.9	45.3
Xylia xylocarpa	113. 5	60.2	47.5	19.5	10.3	46.7	19.5	8.0	58.9	30.0	10.3	65.5	182.5	88.9	54.6

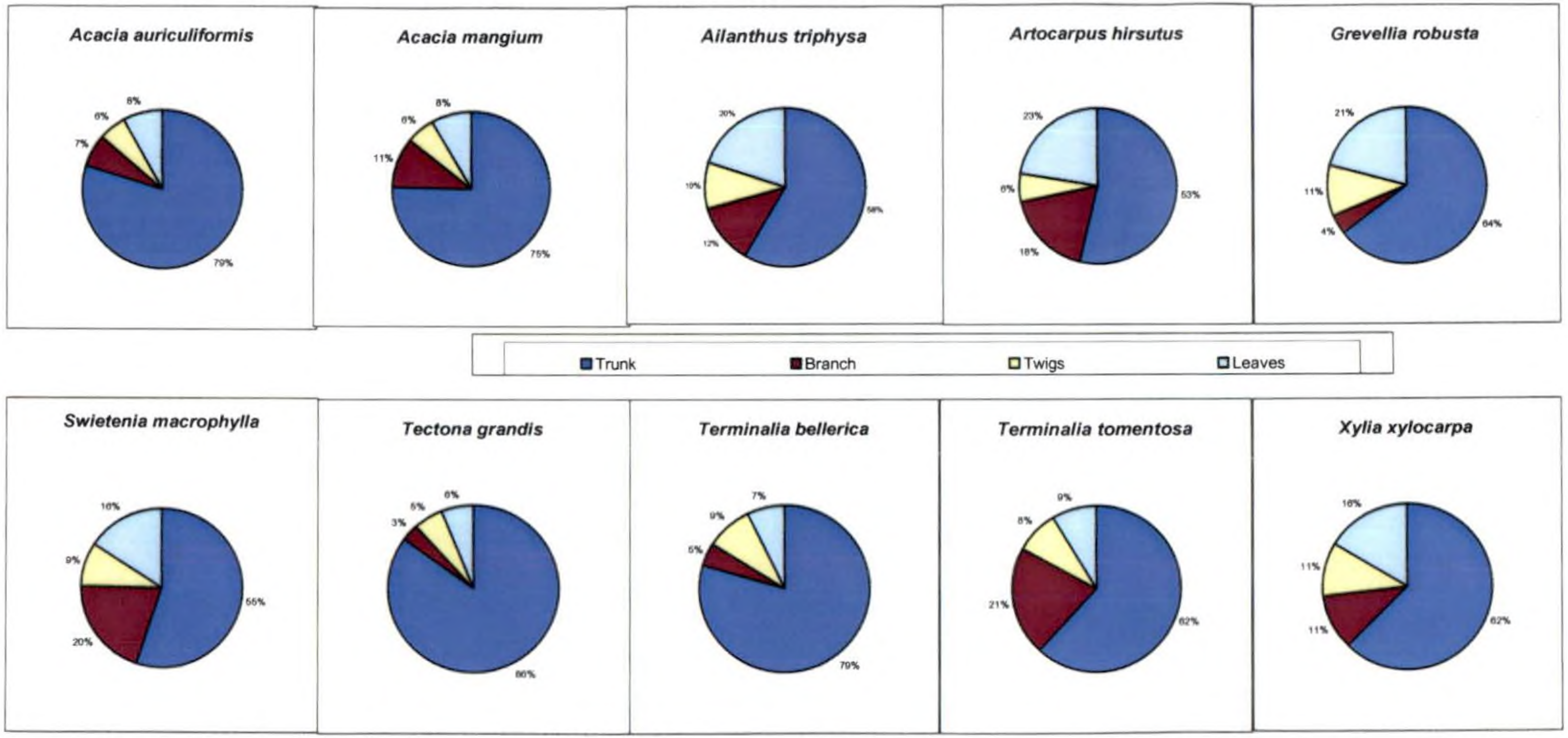


Figure 5. Percentage contribution of various components to total biomass (fresh weight basis)

4.2.2 Dry weight

The total dry weight of the whole trees ranged from 47.9 kg to 319.9 kg. Maximum total dry weight was recorded by *Terminalia tomentosa* and the minimum dry weight by *Swietenia macrophylla*. The trunk biomass was maximum for *Terminalia tomentosa* where it was 211.8 kg followed by *Acacia auriculiformis* (125.8 kg). The least dry weight for trunk was recorded for *Swietenia macrophylla* (29.1 kg) followed by *Artocarpus hirsutus* (34.5 kg). Maximum dry weight for branches was recorded for *Terminalia tomentosa* (68.5 kg). All other species recorded the branch dry weight less than 15 kg while the least was for *Terminalia bellerica* (4.1 kg) followed by *Tectona grandis* (5.8 kg) and *Grevellia robusta* (6.8 kg). In the case of twigs also, dry weight was more for *Terminalia tomentos*a (27.4 kg) which was followed by *Grevellia robusta* (8.7 kg). The least dry weight for twigs was that of *Tectona grandis* (3.0 kg) and *Artocarpus hirsutus* (3.5 kg). Among all the species studied, the maximum dry leaf biomass was accumulated by *Grevellia robusta* (16.0 kg) and minimum by *Terminalia bellerica* (3.4 kg).

It is apparent from Figure 6 that in all the tree species, trunk contributed maximum towards the total dry biomass. The percentage contribution of trunk ranged from 59 per cent in *Artocarpus hirsutus* to 84 per cent in *Terminalia bellerica*. The contribution of trunk was followed by branches in all the tree species except *Grevellia robusta* and *Terminalia bellerica* where the dry weight of twigs was more than that of branches. Dry weight percentage of branches in *Grevellia robusta* and *Terminalia bellerica* was 8 per cent and 4 per cent respectively whereas that of twigs was 10 per cent and 8 per cent respectively. The twigs contributed more percentage of dry weight compared to branches in these tree species. In all other tree species, percentage contribution of branches was more than that of twigs. For instance, in *Artocarpus hirsutus*, the percentage contribution of branches was 16 per cent compared to 6 per cent contribution of twigs to the total dry biomass of the tree. The percentage contribution of branches in biomass production was followed by leaves in species like *Artocarpus hirsutus*, *Grevellia robusta*, *Ailanthus triphysa*, *Acacia auriculiformis* and *Xylia xylocarpa*. In other species, the percentage contribution of twigs was more compared to

