EVALUATION OF TREE SPECIES FOR GROWTH, WOOD PROPERTIES AND LEAF NUTRIENT CONTENT

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled **"Evaluation of tree species for growth, wood properties and leaf nutrient content"** 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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Harsha T. Hegde

Dedicated to

My

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And

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Introduction

INTRODUCTION

A huge gap exists between deforestation and afforestation, more so in the tropics. Extensive deforestation in this region has resulted in the formation of large areas of degraded vegetation that support biodiversity. These natural forests are highly depleting due to forest fires, encroachments, unscientific management, soil erosion, developmental activities, human interference and other man made activities. Raising plantations in those degraded areas and other bare lands play an important role in promoting sustainable development in the tropics by reducing the pressure on natural forests for timber, fuel wood, fodder and other needs.

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. 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 day.

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 is one of the productive indicators of any species. Biomass produced by tree species is also important for carbon sequestration and these trees could be useful for small timber purpose also. So the wood properties and biomass production should be given importance in the choice of species. Changes in nutrient concentration of the foliage during an active growth period of tree determine the nutritional value of leaf fodder and leaf manure obtained at a particular time. It is an established fact that in addition to fodder values, leaf biomass of tree species is rich sources of nutrients which are essential for plant growth. Apart from this, 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.

Very few studies have been 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 valuable data based on which fast growing species with high biomass production, 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

The tree culture is a long term programme and there is a long interval between formation and harvesting of trees. Forestry can be made profitable by selecting proper species, extensive commercial planting of that suitable species and their effective management. 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 behavior

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

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 per ha. per 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 at the sapling stage is a light demanding evergreen tree susceptible to drought and fire.

Pandey *et al.* (1987) conducted studies in *Eucalyptus sps.* 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 11.9 m t 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 seedlings growth. 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 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 particularly in coastal areas of south India (Anon., 2002).

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 height, bark moisture content, stomatal resistance and transpiration rate were recorded three year after planting. *Acacia auriculiformis* recorded highest 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 planted 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 from 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, Dichrostachys cinerea, 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* yielded maximum leaf fodder and fuel wood yield. 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, *Acacia 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 officianalis, 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 with regard to 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* could 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 grown 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 of more than 4 cm and *Albizia lebbek, Anthocephalus chinensis, Terminalia arjuna* and *T.tomentosa* had a mean annual increment for gbh from 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 Chamoli district 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.

Shanmughavel *et al.* (2001) assessed the growth performance and dry matter production of *Leucaena leucocephala* grown in two different agro forestry systems. They reported that though there was not much difference in the height growth of trees between two sites, there was considerable difference in the girth. The basal girth of trees in site I was more than that of site II, and as a result the biomass production was also considerably higher. The dry matter production of various components in site I was more than two times compared to site II.

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 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* sub-species *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 grown 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 ground growth parameters.

Variation in growth, stemform and branching characteristics was assessed in a 48-month old provenance trail of *Casuarina junghuhniana* planted in Kanchanaburi, Thailand. There were significant differences between seed sources in most of the assessed characters such as height and diameter growth, axis persistence, stem straightness, density, thickness and angle of permanent branches and length, thickness and stiffness of branches. In general, seed sources from lower altitudes grew faster than those from high altitudes (Pinyopusarerk *et al.*, 2005).

Kumar *et al.* (2005) reported the relationship between diameter and height of some agro forestry species including neem, shisham and siris. Mean height of neem is significantly different from shisham and shiris and there was always a significant difference among the mean diameters of these three species. From the study they found out that siris give maximum yield in terms of volume.

Shono and Snoock (2006) conducted a study on the diameter growth of *Swietenia macrophylla* grown in natural forests in Jakarta. The annual diameter measurements were carried out for four years to determine growth rates. The results showed that mean diameter increment exceeded 1 cm per year, with slightly higher growth rates in trees of more than 50 cm dbh. The study also showed that inter-individual variation and inter-annual variation in growth rates was significant. Mahogany trees as small as 23 cm dbh that were left standing after harvests could be expected to attain the commercial diameter of 60 cm in 40 years between cutting cycles.

Influence of different site characters, namely soil properties, elevation and exposure to sunlight on the growth rate of *Calamus merrillii* in different plantations of Philippines were studied by Abasolo (2006). The results showed that growth rate was highly affected by soil pH, organic matter, nitrogen, potassium and phosphorus content compared to other characters. The study revealed that growth rate was obviously dependent not only on one site parameter but also on the relationship of all other related characters.

The study conducted by Gupta (2006) in College of Forestry, Vellanikkara, 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.

Piotto (2007) conducted an experiment to study the growth performance of twenty four native tree species, which were planted in different forest types including open pasture, young secondary forest and mature forest of humid tropical zones of Costa Rica. Mean annual increment in volume was used to compare the species performance. Results showed that all plots in mature forest showed low productivity. However, maximum mean annual increment in volume was achieved by *Hyeronima alchorneoides*.

Goel *et al.* (2007) studied the performance of eight species of *Prosopis* in order to identify promising species for short rotation energy plantation on sodic soil sites. Among the species studied, *Prosopis pallida* and *Prosopis affinis,* the two Peruvian species performed almost similar to local dominant species (*Prosopis juliflora*) with respect to characters such as adaptability, height and diameter.

The growth performance of 45 native species, which were planted in degraded areas of Singapore were significantly affected by nature of species, site and interaction between species and site quality. Results showed that many primary forest species performed well over secondary forest species with respect to growth rates and can be grown well in open conditions of deforested sites. Out of 45 species tested, 19 had showed diameter growth exceeding 1 cm per year while seven had growth rates below 0.5 cm per year (Shono *et al.,* 2007).

2.2 Evaluation of tree species for biomass production

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). Gurumurti *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}.

Total dry matter recorded for *Acacia nilotica* (5264 plants ha^{-1}) including roots 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, and branch) was 10.9 and 110.1 t dry matter ha^{-1} respectively. Stemwood contributed 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).

Biomass production potential of ten multipurpose trees species was studied by Gairola *et al.* (1990) and reported that *Sapindus mukorossi, Cellis australis* and *Bauhinia retusa* produced higher biomass in comparison to *Bauhinia purpurea, B. variagala, B. racemosa, Albizia lebbeck, Acacia catechu, Ougeinia dalbergioides and Grewia optiva.*

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. 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 .

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 b) 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). 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).

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}.

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.*

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}.

Aboveground biomass of 17 *Prosopis pallida* trees having the diameters at the base between 12 and 48 cm were measured by destructive methods. The results showed a very high correlation between the above-ground fresh woody biomass (r=0.97, r^2=0.941 and P=0.000) and the above-ground dry woody biomass (r=0.9573, r^2=0.9164 and P=0.000) with the diameters of the tree base (Padron and Navarro, 2004).

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 %).

The total standing tree biomass of shisham *(Dalbergia sissoo)* increased with increasing age and biomass from 53.09 tones per ha during 3rd year to 160.04 tones per ha during 7th year (Das and Chaturvedi, 2003). Vidyasagaran (2003) also reported that biomass production of *Casuarina equesitifolia* during 2nd year was 42.3 tones per ha and at 9th year, it was increased to 366.82 tones per ha. This indicated that the above ground biomass increased nine times from 2nd to 9th year in the plantations of central Kerala.

Aboveground biomass production was estimated for *Gmelina arborea* by harvesting and weighing of 120 trees in plantations ranging from 5 to 21 year old in Oluwa Forest Reserve, Nigeria. The results showed that *Gmelina* has high biomass yield, ranging from 83.2 tones per ha in 5 year old plantation to 394.9 tones per ha in 21 year old plantation and mean annual biomass increment varied from 16.2 to 20.9 tones ha^{-1} yr^{-1}. In this study average biomass allocations of different components of the tree were like, stem about 84 per cent, branch 13 per cent and foliage 3 per cent. The high biomass values were attributed to fast growth, high stand density and good site conditions in the study area (Onyekwelu, 2004).

Rawat and Negi (2004) estimated the biomass production of *Eucalyptus tereticornis* and found that it varied from 11.9 tones per ha in three years to 146 tones per ha in 9 year old plantation in moist regions. In dry tropical region it varied from

5.65 tones per ha in 5 year old plantation to 135.5 tones per ha in 9 year old plantations.

A chronosequence of *Gmelina arborea* stands ranging from one to six year old was measured to document changes in growth, biomass and nutrient contents under 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 one year old plantation at site 3 (Kusumi) and lowest (724 trees/ ha) in 6 year old stand at site 2 (Anandgaon). The stem wood contribution was 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) considering the total biomass (Swamy *et al.*, 2004).

Singh *et al.* (2006) studied the biomass production at harvest age in *Dendrocalamus strictus* plantation grown in dry deciduous areas of North India. In this study for biomass estimation harvest technique and green dry weight ratio method were adopted. Results of the study showed that the total biomass at three years age ranged from 182.7 to 207.4 tones per ha and above and below ground biomass production was 74 per cent and 26 per cent respectively.

A study conducted by Gupta (2006) in College of Forestry, Vellanikkara revealed that the total biomass production was maximum for *Terminalia tomentosa* while the lowest total biomass was produced by *Swietenia macrophylla* in terms of both fresh and dry weight, trunk accounted for maximum biomass production followed by branches. In another study, Navas (2006) found that in *Caesalpinia sappan* biomass components increased with increasing ages. The above ground biomass produced was 23.81 tones per ha at 5 year, 37.80 tones per ha at 6 year and

44.36 tones per ha at 7 year. Percentage contribution of various components to above ground biomass was in the order: bole> branch> twig> fruit> leaves> bark. Kunhamu *et al.* (2006) conducted a study in a seven-year-old *Acacia mangium* stand in Thiruvazhamkunnu to characterize biomass accumulation on per ha basis and reported that the biomass ranged from 5.58 to 97.58 tones per ha among different girth classes.

2.3 Evaluation of tree species for wood properties

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 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.

In acacias, Indonesian samples exhibited the best results in terms of both physical and chemical properties and *Acacia auriculiformis* had better qualities compare to *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 were significantly higher than that from central America with regard to wood specific gravity (Dvorak *et al.*,1998).

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 analysis of wood of *Acacia mangium* of several age groups suggest that ash content increased from 0.31 per cent to 0.83 per cent depending on the age (Siagian *et al.,* 1999). Variation of ash content was also noticed within trees.

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 even 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 dried 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, three recommendations were made viz, (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. (3) *Anthocephalus chinensis, Albizia falcataria, Endospermum peltatum, Eucalyptus deglupta* and *Aleurites moluccana* for light construction purposes where strength and durability are not critical requirements.

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).

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.

Bhat *et al.* (1999) 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 ranged from 0.550 to 0.750.

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 influenced the physical and mechanical properties of wood.

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 were better suited as fuelwood species as they manifested high wood density, low ash content and low nitrogen percentage as compared to exotics (Puri *et al.*, 1994). Furthermore, calorific value of coniferous species was higher than that of broad leaved species (Wang *et al.*, 1999). Presence of resins in most of the coniferous species is said to be the 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.

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.

Study conducted by Robert and Espen (1992) revealed 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 influenced 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).

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. Variations in calorific value among trees of same species between different localities were reported in six indigenous species by Puri *et al.* (1994). Mean calorific value ranged from 18.7 to 21.77 MJ /kg. Calorific value varied with seasonal changes and the seasonal variation of calorific value is due to the change in the ratio between low and high energy components in the tissue as a result of the change in the intensity of physiological and growth processes (Ivask, 1999). Wood density changes according to position in the tree was also reported by Chen *et al.,* (1998) and Damodaran and Chacko (1999).

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

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 $^{-3}$ 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.

One of the most important determinants of fuelwood value is the dry matter content (density) of the 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 fuel wood value. The calorific value per unit volume of wood changed with change in moisture content and the calorific value of wood with equilibrium moisture content (air-dry condition) was greater than the calorific value of 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 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).

Variation in specific gravity with topographic differences was confirmed when it was noticed that the specific gravity of wood of *Grevillea 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 the 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.

Langat and Kariuki (2004) studied the variation in heartwood proportion and basic density between provenances of *Eucalyptus grandis* in Kenya. The study indicated large variations between provenances for the two properties assessed. The average heartwood proportion ranged from 29.5 to 61.5 per cent and it decreased with height with maximum at 12.0 m. The average basic density ranged from 490.4 to 592.7 kg m^{-3} .Basic density decreased between 1.3 and 4.0 m height and thereafter increased slightly for most provenances.

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.* Calorific values of heartwood 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.

The study conducted by Gupta (2006) in College of Forestry, Vellanikkara, revealed that Acacia *mangium* and *Acacia auriculiformis* produced more heartwood compared to other species. A higher heartwood and sapwood percentage ratio was also found in these species. Moisture percentage of trees showed less diversity ranging from 45.3 per cent in *Terminalia tomentosa* to 61.4 per cent in *Tectona grandis.*

2.4 Evaluation of tree species for leaf nutrient content

According to Becker and Johnson (1998), nitrogen accumulation in *Mucuna* varied from 30 to 257 Kg per ha and nitrogen derived from atmosphere varied from 30 to 90 Kg per ha. These benefits were found to be significantly superior to other legumes crops like cowpea, Stylosanthes, Calapogonium and Centrosema. In Kerala *M. pruriens* was found to increase the soil nitrogen content by 60 Kg per ha (Sunitha, 1996).

Srivastava *et al.* (2004) studied the nutrient status of *Populus deltoids* and *Terminalia arjuna* raised on sodic land of Lucknow. From the reports of the study *Populus deltoides* showed higher concentrations of N and K, whereas *Terminalia arjuna* had relatively high concentrations of Na, Fe and Mg. Concentrations of P and Ca were almost similar in both the species. Most of the nutrients recorded highest concentrations in the rainy season which is the period of maximum nutrient stress when extension growth of leaf is completed. Mineral status of *Lannea coromandelica* during leaf active growth period were estimated by Naidu and Swami (2007) and reported that leaf showed high concentration of Ca, N and K and least with regard to Na and P.

The study conducted by Navas (2006) in College of Forestry, Vellanikkara, indicates that leaves had the maximum concentration of the nutrients and bole the lowest. Among the nutrients, N accumulated maximum followed by K and P. It was also found that nutrient use efficiency increased with increasing ages.

Gupta (2006) from the studies conducted in Vellanikkara reported that 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.

An experiment was conducted by Singh and Singh (2007) to study the nutrient build up and the impact of *Acacia nilotica* plantation on soil properties at five available stands representing different age classes. The result showed that foliage nutrient varied significantly with stand age. The level of N and K increased showing positive correlation with stand age, while P did not show significant correlation. Results also showed that, some of the nutrients decreased after 12 years, particularly in 19 year old stand. This study suggested the requirement of silvicultural management like fertilizer application and thinning of the stand after 12 years.

Leaf nutrient analysis of seven species of trees in South-East Queensland showed that the percentage by weight of phosphorus in leaves increased with the proportion of the total stand basal area of *Corymbia citriodora.* This rate of increase was greater for C. *citriodora* than other species, indicating that C. *citriodora* may be more competitive on soils with greater available phosphorus. *Corymbia citriodora* leaves also contained higher concentrations of nitrogen and potassium than the other tree species on multispecies sites. These findings indicate that the most used habitat occupied by C. *citriodora* had higher concentrations of foliar nutrients and were more productive than less used habitats (Wormington *et al.*, 2007).

Materials and Methods

MATERIALS AND METHODS

The present experiment was carried out in the arboretum of College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur, Kerala, during the period 2006 to 2008. The details of the experimental site, materials used and methodology adopted are furnished below:

3.1 Location

The experimental site is situated at 10°32' N latitude, 76°10' E longitude and at an altitude of 22- 23 m above mean sea level.

3.1.1 Climate

The study site experiences a warm humid climate, having a mean annual rainfall of 2668 mm, most of which is received during the south west monsoon (June to September). The mean maximum temperature recorded at Vellanikkara varied from 28.4°C in July to 36.0°C in March. The mean minimum temperature varied from 21.6°C in November to 25.0°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 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. *Adenanthera pavonina* L.(Coral tree)

2. *Artocarpus heterophyllus* Lam. (Jack tree)

3. *Bridelia retusa* L. A. Juss. (Kaja)

4. *Ceiba pentandra* L. Gaertn (White silk cotton tree)

5. *Hydnocarpus wightiana* Blume. (Maroti)

6. *Hymenodictyon excelsum* Roxb. Wall. (Bhaulan)

7. *Peltophorum pterocarpum* Baker. (Copper pod)

8. *Pterocarpus santalinus* L. f. (Red sanders)

9. *Samadera indica* Gaertn. (Niepa Bark Tree)

10. *Tectona grandis* L. f. (Teak)

Details of tree species are described below. General views of these tree species are depicted in plates 1a and 1b also.

1. *Adenanthera pavonina* L. (Family- Leguminosae)

Adenanthera pavonina is native to India and southern China, but now found throughout the tropics. It is a medium to large-sized deciduous tree. The trunk is basically straight with smooth bark and many fissures. The spreading crown has relatively few leaves. This tree is a good nitrogen fixer and is often cultivated as a forage, a medicinal and an ornamental tree which is also used as a garden tree. The beauty of the seeds is their uses as beads for necklace.

2. *Artocarpus heterophyllus* Lam. (Family- Moraceae)

Artocarpus heterophyllus is a tropical large evergreen fruit tree with rather short thick trunk, dark brown, rough and warty bark. It has a large round crown composed of dark green shining foliage. This tree is Indigenous to the rain forests of the western ghats of India. It has spreaded to other parts of India, Southeast Asia. It is well suited to tropical lowlands. The unripe fruit of jack is used as a vegetable or made into pickles while the ripe one is eaten fresh or preserved in syrup. The tree yields an excellant timber, which is easy to work and takes good polish. The leaves and the juice are considered having medicinal properties.