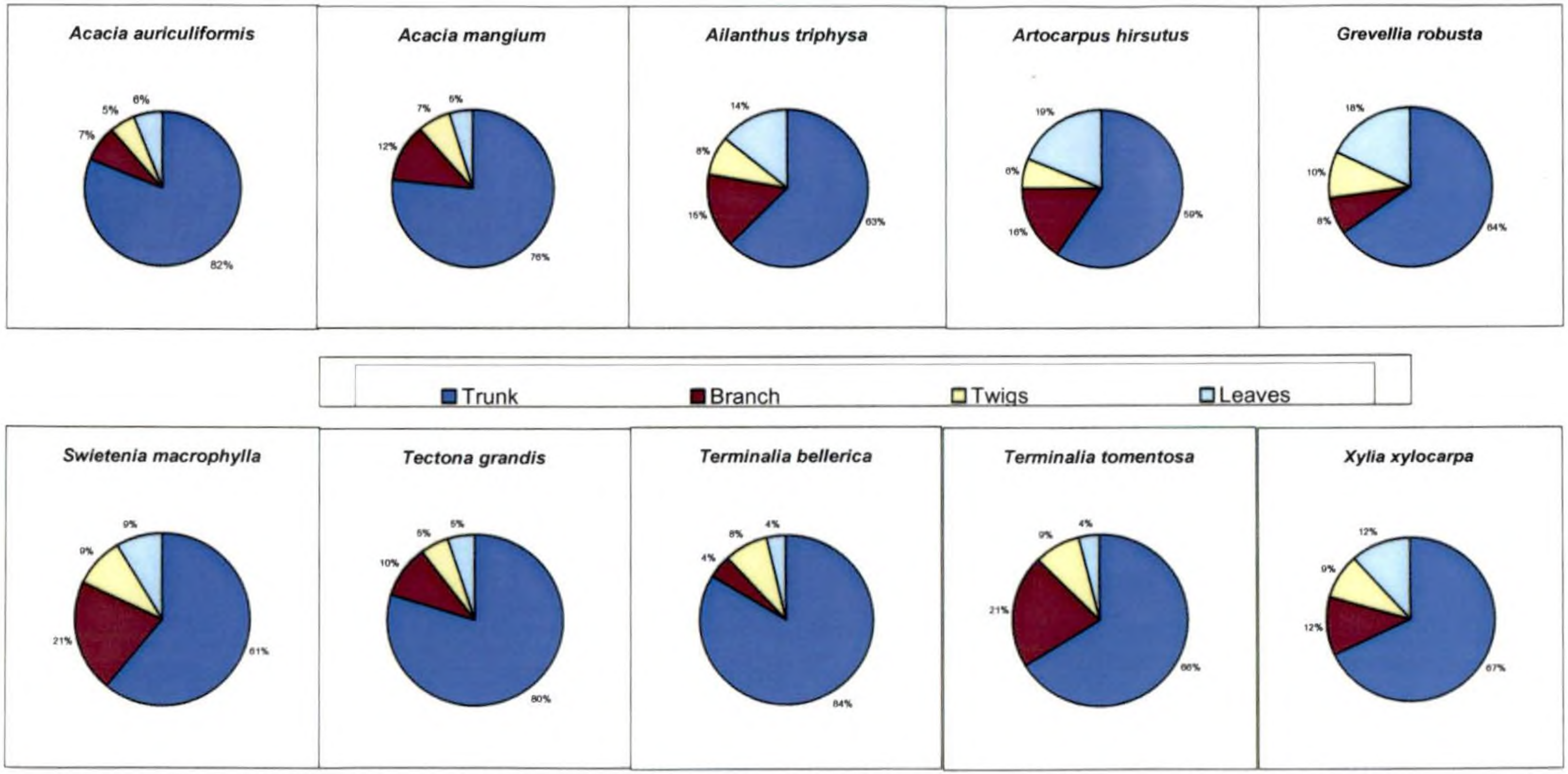


Figure 6. Percentage contribution of various components to total biomass (dry weight basis)

leaves. Percentage contribution of leaves and twigs was similar in case of *Swietenia macrophylla* (9% each) and *Tectona grandis* (5% each). The percentage contribution of leaves ranged from 4 per cent in both *Terminalia bellerica* and *Terminalia tomentosa* to 19 per cent in *Artocarpus hirsutus*.

4.2.3 Moisture percentage

The data furnished in Table 5 also indicate that in general, in all the tree species, leaves are showing higher moisture percentage followed by twigs. Trunk showed minimum moisture percentage among various tree parts and was lowest in *Terminalia tomentosa* (34.3%) followed by *Swietenia macrophylla* (44.8%). In the case of branches, the maximum moisture percentage was observed for *Tectona grandis* (59.7%) and *Terminalia bellerica* (56.2%). Moisture percentage of tree as a whole showed less diversity ranging from 45.3 per cent in *Terminalia tomentosa* to 61.4 per cent in *Tectona grandis*. Most of the tree species were recording a moisture content nearing 50 per cent.

4.3 Physical properties of wood of tree species grown in the arboretum

The observations related to physical properties of wood of tree species grown in the arboretum including heartwood percentage, sapwood percentage, heartwood/sapwood ratio and bark percentage are furnished in Table 6. The cross sectional views of discs collected from the main stem of various tree species are illustrated in Plate 2a and 2b.

4.3.1 Heartwood percentage

Discs of *Acacia mangium* recorded highest proportion (72.61%) of heartwood in basal portions compared to all other species followed by *Acacia auriculiformis* (65.04%) and *Grevellia robusta* (51.02%). Least heartwood percentage was recorded by *Artocarpus hirsutus* (12.18%) and *Xylia xylocarpa* (20.12%). In the disc from middle portion of the trunk, heartwood percentage recorded was maximum for *Acacia mangium* (66.35%) followed by *Acacia auiculiformis* (63.91%) and *Grevellia robusta* (45.94). It

Table 6. Physical properties of the wood of tree species grown in the arboretum

	Base				Middle				Top			
Tree species	Heart wood %	Sapwood %	Heartwood: Sapwood	Bark %	Heartwood %	Sapwood %	Heartwood: Sapwood	Bark %	Heartwood %	Sapwood %	Heartwood: Sapwood	Bark %
Acacia auriculiformis	65.04	19.20	3.30	15.75	63.91	24.51	2.60	11.56	56.75	22.70	2.50	20.54
Acacia mangium	72.61	21.42	3.30	5.95	66.35	26.85	2.47	6.79	64.07	28.19	2.27	7.73
Ailanthus triphysa	27.15	59.79	0.45	13.04	9.02	82.85	0.11	7.53	11.19	79.10	0.14	9.70
Artocarpus hirsutus	12.18	74.12	0.16	13.70	16.49	6.64	0.24	17.01	15.30	62.31	0.24	22.31
Grevellia robusta	51.02	38.87	1.31	10.10	45.94	37.25	1.23	16.79	28.13	52.31	0.53	19.48
Swietenia macrophylla	48.94	23.79	2.05	24.04	32.96	26.40	1.24	22.40	32.20	45.76	0.70	22.01
Tectona grandis	41.94	42.58	0.98	15.48	44.00	35.20	1.25	20.30	35.60	38.17	0.93	26.23
Terminalia bellerica	46.34	47.77	0.97	5.88	42.85	44.28	0.96	12.85	41.93	37.90	1.10	20.16
Terminalia tomentosa	41.93	34.13	1.22	23.98	26.23	52.56	0.50	21.76	14.86	53.09	0.27	19.50
Xylia xylocarpa	20.12	57.79	0.34	22.07	15.88	67.28	0.23	16.82	11.47	68.57	0.16	37.90

Plate 2a. Disc from the main stem of tree species grown in the arboretum

Swietenia macrophylla

Tectona grandis

Terminalia bellerica

Terminalia tomentosa

Xylia xylocarpa

Plate 2b.Disc from the main stem of tree species grown in the arboretum

could also be seen from the table that the least heartwood percentage was recorded for *Ailanthus triphysa* (9.02%) and *Xylia xylocarpa* (15.88%). In the disc from top of the trunk, heartwood percentage was maximum for *Acacia mangium* (64.07%) followed by *Acacia auriculiformis* (56.75%) and *Terminalia bellerica* (41.93%). However, the least was noted for *Ailanthus triphysa* (11.19%) and *Xylia xylocarpa* (11.47%).