3. *Bridelia retusa* L. A. Juss. (Family- Euphorhiaceae)

Bridelia retusa is most commonly grown in South India. This medium sized, spiny deciduous tree can be used in agroforestry. Bark is ash or brown coloured and is distributed throughout India except in very dry areas. Trees usually shed their leaves during summer season. Young leaves appear during May-June months. Bark of the *Bridelia retusa* contains tannin which is used in tanning industry. Pods are edible and wood is used for making buildings, agricultural weapons, cartons *etc.*

4. *Ceiba pentandra* L. Gaertn. (Family-Bombacaceae)

A small to medium-sized tree, introduced from Amazon long ago. It is now common in South India, Sri Lanka and Myanmar. Young stems bear conical prickles, the branches arise in whorls and the adult trees are buttressed. Tree yields the commercially important fibre called kapok fibre. It is light, brittle, elastic, lustrous and white or pale yellow in colour. Kapok finds use in bedding and upholstery industries. Flosses are used in the production of life saving equipments and in the construction of thermally insulated and soundproof cover and walls. It is also used for stuffing cushions, pillows and mattresses.

5. *Hydnocarpus wightiana* Blume. (Family- Flacourtiaceae)

Hydnocarpus wightiana is an evergreen species quite common in the humid areas. It is also widely seen in the forest areas of south Konkan, Mysore and Coorg. *Hydnocarpus wightiana* is reported to show good growth in well drained moist red soils. However, it does not tolerate water logging and fire. While choosing the planting site for *H. wightiana*, care must be taken to identify those areas which receive an annual rainfall of 2250 to7500 mm with a temperature range between 35 to 40°C. The selected site necessarily should have a good soil depth. The wood of this species is preferred for making packing cases, beams and catamarans. This species is also used as a good avenue tree. Oil extracted from seeds is used in treatment of leprosy and chronic skin affections.

6. *Hymenodictyon excelsum* Roxb. Wall. (Family- Rubiaceae)

Hymenodictyon excelsum is a small to medium sized tree. Bark of the tree is smooth and grayish-brown in colour. This tree is usually confined to India, Burma, China, Thailand, Sumatra, Java, Philippines and Peninsular Malaysia. It occurs more frequently in drier areas where the forest is more open. The wood of *H. excelsum* is used locally in house building and for making boats. It is also used for making boxes, packing cases, agricultural implements, toys and matches.

7. *Peltophorum pterocarpum* Baker. (Family: Leguminoceae)

Peltophorum pterocarpum is a native of Sri Lanka. It was introduced to Calcutta botanic garden from Moluccas during the 19th century. It is most commonly found in Bihar. West Bengal, Kerala and Maharashtra. It is a deciduous tree and grows to a height of about of 15m. The tree blooms twice in the year, March to May and September to November. The handsome foliage and bright yellow flowers give wonderful contrast and attract the viewers. The wood is used for making cabinets, boxes, planks and suitable for coach building. This ornamental tree can be planted in avenues, parks, gardens, near railway platforms and vehicle parking places.

8. *Pterocarpus santalinus* L.f. (Family- Fabaceae)

Pterocarpus santalinus is an endangered species and endemic to Andhra Pradesh. Red coloured, dried broken bark is its characteristic feature. Tree blooms once in a year during dry season from late March to late May. The tree is renowned for its characteristic timber of exquisite colour, beauty and superlative technical qualities and ranks among finest luxury in Japan. The red wood yields a natural dye santalin, which is used in colouring pharmaceutical preparations, foodstuffs and also used in the manufacture of musical instruments.

9. *Samadera indica* Gaertn. (Family-Simaroubaceae)

Samadera indica is a small tree with stout branches and pale yellow bark. Leaves are large, up to 25 cm long and 9 cm broad and shining. Its fruits are also large, flat, pear shaped, much compressed, smooth reticulate, containing a large brown curved seed. This tree is found in evergreen forests and along backwaters of south India. The bark and wood are stomachic, emmenagogue, febrifuge and tonic. The leaves are useful in erysipelas.

10. *Tectona grandis* L. f. (Family-Verbenaceae)

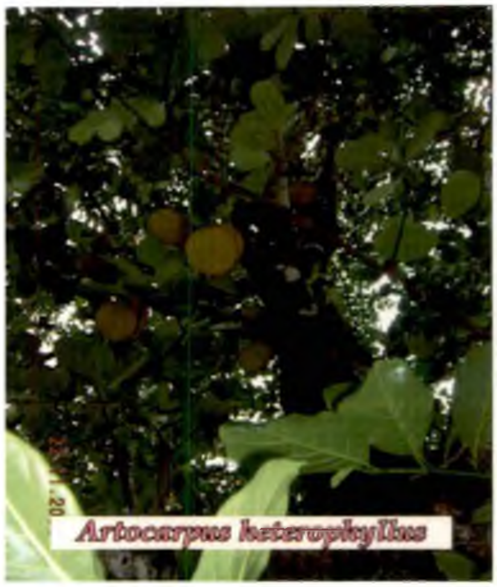
A large deciduous tree with a rounded crown and under favourable conditions, a tall clear cylindrical bole is produced, which is often buttressed at the base and some times fluted. It is the most important timber tree species of India. It is indigenous throughout the greater part of Burma and the Indian Peninsula, in Siam and in Java and other islands of the Indian Archipelago. *Tectona grandis* (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. Teak is used extensively to make doors and window frames, furniture, columns and beams. It is very resistant to termite attacks. Mature teak fetches a very good price. It is grown extensively by forest departments of different states.

3.3 Growth performance of the tree species grown in the arboretum

The following growth observations were recorded at yearly intervals. The earlier data from 1992 to 2006 were taken from department register.

3.3.1 Height

Adenanthera pavonina



Artocarpus heterophyllus

Bridelia retusa

Ceiba pentandra

Hydnocarpus wightiana

Plate 1a.A view of tree species selected for the study

Plate 1b.A view of tree species selected for the study

Height of the each tree was measured from the ground level using a standard pole. After measuring the height of all individual trees the mean height was worked out.

3.3.2 Commercial bole height

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

3.3.3 Girth

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

3.3.4 Number of primary branches

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

3.3.5 Spread

N-S and E-W spread of individual tree was measured using a measuring tape and mean spread was estimated.

3.3.6 Volume

Volume increment of individual tree was estimated by using following formula:-

$$\text{Volume} = \frac{g2}{4\Pi} \times h \times FF$$

Where, g = girth, h = height and FF = Form Factor

3.4 Biomass production of the tree species grown in the arboretum

For biomass estimation, one representative mean tree, from each species was cut at the ground level at the end of study using a peg tooth saw and mechanical chain saw.

The felled trees were then partitioned into:

1. Stem (main shoot, if the main shoot forked below the breast height level then such branches were also treated as stem).
2. Branch (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 portion of the felled trees was found out separately. Samples of the felled trees viz., stem (disc), branch, twigs and foliage were weighed in green condition to know their fresh weight. There after, they were placed in an oven at 70°C till their constant weights were realized. The moisture percentage was calculated by using following formula:-

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

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

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

Stem discs of one inch width were cut at the base, middle and at the top of stem from a randomly selected tree of each species for the estimation of heartwood percentage, sapwood percentage, heartwood - sapwood ratio and specific gravity. The procedures followed were described hereunder.

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. Total area of the disc was also calculated by using similar method.

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

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

3.5.3 Heartwood - sapwood ratio

Heartwood - sapwood ratio was estimated by using following formula:-

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

3.5.4 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 °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. Mean specific gravity was also found out.

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

3.6 Estimation of calorific value of the tree species grown in the arboretum

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)

3.7 Estimation of leaf nutrient content grown in the arboretum

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.

3.7.1 Nitrogen

Nitrogen content in the powdered sample was determined by digesting 0.5 g of samples in 10 ml of concentrated H_2SO_4 using 5ml 30 per cent H_2O_2 .

Nitrogen in the digest was estimated colorimetrically using Nessler's reagent. The colour was read in UV spectrophotometer at 410nm.

3.7.2 Phosphorus

One gram of the powdered leaf sample was digested with diacid mixture (HNO_3 and $HClO_4$ in 2:1 ratio) 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 spectrophotometer at 410 nm.

3.7.3 Potassium

A known quantity of aliquot from the diacid extract was taken to read potassium concentration using flame photometer.

3.8 Statistical analysis

The observations recorded on vegetative growth parameters of the tree species were analysed with analysis of variance technique.

Results

RESULTS

The present study has been taken up in College of Forestry, Vellanikkara to evaluate the tree species based on their growth behaviour, biomass production, wood properties and leaf nutrient content. The salient findings of the studies are furnished here under.

4.1 Growth performance of tree species grown in the arboretum

The observations taken on various growth parameters of tree species viz., height, commercial bole height, girth, number of branches, mean spread and volume for the period from 1992 to 2008 are presented here.

4.1.1 Height

The average height of tree species grown in the arboretum during the period from 1992 to 2008 along with total increment is tabulated in Table 1 and illustrated in Figure 1. The observations showed that the total height increment was maximum for *Tectona grandis* (16.5 m) followed by *Ceiba pentandra* (15.0 m) and *Artocarpus heterophyllus* (11.0 m). The lowest height increment was recorded for *Samadera indica* (6.0 m) followed by *Bridelia retusa* (8.7 m). *Hymenodictyon excelsum* recorded a total height increment of 10.6 m. Species like *Adenanthera pavonina, Bridelia retusa* and *Ceiba pentandra* showed a good height increment during initial stage while height increment was slow in some species especially *Samadera indica, Hymenodictyon excelsum and Hydnocarpus wightiana.* In the later stages of study, the species like *Tectona grandis, Ceiba pentandra* and *Artocarpus heterophyllus* achived good height increment. The height measurements were significantly different between all the species during the entire course of study . The height of tree species

Table – 1 Height (meter) of tree species grown in the arboretum

Tree species	Year of observation																	Total increment
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	
Adenanthera pavonina	2.5	4.0	5.6	7.4	9.3	9.5	9.7	9.9	10.1	10.3	10.5	10.7	10.8	11.3	11.5	11.8	12.0	9.5
Artocarpus heterophyllus	2.0	3.7	5.2	6.1	7.2	8.1	9.2	10.2	10.7	11.2	11.7	11.8	11.9	11.9	12.3	12.4	13.0	11.0
Bridelia retusa	2.8	4.7	5.9	7.0	8.3	9.5	9.6	9.7	9.8	9.9	10.1	10.3	10.5	10.8	10.9	11.2	11.5	8.7
Ceiba pentandra	2.7	4.7	6.5	8.4	8.6	8.8	9.1	9.2	9.4	9.6	9.8	10.1	10.5	12.7	12.9	15.4	17.7	15.0
Hydnocarpus wightiana	1.3	2.2	3.4	4.1	4.9	5.6	6.3	7.1	7.8	8.5	9.2	9.9	10.2	10.6	10.7	11.1	11.3	10.0
Hymenodictyon excelsum	1.0	1.6	2.9	3.7	4.5	5.3	6.1	6.9	7.7	8.5	9.2	10.1	10.4	10.9	11.2	11.4	11.6	10.6
Peltophorum pterocarpum	2.2	3.8	4.9	6.1	7.4	8.7	10.0	10.3	10.6	10.9	11.2	11.4	11.5	12.2	12.4	12.5	12.7	10.5
Pterocarpus santalinus	1.1	3.0	4.4	5.1	6.0	6.8	7.6	8.4	8.5	8.6	8.7	8.8	8.9	9.8	10.0	10.1	10.3	9.2
Samadera indica	0.6	0.8	1.6	2.1	2.7	3.3	3.9	4.5	4.7	4.9	5.1	5.2	5.3	6.2	6.3	6.4	6.6	6.02
Tectona grandis	1.3	3.3	5.1	5.9	7.6	8.7	10.2	11.3	11.7	12.2	12.6	13.3	13.6	17	17.2	17.5	17.9	16.5
F	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	
CD (0.05)	0.27	0.18	0.18	0.18	0.18	0.25	0.36	0.20	0.19	0.20	0.27	0.24	0.25	0.23	0.23	0.24	0.24	
S.Em ±	0.13	0.08	0.09	0.08	0.09	0.12	0.17	0.10	0.09	0.10	0.13	0.12	0.12	0.11	0.11	0.12	0.12	

** Significant at 1 per cent level

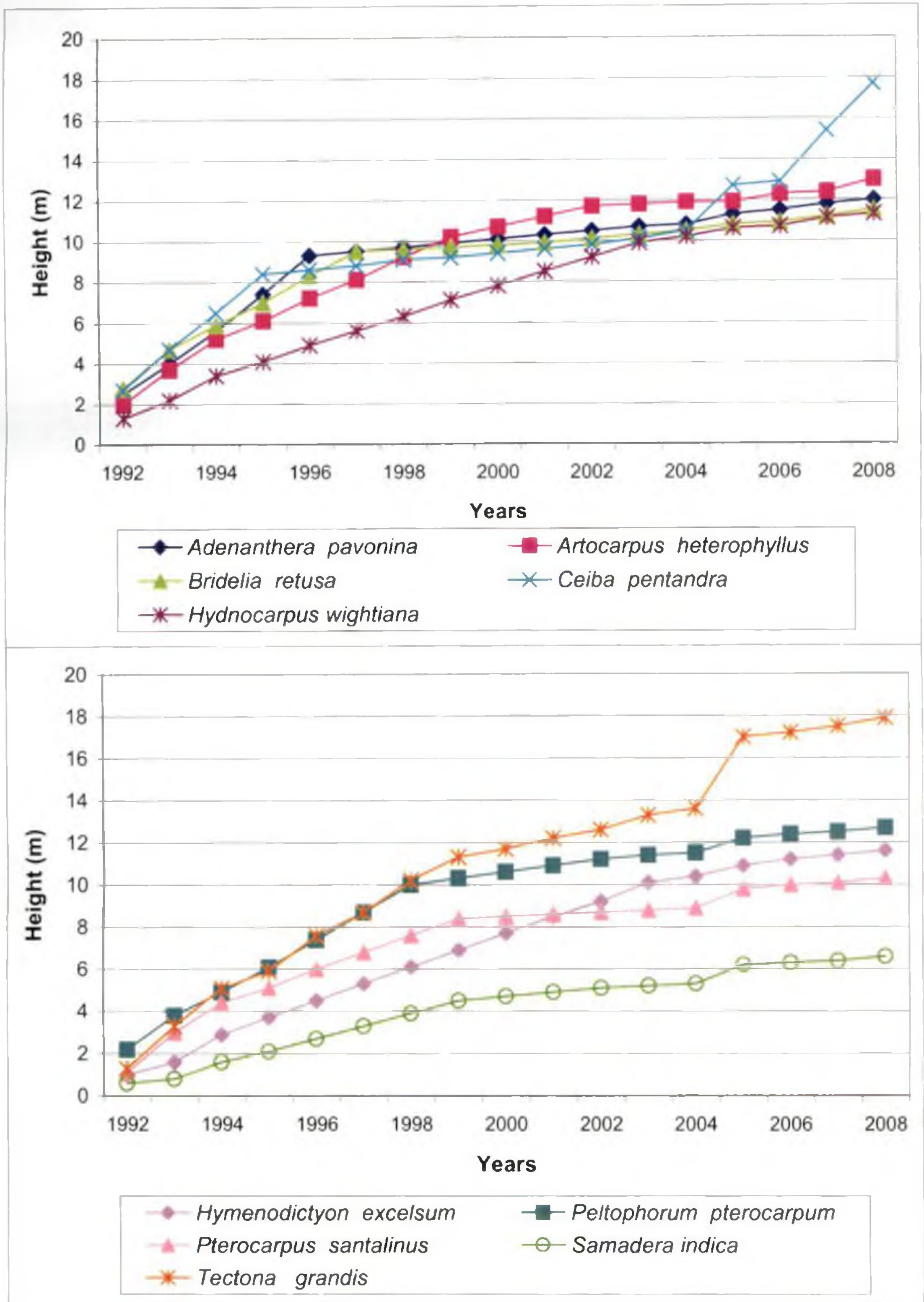


Figure 1. Height of tree species grown in the arboretum

ranged from 6.6 m in *Samadera indica* to 17.9 m in *Tectona grandis* during the last year of observation.

4.1.2 Commercial bole height

The variation showed by all the ten tree species with respect to commercial bole height during the period 2004 to 2008 along with total increment is tabulated in Table 2 and illustrated in Figure 2. The data showed that maximum commercial bole height was recorded by *Tectona grandis* (14.0 m) during 2008 followed by *Ceiba pentandra* (13.8 m). However, the difference between these two species with regard to this parameter was not significant. The lowest commercial bole height was recorded for *Samadera indica* (3.1 m) followed by *Pterocarpus santalinus* (6.6 m). *Peltophorum pterocarpum* and *Artocarpus heterophyllus* also yielded relatively good commercial bole where it was respectively 8.8 m and 8.1 m even though the difference between these two species was not significant. *Hymenodictyon excelsum* and *Hydnocarpus wightiana* were poor with regard to commercial bole height. *Tectona grandis* recorded maximum total increment with regard to commercial bole height (6.6m) while the minimum was noticed for *Hymenodictyon excelsum* (0.8 m). These trends are clear from the figure 2 also.