4.3.2 Sapwood percentage

In the disc collected from basal portion of the trunk, sapwood percentage recorded was maximum for *Artocarpus hirsutus* (74.2%) closely followed by *Ailanthus triphysa* (59.79%). *Acacia auriculiformis* recorded the least (19.20%) followed by *Acacia mangium* (21.42%). In the case of disc collected from middle portion, the sapwood percentage ranged from 6.64 per cent in *Artocarpus hirsutus* to 82.85 per cent in *Ailanthus triphysa* while in the case of top disc, variation was from 22.70 per cent in *Acacia auriculiformis* to 68.57 per cent in *Xylia xylocarpa.*

4.3.3 Heartwood: Sapwood

In disc from the base of trunk, highest heartwood/sapwood ratio of 3.39 was recorded for *Acacia mangium* closely followed by *A. auriculiformis* (3.38). The ratio was minimum for *Artocarpus hirsutus* (0.16). The ratio of heartwood/sapwood decreased in the order *Acacia mangium* > *A. auriculiformis* > *Swietenia macrophylla* > *Grevellia robusta* > *Terminalia tomentosa* > *Tectona grandis* > *Terminalia bellerica* > *Ailanthus triphysa* > *Xylia xylocarpa* and *Artocarpus hirsutus.*

In the disc from middle of the trunk of the tree species, highest heartwood: sapwood ratio was recorded in *Acacia auriculiformis* (2.60) followed by *Acacia mangium*(2.47). It was least in case of *Ailanthus triphysa* (0.11). In the disc collected from top of the trunk, highest heartwood: sapwood ratio was seen in *Acacia auriculiformis* (2.50) followed by *Ailanthus triphysa* (2.27) and the ratio was least for *Ailanthus triphysa* (0.14).

4.3.4 Bark percentage

Swietenia macrophylla recorded maximum bark percentage (24.04%) closely followed by *Terminalia tomentosa* (23.98%) in the basal portion of the tree. *Terminalia bellerica* recorded minimum bark percentage (5.88%) immediately followed by *Acacia mangium* where it was 5.95 per cent. With regard to middle portion of the trees, *Swietenia macrophylla* recorded the maximum bark percentage (22.40%) followed by *Terminalia tomentosa* (21.76%). *Acacia mangium* recorded minimum bark percentage of 6.79 per cent with regard to middle portion and 7.73 per cent with regard to top portion of trees. In the top portion of trees, highest bark percentage was recorded in *Xylia xylocarpa* (37.90%) followed by *Tectona grandis* (26.23%) and *Artocarpus hirsutus* (22.31%).

4.3.5 Calorific value

The observations furnished in Table 7 and illustrated in Figure 7 indicate that the basal portion of the trunk of *Terminalia bellerica* recorded highest calorific value (7091.79 cal.g^{-1}) followed by *Artocarpus hirsutus* (5187.69 cal.g^{-1}) and *Acacia auriculiformis* (5081.58 cal.g^{-1}). *Swietenia macrophylla* has the least calorific value of 4057.70 cal.g^{-1} followed by *Acacia mangium* (4161.92 cal.g^{-1}). In the middle portion of trunk, *Terminalia bellerica* recorded the highest calorific value (5341.23 cal.g^{-1}) followed by *Acacia auriculiformis* (4775.95 cal.g^{-1}) and *Swietenia macrophylla* (4670.38 cal.g^{-1}) while *Ailanthus triphysa* had the least (3905.82 cal.g^{-1}). With regard to the top portions of trunk of all the tree species, *Acacia auriculiformis* recorded highest calorific value (5085.01 cal.g^{-1}) followed by *Artocarpus hirsutus* (4621.98 cal.g^{-1}). The calorific values are decreasing in the order : *Acacia auriculiformis* >*Artocarpus hirsutus* > *Xylia xylocarpa* > *Grevellia robusta* > *Tectona grandis* > *Terminalia tomentosa* > *Alianthus triphysa* > *Terminalia bellerica* > *Swietenia macrophylla* and *Acacia mangium*.

From the table, it is also evident that the mean calorific value was maximum for *Terminalia tomentosa* (5537.07 cal.g^{-1}) as in case of base and middle portions of the tree

Table 7. Calorific value and specific gravity of wood of tree species grown in the arboretum

Tree species	Calorific value (cal./g)				Specific gravity
	Base	Middle	Top	Mean	
Acacia auriculiformis	5081.58	4775.95	5085.01	4980.847	0.62
Acacia mangium	4161.92	4109.16	4006.46	4092.513	0.45
Ailanthus triphysa	4362.45	3905.82	4213.53	4160.600	0.33
Artocarpus hirsutus	5187.69	4517.59	4621.98	4775.753	0.45
Grevellia robusta	4883.05	4110.08	4412.62	4468.583	0.56
Swietenia macrophylla	4057.70	4670.38	4105.86	4277.980	0.82
Tectona grandis	4413.48	4366.01	4367.91	4382.468	0.47
Terminalia bellerica	7091.79	5341.23	4178.21	5537.077	0.30
Terminalia tomentosa	4165.80	4360.10	4365.15	4297.017	0.62
Xylia xylocarpa	4517.90	4005.12	4520.12	4347.713	0.54
F	**	**	**	-	*
CD (0.02)	7.56	6.86	17.02	-	0.05
S.Em ±	3.60	3.27	8.10	-	0.02