4.1.3 Girth

The observations taken on the girth of tree species are tabulated in Table 3 and presented in Figure 3. The data clearly indicate that the maximum girth increment was recorded for *Ceiba pentandra* (94.8 cm) which was followed by *Bredelia retusa* (75.8 cm), *Artocarpus heterophyllus* (62.8 cm) and *Peltophorum pterocarpum* (60.7 cm). On the other hand, the lowest girth increment was recorded by *Samadera indica* followed by *Hymenodictyon excelsum* and *Pterocarpus santalinus* where the total increments for a period of 16 years were 28.9cm, 39.7 cm and 39.9 cm respectively. *Ceiba pentandra* showed a fast and steady increase in girth during the course of observation . *Bredelia retusa* also

Table- 2 Commercial bole height (meter) of tree species grown in the arboretum

Tree species	Year of observation					Total Increment
	2004	2005	2006	2007	2008	
Adenanthera pavonina	6.2	7.0	7.2	7.2	7.5	1.3
Artocarpus heterophyllus	6.7	6.9	7.0	7.0	8.1	1.4
Bridelia retusa	6.9	7.3	7.5	7.7	7.9	1.0
Ceiba pentandra	9.6	10.5	10.7	13.2	13.8	4.2
Hydnocarpus wightiana	6.0	6.3	6.5	6.7	6.9	0.9
Hymenodictyon excelsum	5.9	6.3	6.5	6.6	6.8	0.8
Peltophorum pterocarpum	6.4	8.3	8.5	8.6	8.8	2.9
Pterocarpus santalinus	5.4	6.2	6.4	6.5	6.6	1.2
Samadera indica	2.1	2.9	3.0	3.1	3.1	1.0
Tectona grandis	7.4	13.2	13.7	13.8	14.0	6.6
F	**	**	**	**	**	
CD (0.05)	0.31	0.27	0.29	0.30	0.28	
S.Em ±	0.15	0.13	0.14	0.15	0.14	

** Significant at 1 per cent level

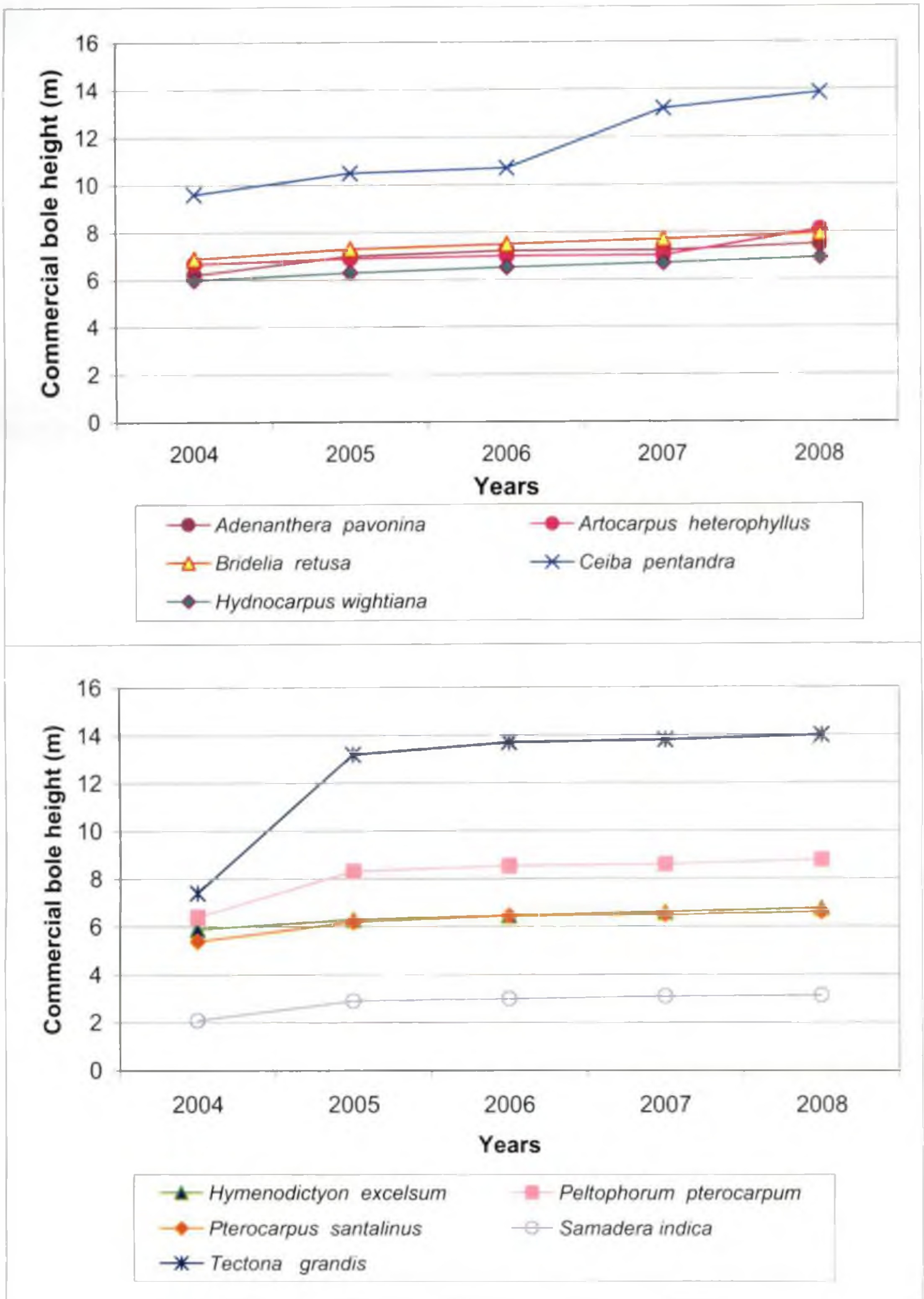


Figure 2. Commercial bole height of tree species grown in the arboretum

Table- 3 Girth (cm) of tree species grown in the arboretum

Tree species	Year of observation																	Total increment
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	
Adenanthera pavonina	9.0	20.3	28.8	32.0	35.8	39.3	42.9	46.5	47.9	49.3	50.8	52.2	53.7	57.3	58.0	59.7	63.0	54.0
Artocarpus heterophyllus	6.7	18.9	30.2	33.2	36.1	39.2	42.3	45.4	48.5	51.6	54.7	57.8	61.1	63.3	65.1	68.5	69.5	62.8
Bridelia retusa	12.6	37.8	44.1	47.5	51.0	54.6	58.5	62.0	65.8	69.6	73.5	77.3	81.2	82.2	83.3	87.2	88.4	75.8
Ceiba pentandra	16.7	40.4	51.8	57.2	62.9	68.0	73.4	73.5	73.6	73.7	73.8	73.8	73.8	75.9	80.1	103.0	111.5	94.8
Hydnocarpus wightiana	5.0	17.5	21.7	23.6	25.1	27.5	29.6	31.5	36.1	40.7	45.3	49.9	54.8	56.4	58.0	60.3	60.8	55.8
Hymenodictyon excelsum	9.9	18.5	32.3	33.3	34.3	35.3	36.3	37.3	39.8	42.5	44.1	45.8	49.0	49.1	49.5	49.5	49.6	39.7
Peltophorum pterocarpum	8.6	21.9	29.8	33.2	37.0	40.4	44.4	48.0	50.8	53.6	56.4	59.2	62.0	64.4	66.4	67.2	69.3	60.7
Pterocarpus santalinus	5.0	16.2	23.8	25.9	28.0	30.1	32.4	34.5	36.1	37.7	39.3	40.9	42.5	44.6	44.9	44.9	44.9	39.9
Samadera indica	2.9	6.6	10.4	12.5	14.6	16.9	19.0	21.1	22.1	23.1	24.1	25.2	26.2	26.3	26.4	31.7	31.8	28.9
Tectona grandis	6.8	18.8	21.4	24.1	26.7	29.4	32.0	34.4	39.2	44.0	48.8	53.6	58.7	64.1	64.8	65.0	65.6	58.8
F	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	
CD (0.05)	0.17	0.17	0.21	0.23	0.17	0.19	0.18	0.20	0.24	0.22	0.23	0.25	0.20	0.23	0.23	0.22	0.21	
S.Em ±	0.08	0.08	0.10	0.11	0.08	0.09	0.09	0.09	0.11	0.10	0.11	0.12	0.09	0.11	0.11	0.11	0.10	