** Significant at 1 per cent level
* Significant at 5 per cent level

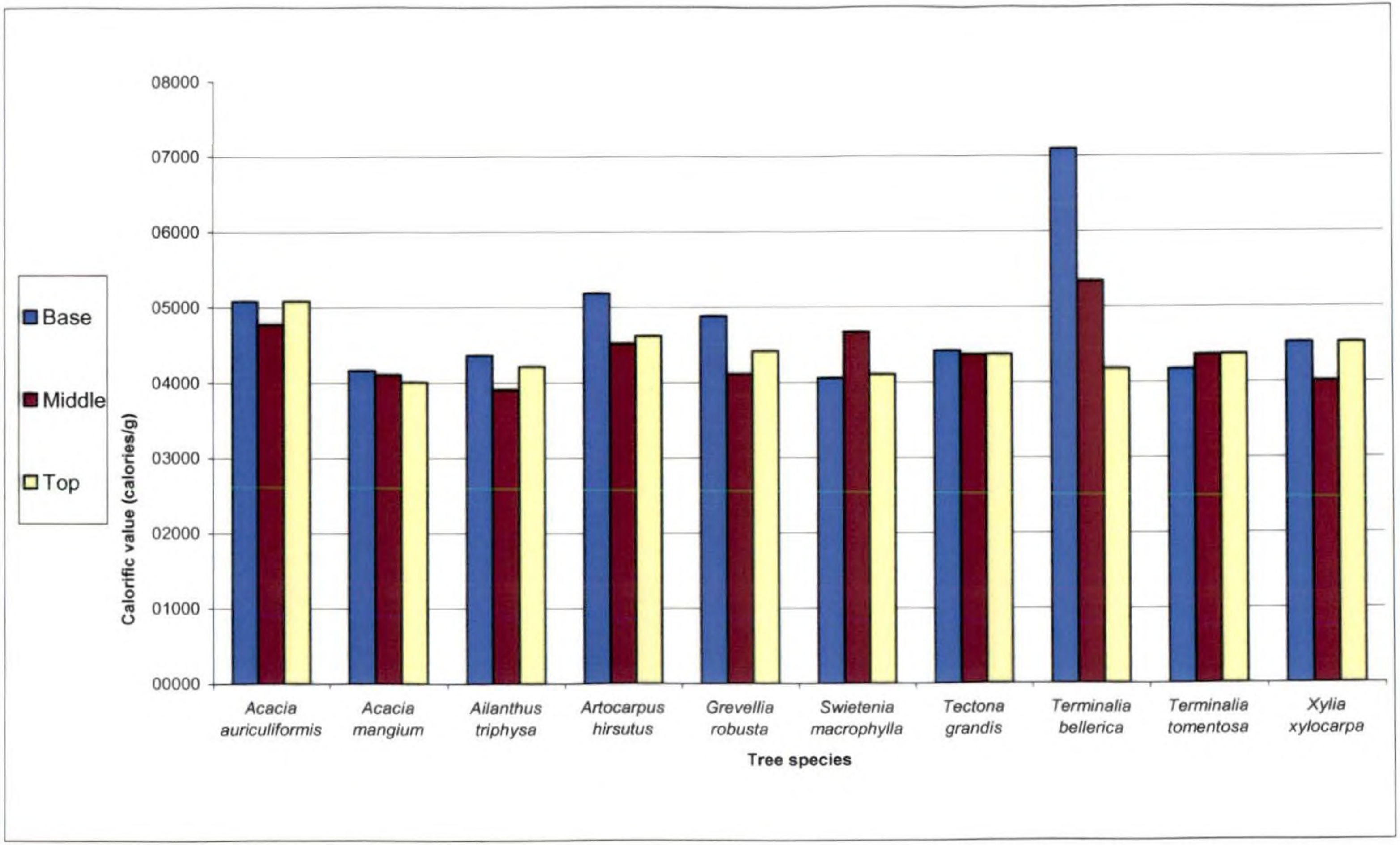


Figure7.Calorific value of tree species grown in the arboretum

Table 8. Leaf nutrient concentration of tree species grown in the arboretum

Tree species	Nitrogen (%)	Phosphorus (%)	Potassium (%)
Acacia auriculiformis	1.629	0.041	0.680
Acacia mangium	1.834	0.030	0.800
Ailanthus triphysa	1.915	0.046	0.479
Artocarpus hirsutus	1.311	0.016	0.401
Grevellia robusta	1.308	0.025	0.668
Swietenia macrophylla	1.230	0.018	0.465
Tectona grandis	1.071	0.045	0.846
Terminalia bellerica	1.581	0.018	0.419
Terminalia tomentosa	0.981	0.025	0.477
Xylia xylocarpa	1.638	0.014	0.320
F	**	*	**
CD (0.05)	0.060	0.021	0.220
S.Em ±	0.031	0.010	0.110

**Significant at 1 per cent level
* Significant at 5 per cent level

followed by *Acacia auriculiformis* (4980.84 $cal.g^{-1}$) and *Artocarpus hirsutus* (4775.75 $cal.g^{-1}$). Least average calorific value was that of *Acacia mangium* (4092.51 $cal.g^{-1}$) and *Ailanthus triphysa* (4160.60 $cal.g^{-1}$).

4.3.6 Specific gravity

The specific gravity of wood of various tree species ranged from 0.30 in *Terminalia bellerica* to 0.82 in *Swietenia macrophylla.* The species viz., *Acacia auriculiformis, A.mangium, Artocarpus hirsutus, Grevellia robusta, Tectona grandis, Terminalia tomentosa* and *Xylia xylocarpa* recorded a specific gravity of 0.62, 0.45, 0.45, 0.56, 0.47, 0.62 and 0.54 respectively.

4.4 Tissue nutrient concentration

It is evident from Table 8 that among all the tree species, tissue nitrogen content was significantly highest in *Ailanthus triphysa* (1.915%) followed by *Acacia mangium* (1.834%) and *Xylia xylocarpa* (1.638%). On the other hand, *Terminalia tomentosa* recorded minimum (0.981%) nitrogen concentration in the leaf samples. The nitrogen concentration in the leaf samples of tree species is decreasing in the order : *Ailanthus triphysa* > *Acacia mangium* > *Xylia xylocarpa* > *Acacia auriculiformis* > *Terminalia bellerica* > *Artocarpus hirsutus* > *Grevellia robusta* > *Swietenia macrophylla* > *Tectona grandis* > and *Terminalia tomentosa* (Figure 8).

The phosphorus content was found to be maximum (0.046) in *Ailanthus triphysa* followed by *Tectona grandis* (0.045%). However, the difference between these two species was not statistically significant. These two species were followed by *Acacia auriculiformis* (0.041). The lowest concentration of phosphorus was found in the leaves of *Xylia xylocarpa* (0.014%) followed by *Artocarpus hirsutus* (0.016%). The difference between these two species was also not significant.

From the above table and figure, it is also evident that the potassium content ranged from 0.320 per cent in *Xylia xylocarpa* to 0.846 per cent in *Tectona grandis*. With regard to higher potassium content, tree species *Tectona grandis* , *Acacia mangium* and *Grevellia robusta* were on par while with regard to lower potassium content, species like *Xylia xylocarpa*, *Artocarpus hirsutus*, *Terminalia bellerica* and *Terminalia tomentosa* were on par.

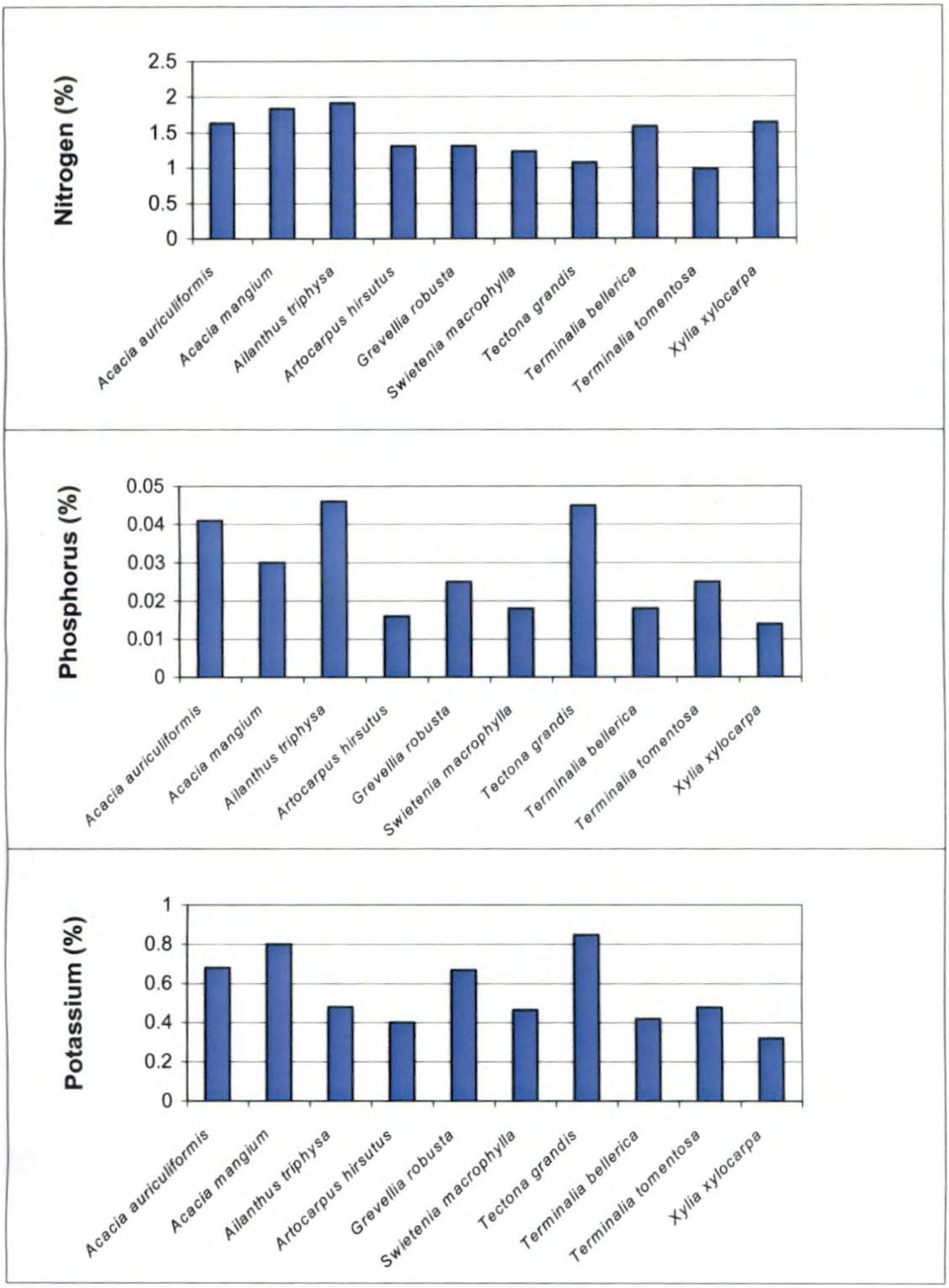


Figure 8.Leaf nutrient concentration of tree species grown in the arboretum

Discussion

DISCUSSION

The state of Kerala is blessed with high rainfall and ideal humidity conditions which favour the growth of wide varieties of tree species in the state. The state has large percentage of tropical rain forests which nurture immense flora and fauna besides many endemic species. The natural forests of Kerala are fastly depleting due to encroachments, forest fires, fire wood collection, grazing, soil erosion, developmental activities and other human interferences. Even when so many methods are being developed to improve the natural forests, it would not be possible to meet the increasing demand for food, fuel, fibre and timber. To meet this demand, the degraded forest, marginal land, village common land, strips on sides of roads, canals, railway, rivers and peripheries of agricultural fields could be utilized for planting of trees. For this purpose choice of species is an important criterion. The proper choice of tree species at a particular place which can yield enormous benefits is the need of the hour. Keeping in view of this consideration, the present research was taken up. In the present study, an attempt has been made to screen the tree species grown in the arboretum based on their growth behaviour and wood properties. Imporant findings are discussed below.

5.1 Evaluation of tree species grown in the arboretum for growth behaviour

From the observations recorded, it is apparent that among the ten tree species studied, species like *Terminalia bellerica*, *T. tomentosa, Acacia auriculiformis* and *A. mangium* were found fast growing in terms of height and girth. *Grevellia robusta*, *Xylia xylocarpa*, *Artocarpus hirsutus etc.* showed lowest increment in height and girth. *Artocarpus hirsutus* and *Grevellia robusta,* however, produced maximum number of branches. Commercial bole height of *Tectona grandis* showed maximum increment followed by *Acacia auriculiformis* whereas *Grevellia robusta* recorded minimum increment with respect to commercial bole height. The observations recorded in the present study reveal that the height and girth of *Acacia mangium* was 0.9 m and 7.3 cm respectively at the age of one year. Lahiri (1984) reported that *Acacia mangium* recorded a height and girth of 2.0 m and 4.0 cm respectively within one year when planted on the lateritic tract.

In the present study, *Grevellia robusta* was found to be poor in terms of height and girth. However, Art and Mark (1971) reported that *Grevillea robusta* was superior in growth when grown under Dehradun conditions. This indicates the better suitability of *Grevellia robusta* to subtropical and temperate conditions compared to tropical conditions. The observations recorded in the present study showed that the girth and height of *Acacia auriculiformis* at the end of third year were 35.4 cm and 7.4 m respectively. Similar studies were conducted by Pandey *et al.* (1987) on *Acacia auriculiformis* plantation in Bihar where at the end of the third year, it recorded a girth of 34 cm and a height of 3.7 m only. This indicates better suitability of *Acacia auriculiformis* to tropical high rainfall area compared to dry subtropical areas.

The observations recorded in the present study clearly reveal that both *Acacia auriculiformis* and *A. mangium* performed well in terms of height and girth. During the period from 1982 to 1995, species and provenance trials using 73 provenances of *Acacia* species have been carried out at the Institute of Forest Science, Vietnam and its research centers located across the whole country. Among the species tested, *Acacia auriculiformis, A. mangium* and *A. crassicarpa* were reported to be most promising (Kha *et al.*, 1996).