** Significant at 1 per cent level

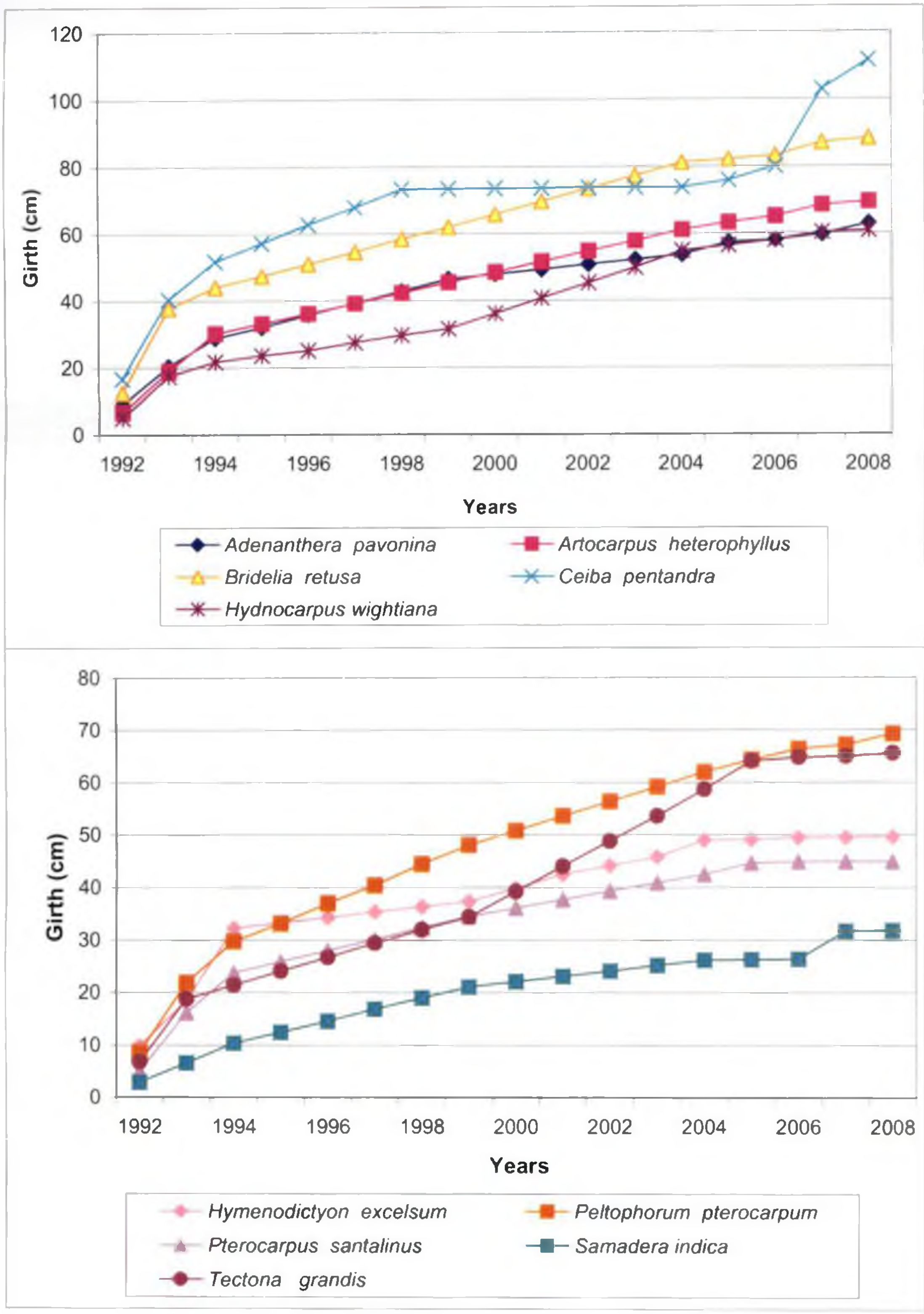


Figure 3. Girth of the tree species grown in the arboretum

showed almost steady increase in girth throughout the experimental period. With regard to total girth increment, the trees decreased in the order: *Ceiba pentandra* > *Bridelia retusa* > *Artocarpus heterophyllus* > *Peltophorum pterocarpum* > *Tectona grandis* > *Hydnocarpus wightiana* > *Adenanthera pavonina* > *Pterocarpus santalinus* > *Hymenodictyon excelsum* > *Samadera indica*. At the end of the study *i.e* in 2008, *Ceiba pentandra* recorded maximum girth of 94.8 cm which was significantly superior to all other species. The observed girth in all the species during every year is significantly different.

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 recorded by *Peltophorum pterocarpum* (60.0) followed by *Tectona grandis* (32.8) and the lowest by *Ceiba pentandra* (13.5) followed by *Pterocarpus santalinus* (13.8). The total number of branches produced by *Samadera indica* and *Hydnocarpus wightiana* at the end of study period was 22.7 and 24.1 respectively. Total increment in primary branches was also maximum in *Peltophorum pterocarpum* (57.2) and minimum in *Ceiba pentandra* (7.4). *Ceiba pentandra* started with a fair number of branches (6.1) in the first year which was significantly highest compared to all other species (Figure 4).

4.1.5 Spread

Mean spread of all the ten tree species along with total increment are tabulated in Table 5 and depicted in Figure 5. From the table and figure it is clear that the total mean increment in spread was maximum for *Artocarpus heterophyllus* (6.1 m) followed by *Adenanthera pavonina* (5.8 m) and *Tectona grandis* (5.7 m). The minimum mean spread increment was for *Samadera indica* (4.4 m) followed by both *Hymenodictyon excelsum* and *Pterocarpus santalinus*

Table – 4 Number of primary branches of tree species grown in the arboretum

Tree species	Year of observation																	Total increment
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	
Adenanthera pavonina	0.01	5.1	5.5	6.0	6.5	6.9	7.3	7.8	8.7	9.1	9.5	10.1	10.4	13.5	15.0	17.7	21.3	21.3
Artocarpus heterophyllus	5.5	4.4	7.4	8.3	9.4	10.2	10.3	10.4	10.5	10.6	10.7	11.0	11.2	11.3	14.5	16.6	17.1	11.6
Bridelia retusa	4.4	4.7	5.0	5.4	5.7	6.2	6.7	6.9	7.2	7.7	7.9	8.2	9.0	11.9	14.1	16.7	18.4	14.0
Ceiba pentandra	6.1	6.3	6.7	6.9	7.1	7.4	7.7	7.9	8.1	8.3	8.5	8.7	8.6	8.9	10.3	12.6	13.5	7.4
Hydnocarpus wightiana	5.8	6.2	6.6	7.0	7.4	7.8	8.3	8.7	9.2	9.6	10.0	10.4	15.2	16.4	18.0	20.2	24.1	18.3
Hymenodictyon excelsum	2.7	3.4	4.0	4.7	5.4	6.0	6.7	7.4	8.0	8.6	9.4	9.9	10.6	12.3	15.5	17.0	20.4	17.6
Peltophorum pterocarpum	2.9	3.8	4.6	5.6	6.5	7.5	8.4	9.3	10.2	11.1	12.1	13.0	14.0	18.0	20.1	22.4	60.0	57.2
Pterocarpus santalinus	2.5	2.7	2.9	3.2	3.5	3.7	3.9	4.2	4.5	4.9	5.3	5.5	6.5	9.3	10.5	13.0	13.8	11.3
Samadera indica	0.01	6.8	7.5	8.0	8.6	9.2	9.8	10.4	11.0	11.5	11.8	13.4	14.0	14.2	16.0	17.0	22.7	22.7
Tectona grandis	1.5	3.4	5.2	8.5	12.5	15.0	15.6	16.4	16.4	16.9	17.5	17.1	20.0	23.0	26.9	27.8	32.8	31.3
F	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	
CD (0.05)	0.19	0.20	0.23	0.23	0.24	0.44	0.31	0.32	0.40	0.32	0.27	0.27	0.29	0.28	0.27	0.29	0.33	
S.Em ±	0.09	0.10	0.11	0.11	1.04	0.21	0.15	0.15	0.19	0.15	0.13	0.13	0.14	0.13	0.13	0.14	0.16	