Present study also reveals that *Tectona grandis* was slow growing with regard to girth and height during the first three years. Similarly, Gera *et al.* (1996) conducted a field screening trial of 17 multipurpose tree species grown in acidic soil in the Barha experimental area, Jabalpur and reported the slow growing nature of teak particularly during the initial years. Tiwari *et al.* (1999) analyzed the growth behavior of 39 species of multipurpose trees grown in the arboretum in Madhya Pradesh on sandy loam soil and reported similar growth nature in respect of teak and terminalias.

In the present study, it is seen that the growth rates of most of the species were steady for first five years of juvenile stage. Similarly, Kumar *et al.* (2002) conducted a study on the growth rate convergence in teak trees from three sites in Karnataka and reported that growth rates of similar aged trees were relatively constant even beyond their juvenile stage.

The recent study categorises *Terminalia tomentosa* as medium to fast growing tree species both in terms of height and girth. Jisha (2006) also reported similar findings. She conducted a study to evaluate the growth performance of ten tree species grown under Vellanikkara conditions and observed significant variation with regard to growth in terms of height and girth. In terms of height increment, among the ten species studied, Casuarina *equisetifolia* and *Terminalia tomentosa* were found to be fast growing while *Pongamia pinnata*, *Tamarindus indica* and *Wrightia* tinctoria as slow growing. With regard to girth increment, *Terminalia tomentosa* and *Samanea saman* were fast growing species while *Pongamia pinnata* and *Tamarindus indica* were reported to be slow growing. *Acacia auriculiformis* and *Acacia mangium* were also found to be fast growing species according to the present study which is in agreement to the reports made by Kha *et al.* (1996). The fast growth of these species can be attributed to their nitrogen fixing ability and thick dense foliage (Chundawat and Gautam, 1993). *Artocarpus hirsutus* produced highest number of branches at the end of 15 years of age indicating its suitability for fodder and fuel when raised as social/agroforestry plantations.

5.2 Evaluation of tree species grown in the arboretum for biomass production

From the present study conducted to estimate biomass production, it is evident that the maximum biomass was produced by *Terminalia tomentosa* in terms of fresh and dry weight followed by *Acacia auriculiformis*, *Terminalia bellerica* and *Acacia mangium*. The high biomass yield of Acacias can be attributed to its wider adaptability and nitrogen fixing ability (Chundawat and Gautam, 1993), lower transpirational loss of water (Kallarackal and Soman, 1992) and the consequent lower probability of being subjected to an episode of water stress. This is of special significance in view of the monomodal rainfall distribution characteristic of the experimental site. Similar high growth rate and volume production of Acacia stands were reported by Mathew *et al.* (1992). George (1993) also reported a significantly higher value for biomass production for *Acacia, Casuarina, Leucaena* and *Ailanthus* under the similar ecoclimatic conditions of the present study. Jisha (2006) also reported the production of better biomass for *Terminalia tomentosa* compared to other species grown in Vellanikkara conditions.

Artocarpus hirsutus produced 126 kg/plant of fresh biomass in the present study which is very less compared to many other tree species. Gopikumar (2000 a) has also made similar observations where *Artocarpus hirsutus* was reported to produce lesser biomass compared to *Albizia falcataria.* Singh and Gupta (1993) found that biomass production of *Acacia auriculiformis* under Raipur conditions was 6.49 kg/plant at 7 years of age. They also reported that *Tectona grandis* yielded 11.34 kg/plant at 30 years of age. They have stated that the lower productivity of *Acacia auriculiformis* and *Tectona grandis* may be due to the fact that both the species are performing better in growth in humid conditions instead of semi arid conditions. Perez and Kanninen (2003) conducted a study on above ground biomass of *Tectona grandis* plantations in Costa Rica. Foliage dry biomass varied between 70 to 221 tonnes and total above ground biomass between 84 to 284 tonnes ha^{-1}. Foliage dry biomass was 4.1 kg/plant and total above ground biomass was 47.9 kg/plant. Jisha (2006) reported total above ground biomass of 319.9 kg/plant for *Terminalia tomentosa.* All these reports are in agreement with the observations made in the present study.

It is also evident from the present study that in all the species, trunk contributed maximum proportion of tree biomass ranging from 59 per cent in *Artocarpus hirsutus* to 82 per cent in *Acacia auriculiformis.* The contribution of branches ranged from 4.0 per cent in *Terminalia bellerica* to 21 per cent in *Swietenia macrophylla* and *Terminalia tomentosa.* Percentage contribution of twigs ranged from 5.1 per cent in *Acacia auriculiformis* and *Tectona grandis* to 10 per cent in *Grevellia robusta.* The range of leaf percentage contribution was from 4 per cent in *Terminalia bellerica* and *T. tomentosa* to 19 per cent in *Artocarpus hirsutus.*

From a four year old *Acacia auriculiformis* stand, Osman *et al.* (1992) found that the percentage of biomass allocation to the system was to the tune of 72 to 76 per cent and that to the leaves was 9 to 12 per cent. In the present study, the findings are 80.6 per cent for the bole and 6.2 per cent for the foliage. The little variation may be due to the difference in age. With regard to *Ailanthus triphysa* at 15 years of age, the foliage contributed to 14 per cent whereas stem wood contributed to 63 per cent. Naveed and Kumar (2003) evaluated the performance of *Ailanthus triphysa* grown at different densities and fertilizer regimes in Kerala. Ninety six randomly selected average sized trees were felled at 8.8 years of age for assessment. Stem wood represented the principal component (77 %), while foliage contributed the least (< 7 %).

5.3 Evaluation of tree species grown in the arboretum for wood properties

The heartwood percentage of the discs collected from basal portions of tree species was more compared to the discs collected from middle portions and the heartwood from discs from middle portions was more compared to the discs collected from top portions. This clearly indicates that heartwood is more accumulated in basal old part compared to younger top part. Being old, more of the wood is converted to heartwood as also reported by Makela (2002). Hence, for using tree species for timber purpose, the wood from the basal portions would be superior as more of heartwood would make the wood harder and more resistant to insect and pest attacks. Sapwood does not show any such regular trends. In many tree species, bark percentage is higher in the top portions of the wood compared to other portions. This may be for giving better protection to sapwood and growing tissues towards the top portion of the tree as has been reported by Klasnja *et al.* (2002).

The basal portion of the trunk of *Terminalia bellerica* recorded highest calorific value (7091.79 $cal.g^{-1}$) followed by *Artocarpus hirsutus* (5187.69 $cal.g^{-1}$) and *Acacia auriculiformis* (5081.58 $cal.g^{-1}$). *Swietenia macrophylla* has the least calorific value of 4057.70 $cal.g^{-1}$ followed by *Acacia mangium* (4161.92 $cal.g^{-1}$). In the middle portion of trunk, *Terminalia bellerica* recorded the highest calorific value (5341.23 $cal.g^{-1}$) followed by *Acacia auriculiformis* (4775.95 $cal.g^{-1}$) and *Swietenia macrophylla* (4670.38 $cal.g^{-1}$)

while *Ailanthus triphysa* had the least (3905.82 cal.g^{-1}). With regard to the top portions of trunk of all the ten tree species, *Acacia auriculiformis* recorded highest calorific value (5085.01 cal.g^{-1}) followed by *Artocarpus hirsutus* (4621.98 cal.g^{-1}).