** Significant at 1 per cent level

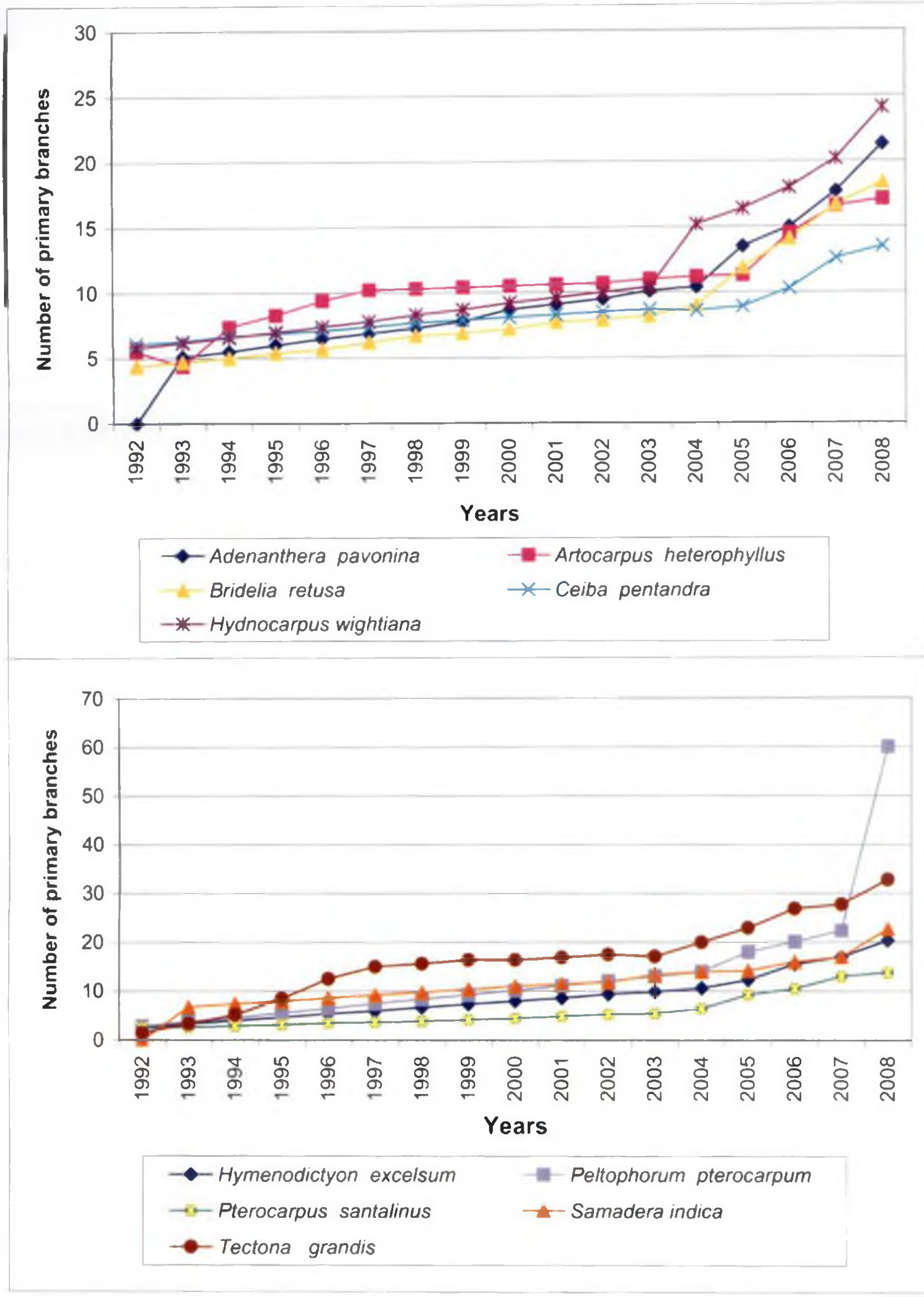


Figure 4. Number of primary branches of tree species grown in the arboretum

Table – 5 Mean spread (meter) of tree species grown in the arboretum

Tree species	Year of observation																	Total increment
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	
Adenanthera pavonina	0.8	1.2	1.7	2.1	2.5	3.0	3.4	3.8	4.3	4.5	4.7	5.1	5.5	6.1	6.3	6.4	6.6	5.8
Artocarpus heterophyllus	0.7	1.1	1.4	1.8	2.2	2.5	2.9	3.3	3.7	4.0	4.4	4.8	5.3	5.7	6.0	6.1	6.8	6.1
Bridelia retusa	0.7	1.1	1.4	1.8	2.2	2.5	2.9	3.3	3.7	4.0	4.4	4.8	5.3	5.8	6.3	6.3	6.0	5.3
Ceiba pentandra	0.4	0.7	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.7	3.7	3.9	5.0	5.7	5.3
Hydnocarpus wightiana	1.0	1.6	2.1	3.1	3.2	3.7	4.3	4.8	5.4	5.9	6.0	6.1	6.2	6.3	6.4	6.4	6.7	5.7
Hymenodictyon excelsum	0.5	0.8	1.1	1.3	1.6	1.9	2.2	2.5	2.8	3.0	3.3	3.6	3.7	4.9	5.1	5.1	5.3	4.8
Peltophorum pterocarpum	0.9	1.3	1.8	2.2	2.7	3.1	3.6	4.0	4.5	4.9	5.4	5.8	5.9	6.0	6.3	6.3	6.5	5.6
Pterocarpus santalinus	0.4	0.7	0.9	1.1	1.4	1.6	1.9	2.1	2.4	2.6	2.8	3.1	4.0	5.0	5.0	5.0	5.2	4.8
Samadera indica	0.4	0.6	0.9	1.2	1.3	1.6	1.8	2.0	2.3	2.5	2.7	2.9	3.1	4.3	4.4	4.4	4.8	4.4
Tectona grandis	0.7	1.0	1.4	1.8	2.1	2.5	2.8	3.2	3.6	3.9	4.3	4.6	4.7	5.3	6.1	6.3	6.4	5.7
F	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	
CD (0.05)	0.31	0.35	0.37	0.30	0.29	0.30	0.33	0.31	0.33	0.30	0.34	0.31	0.35	0.27	0.33	0.18	0.30	
S.Em ±	0.15	0.17	0.18	0.15	0.14	0.15	0.16	0.15	0.16	0.15	0.17	0.15	0.17	0.13	0.16	0.09	0.15	

** Significant at 1 per cent level

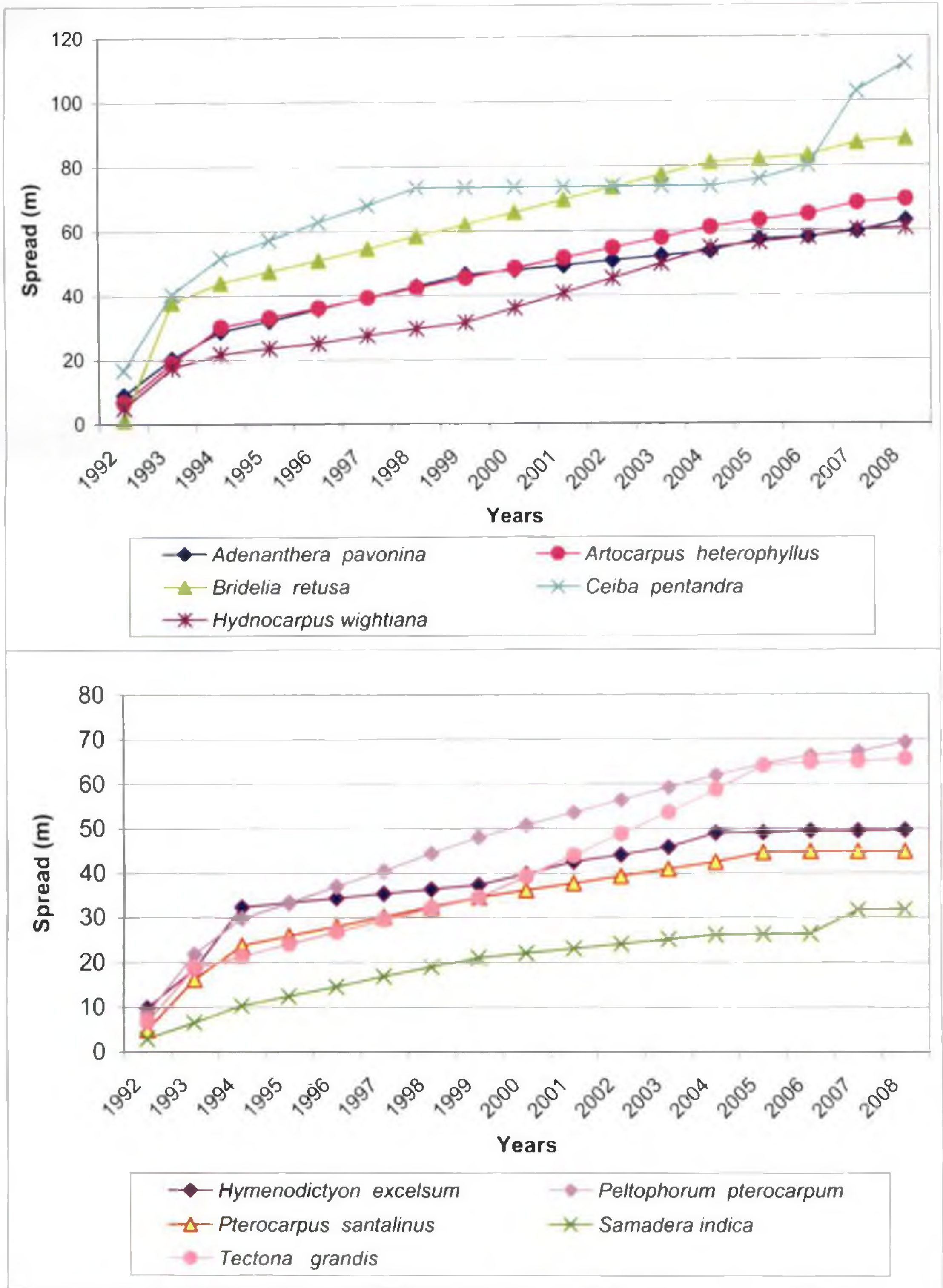


Figure 5. Mean spread of tree species grown in the arboretum

(4.25 m). From 1992 till 2007, the mean spread was highest for *Adenanthera pavonina, Hydnocarpus wightiana, Peltophorum pterocarpum* and *Tectona grandis* with regard to mean spread during 2008.

4.1.6 Volume

The observations furnished in Table 6 and Figure 6 revealed that during the end of the study in 2008, maximum volume was recorded by *Ceiba pentandra* (1.222 cu. m) followed by *Bridelia retusa* (0.497 cu. m) and *Tectona grandis* (0.435 cu. m) while the least was for *Samadera indica* (0.037 cu. m) followed by *Pterocarpus santalinus* (0.116 cu. m) and *Hymenodictyon excelsum* (0.155 cu. m). It is also clear from the data that the volume of tree species increased gradually with the increasing age. Total increment in volume of tree species studied during the period from 1994 to 2008 varied from 0.036 cu. m in *Samadera indica* to 1.124 cu. m in *Ceiba pentandra*. Species like, *Hydnocarpus wightiana, Adenanthera pavonina, Peltophorum pterocarpum* and *Artocarpus heterophyllus* recorded comparatively poor volume increment of respectively 0.219 cu. m, 0.248 cu. m, 0.313 cu. m and 0.320 cu. m.

4.2 Biomass production of tree species grown in the arboretum

The data related to biomass produced by tree species in terms of fresh and dry weight is tabulated in Table 7. The percentage contribution of various components to total biomass production is illustrated in Figures 7 and 8.