Shanavas (2003) has reported the calorific values of 45 important fuelwood tree species grown in Kerala. Based on results, trees were classified into high calorific value trees(>4500 $cal^{-1}g$), medium calorific value trees (3750-4500 $cal^{-1}g$) and low calorific value trees(<3750 $cal^{-1}g$). He has reported high calorific values for bottom portion of trees. In the present study also, generally bottom portion of most of the trees had high calorific value. This may be due to the fact that tissues had low moisture content in these portions of the tree. However, this needs further investigations. Based on the mean calorific values, *Artocarpus hirsutus, Acacia mangium, Grevellia robusta, Swietenia macrophylla* and *Terminalia bellerica* could be classified under high calorific value class.

Groves *et al.* (1989) reported that usually high density species take longer time to ignite and burn more slowly but produce hot embers, which continue to give off a steady heat, hence giving high calorific values in high density species. This statement is true with regard to present study also. *Acacia auriculiformis* with high specific gravity of 0.62 has high mean calorific value (4980.847 $cal.^{-1}g$). Likewise *Acacia mangium* with low calorific value (4092.513 $cal.^{-1}g$) was having low specific gravity (0.45). It was reported that with increase in tree age, the specific gravity has increased from 0.47 to 0.56 in case of *Acacia mangium* (Siagian *et al.*, 1999).

The specific gravity of wood of various tree species ranged from 0.30 in *Terminalia bellerica* to 0.82 in *Swietenia macrophylla*. The species viz., *Acacia auriculiformis, A.mangium, Artocarpus hirsutus, Grevellia robusta, Tectona grandis, Terminalia tomemtosa* and *Xylia xylocarpa* recorded a specific gravity of 0.62, 0.45, 0.45, 0.56, 0.47, 0.62 and 0.54 respectively. In general, the specific gravity of the wood of most of the tree species was lower compared to the specific gravity reported for these species by earlier workers like Sahri *et al.* (1998), Bhat and Todaria (1990) and Shukla *et* *al.* (1990). This may be due to the fact that in the present study, the trees from where samples were taken were not too old and mature.

In the present study, generally leaves are showing much higher moisture percentage followed by twigs. Trunk showed minimum moisture percentage in all the tree species and was lowest in *Terminalia tomentosa* (34.3%) and *Swietenia macrophylla* (44.8%). In the case of branches, the maximum moisture percentage was observed for *Tectona grandis* (59.7%) and *Terminalia bellerica* (56.2%). Moisture percentage of tree as a whole showed less diversity ranging from 45.3 per cent in *Terminalia tomentosa* to 61.4 per cent in *Tectona grandis*. Most of the trees were recording a moisture nearing 50 per cent. Moisture in the tissues adversely affects the calorific value (Skrinska *et al.*, 1999). Water in green tissues exists primarily in the form of free water filling the wood capillaries and water of constitution of the various cell wall components. The number and size of wood capillaries, and the amount of water constitution , however, varies from species to species. In the present study, the wood moisture is profoundly variable. Among the tissue types, leaves showed the highest moisture content and otherwise having lowest calorific value. In the present study, the wood samples were collected during summer months of April-May and hence relatively low moisture content were recorded. Moreover, some moisture might have been lost during felling and subsequent conversion into scantlings. Burmester and Ranke (1982) reported similar experiences in larch trees in which the moisture content was highest during winter and lowest during summer.

5.4 Tissue nutrient concentration

Tissue nitrogen content was significantly highest in *Ailanthus triphysa* (1.915%) followed by *Acacia mangium* (1.834%) and *Xylia xylocarpa* (1.638%). On the other hand, *Terminalia tomentosa* recorded minimum (0.981%) nitrogen concentration in the leaf samples. The phosphorus content was found to be maximum (0.046) in *Ailanthus triphysa* followed by *Tectona grandis* (0.045%). However, the difference between these two species was not statistically significant. These two species were followed by *Acacia auriculiformis* (0.041). The lowest concentration of phosphorus was found in the leaves of *Xylia xylocarpa* (0.014%) followed by *Artocarpus hirsutus* (0.016%). The potassium content ranged from 0.320 per cent in *Xylia xylocarpa* to 0.846 per cent in *Tectona grandis*. With regard to higher potassium content, tree species *Tectona grandis* , *Acacia mangium* and *Grevellia robusta* were on par while with regard to lower potassium content, species like *Artocarpus hirsutus, Terminalia bellerica* and *Terminalia tomentosa* were on par. High content of nutrients particularly N, P, K and S in leaf tissues were also reported by Jamaludheen (1994), Kunhamu and Gopikumar (1996) and Hegde and Gopikumar (1996). Gopikumar (2000 b) has also reported the scope of selecting tree species based on the nutrient content in leaf tissues based on his studies using 20 different tree species.

It could be well established that the leaf biomass of most of the tree species contain considerable amount of nutrients, particularly nitrogen, phosphorus and potassium. These leaves can be used as a good manure as a source of nutrients. When the leaf biomass are incorporated to soil, it is exposed to various physical and biological factors resulting the decomposition and this upon mineralization serve as a potential source for most of the macro and micro nutrients to the plants.

A large quantity of leaf litters are produced in tropical forests. Unlike commercially manufactured products, leaf biomass does not carry any label giving specifications regarding its chemical composition and quality as it keeps on changing based on lot of environmental and genetical factors and also management practices. The practice of leaf litter application is having an added advantage as it is largely based on local and accessible resources. Extensive use of these materials will certainly improve the nutrient status of the soil with out any deleterious effects on the physico-chemical properties of the soil.

The present series of investigations clearly indicate that there is wide scope for selecting tree species based on their growth behaviour, wood properties and tissue nutrient content before recommending for commercial cultivation under social/agroforestry programme.

Summary

SUMMARY

The present series of studies were undertaken in the College of Forestry, Kerala Agricultural University, Vellanikkara to find out the growth behaviour of ten tree species viz., *Acacia auriculiformis, Acacia mangium, Ailanthus triphysa, Artocarpus hirsutus, Grewellia robusta*, *Swietenia macrophylla, Tectona grandis, Terminalia bellerica, Terminalia tomentosa* and *Xylia xylocarpa* grown in the arboretum. The information generated from the experiment, in turn will help to screen the species for extensive planting programme under agro/social/farm forestry system. The salient findings of the studies are summarized here under:

1. In terms of height increment, among the ten species studied, *Terminalia bellerica, Terminalia tomentosa* and *Tectona grandis* were found to be fast growing while *Grevellia robusta* and *Artocarpus hirsutus* were slow growing. *Ailanthus triphysa* and *Acacia mangium* could be considered as moderately fast growing species. A uniform height increment during the last 15 years was observed for *Terminalia tomentosa, Terminalia bellerica and Ailanthus triphysa* while the height increment was highly erratic in most of the other species especially, *Xylia xylocarpa* which showed a slow height growth during the initial stages which was stabilized only in the last years of growth.

2. The commercial bole heights of all the ten tree species showed wide variation. The observations recorded at the end of the study showed that maximum commericial bole height was recorded for *Terminalia tomentosa* followed by *Tectona grandis* and *Acacia auriculiformis*. However, the difference between these species with regard to this parameter was not significant. *Grevellia robusta* yielded the lowest commercial bole height followed by *Artocarpus hirsutus*.

3. With regard to girth increment, *Acacia auriculiformis* and *Terminalia bellerica* could be considered as superior while *Grevellia robusta* and *Xylia xylocarpa* as slow growing. *Terminalia tomentosa and Ailanthus triphysa* could be considered as moderately fast growing species with regard to this parameter. *Terminalia tomentosa* showed a fast and steady increase in girth during the course of experiment. *Ailanthus triphysa* showed almost steady increase in girth upto 2004. It could also be seen that during the second year, *Terminalia tomentosa* had a girth increase of more than three times of the first year. *Artocarpus hirsutus* also had a large increment in 2006 compared to 2005.

4. Based on the production of primary branches, *Artocarpus hirsutus* could be considered as most superior. The minimum number of branches was produced by *Acacia auriculiformis* and *Terminalia tomentosa. Grevellia robusta* had quick increase in number of branches during the first few years but later on, the rate of increase was very slow.

5. From the studies conducted to estimate the total biomass production, it is evident that the maximum biomass was produced by *Terminalia tomentosa* both in terms of fresh and dry weight. *Swietenia macrophylla* appeared to be most inferior with regard to total biomass production.

6. The dry weight of trunk was maximum for *Terminalia tomentosa* followed by *Acacia auriculiformis*. The least dry weight for trunk was recorded for *Swietenia macrophylla* followed by *Artocarpus hirsutus*. Trunk accounted for maximum biomass production followed by branches. The contribution of trunk was followed by branches in all the tree species except *Grevellia*

robusta and *Terminalia bellerica* where the dry weight of twigs was more than that of branches. The percentage contribution of the twigs to the total fresh weight was the least in all the species except *Terminalia bellerica* where the contribution of twigs was more compared to that of leaves.

7. Moisture percentage of trees showed less diversity ranging from 45.3 per cent in *Terminalia tomentosa* to 61.4 per cent in *Tectona grandis*. Most of the trees were recording a moisture nearing 50 per cent.

8. At the end of the study period, *Acacia mangium* and *Acacia auriculiformis* produced more heartwood compared to other species. The heartwood percentage of the discs collected from basal portions of tree species was more compared to other portions. A higher heartwood and sapwood percentage ratio was also found in *Acacia mangium* and *Acacia auriculiformis*. Sapwood percentage recorded was maximum for *Artocarpus hirsutus* closely followed by *Ailanthus triphysa*. *Terminalia bellerica* had a low bark percentage and high sapwood percentage unlike *Acacia mangium*. *Swietenia macrophylla* recorded maximum bark percentage closely followed by *Terminalia tomentosa*.

9. *Terminalia tomentosa* recorded highest mean calorific value followed by *Acacia auriculiformis*, *Artocarpus hirsutus* and *Acacia mangium* recorded the least calorific value followed by *Ailanthus triphysa*.

10. Specific gravity was observed to be highest in *Swietenia macrophylla* followed by *Acacia auriculiformis* and lowest in *Terminalia bellerica* followed by *Ailanthus triphysa*.

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11. Tissue nitrogen content was significantly highest in *Ailanthus triphysa* followed by *Acacia mangium* and *Xylia xylocarpa.* The nitrogen concentration in the leaf samples of tree species is decreasing in the order : *Ailanthus triphysa* > *Acacia mangium* > *Xylia xylocarpa* > *Acacia auriculiformis* > *Terminalia bellerica* > *Artocarpus hirsutus* > *Grevellia robusta* > *Swietenia macrophylla* > *Tectona grandis* > and *Terminalia tomentosa* .

12. The phosphorus content was found to be maximum in leaves of *Ailanthus triphysa* followed by *Tectona grandis*. However, the difference between these two species was not statistically significant. The lowest concentration of phosphorus was found in the leaves of *Xylia xylocarpa* followed by *Artocarpus hirsutus*. The difference between these two species also was not significant.

13. Leaf tissues of *Tectona grandis* recorded highest potassium content followed by *Acacia mangium* and *Acacia auriculiformis* while minimum content was recorded in *Xylia xylocarpa*.

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SCREENING OF TREE SPECIES FOR GROWTH BEHAVIOUR, BIOMASS AND WOOD PROPERTIES

By

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ABSTRACT OF THE THESIS

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ABSTRACT

The present study was conducted in College of Forestry, Kerala Agricultural University, Vellanikkara to evaluate the growth performance, biomass production, physical properties of wood and leaf nutrients of selected tree species grown in the arboretum during the period 2004 to 2006. A total of ten species were included in the study with an objective of screening the promising species for their further multiplication in the college nursery on large scale for distribution to farmers for farm/agro forestry and general afforestation programme.

The results revealed that species like *Terminalia tomentosa, Terminalia bellerica, Acacia auriculiformis* and *Acacia mangium* were found fast growing in terms of height and girth. *Grevellia robusta, Artocarpus hirsutus* etc. showed lowest increment in height and girth. *Artocarpus hirsutus* produced highest number of branches followed by *Grevellia robusta*. Number of branches did not differ significantly among other species.

The total biomass production was found to be maximum for *Terminalia tomentosa* while the lowest total biomass was produced by *Swietenia macrophylla* in terms of both fresh and dry weight. The least dry weight for trunk was also recorded for *Swietenia macrophylla* followed by *Artocarpus hirsutus*. Trunk accounted for maximum biomass production followed by branches. The contribution of trunk was followed by branches in all the tree species except *Grevellia robusta* and *Terminalia bellerica* where the dry weight of twigs was more than that of branches. *Acacia mangium* and *Acacia auriculiformis*

produced more heartwood compared to other species. *Acacia mangium, Acacia auriculiformis and Swietenia macrophylla* could be used for small timber purpose as they showed higher heartwood-sapwood percentage ratio. *Swietenia macrophylla* recorded maximum bark percentage closely followed by *Terminalia tomentosa. Terminalia bellerica, Artocarpus hirsutus* and *Acacia auriculiformis,* were having high calorific values and hence could be used for fuel wood purpose also. Specific gravity was found to be maximum for *Swietenia macrophylla* and minimum for *Terminalia bellerica.*

Leaf tissue nitrogen content was significantly highest in *Ailanthus triphysa* followed by *Acacia mangium* and *Xylia xylocarpa.* The phosphorus content was found to be maximum in *Ailanthus* while potassium in *Tectona grandis.* Leaves of *Xylia xylocarpa* were found to record minimum content of phosphorus and potassium.