4.2.1 Fresh weight

The total fresh weight (Table 7) of the whole trees ranged from 43.6 kg in *Pterocarpus santalinus* to 302.9 kg in *Ceiba pentandra*. The maximum trunk biomass was recorded for *Adenanthera pavonina* where it was 217.2 kg, followed by *Bridelia retusa* (186.7 kg). The trunk biomass was least for *P. santalinus* where

Table – 6 Volume (cu. meter) of tree species grown in the arboretum

Species Name	Year of observation															Total Increment
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	
Adenanthera pavonina	0.027	0.043	0.067	0.083	0.100	0.120	0.130	0.141	0.152	0.164	0.175	0.208	0.217	0.236	0.275	0.248
Artocarpus heterophyllus	0.027	0.038	0.053	0.07	0.093	0.118	0.141	0.167	0.197	0.221	0.249	0.268	0.292	0.326	0.347	0.320
Bridelia retusa	0.065	0.089	0.121	0.159	0.184	0.209	0.238	0.269	0.306	0.345	0.388	0.409	0.424	0.477	0.497	0.432
Ceiba pentandra	0.098	0.154	0.191	0.228	0.275	0.279	0.286	0.293	0.299	0.309	0.321	0.41	0.464	0.915	1.222	1.124
Hydnocarpus wightiana	0.009	0.013	0.018	0.024	0.031	0.040	0.057	0.079	0.106	0.139	0.172	0.189	0.202	0.227	0.228	0.219
Hymenodictyon excelsum	0.017	0.023	0.030	0.037	0.046	0.054	0.069	0.086	0.101	0.119	0.140	0.148	0.154	0.157	0.155	0.138
Peltophorum pterocarpum	0.025	0.038	0.057	0.08	0.111	0.133	0.154	0.176	0.200	0.224	0.248	0.284	0.307	0.317	0.338	0.313
Pterocarpus santalinus	0.014	0.020	0.027	0.035	0.045	0.056	0.063	0.069	0.076	0.083	0.091	0.110	0.113	0.115	0.116	0.102
Samadera indica	0.001	0.002	0.004	0.006	0.008	0.012	0.013	0.015	0.017	0.019	0.021	0.025	0.025	0.037	0.037	0.036
Tectona grandis	0.014	0.02	0.031	0.043	0.059	0.075	0.101	0.133	0.169	0.214	0.263	0.392	0.405	0.415	0.435	0.421
F	*	*	*	**	**	**	**	**	**	**	**	**	**	**	**	
CD (0.05)	0.03	0.05	0.08	0.09	0.12	0.14	0.14	0.15	0.16	0.19	0.20	0.22	0.23	0.24	0.24	
S.Em ±	0.01	0.02	0.04	0.04	0.06	0.06	0.07	0.08	0.08	0.08	0.09	0.10	0.11	0.11	0.12	

* Significant at 5 per cent level

** Significant at 1percent level

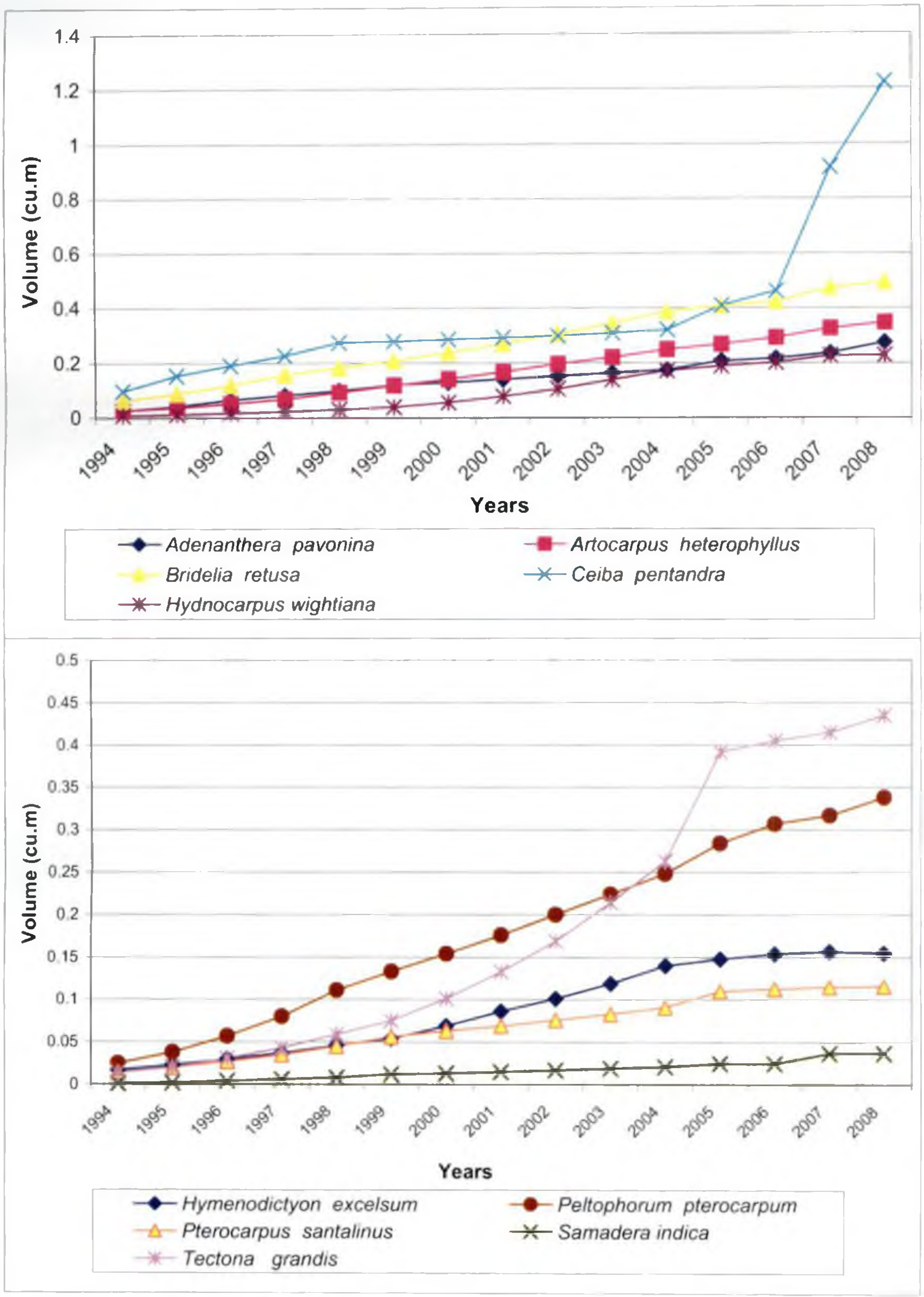


Figure 6. Volume of tree species grown in the arboretum

it was 19.6 kg followed by *Samadera indica* (47.8 kg). Maximum weight for branches was recorded by *Hydnocarpus wightiana* (90.2 kg) while the least was for *Pterocarpus santalinus* (8.0 kg) followed by *Tectona grandis* (14.5 kg) and *Samadera indica* (16.0 kg). In the case of twigs, fresh weight was more for *Bridelia retusa* (31.7 kg) which was followed by *Hydnocarpus wightiana* (26.5 kg). The least fresh weight for twigs was for *Adenanthera pavonina* (3.9 kg) followed by *Pterocarpus santalinus* and *Tectona grandis* (7.5 kg each). Among all the species studied, the maximum leaf biomass was accumulated by *Ceiba pentandra* (98.5 kg) and minimum by *Hymenodictyon excelsum* (2.0 kg).

The data illustrated in Figure 7 indicate that in all the species, trunk contributed maximum towards the total fresh biomass. The percentage contribution of trunk ranged from 46 per cent in *Pterocarpus santalinus* to 79 per cent in *Tectona grandis*. The contribution of trunk was followed by branches in all the tree species except *Ceiba pentandra* and *Pterocarpus santalinus* where the contribution from leaves was more than that of branches. The percentage contribution of branches towards total fresh weight in *Ceiba pentandra* and *Pterocarpus santalinus* was 8 and 18 per cent respectively whereas that of leaves was 33 and 19 per cent respectively. The percentage contribution of twigs ranged from 1 per cent in *Adenanthera pavonina* to 17 per cent in *Pterocarpus santalinus*.

4.2.2 Dry weight

The total dry weight of the whole trees ranged from 15.9 kg to 178.0 kg as is evident from the data furnished in Table 7. Maximum total dry weight was recorded by *Adenanthera pavonina* and the minimum by *Pterocarpus santalinus*. The trunk biomass was the maximum for *Adenanthera pavonina* where it was 140.3 kg followed by *Bridelia retusa* (98.2 kg). The least dry weight for trunk was recorded for *Pterocarpus santalinus* (9.2 kg) followed by *Samadera indica* (26.3 kg). Maximum dry weight for branches was recorded for *Hydnocarpus wightiana* (39.7 kg) while the least was for *Pterocarpus santalinus* (3.4 kg) followed by

Table-7 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 %
Adenanthera pavonina	217.2	140.3	35.4	43.0	25.4	41.1	3.9	2.3	39.2	25.0	9.9	50.1	289.1	178.0	41.4
Artocarpus heterophyllus	87.2	48.0	42.7	35.5	19.2	44.4	16.5	6.7	56.5	2.4	0.62	70.5	141.6	74.5	53.5
Bridelia retusa	186.7	98.2	45.3	45.8	25.6	41.8	31.7	15.2	49.2	8.5	2.16	70.9	272.7	141.4	51.8
Ceiba pentandra	169.2	48.4	67.9	25.1	8.8	61.5	10.1	2.1	75.0	98.5	43.6	56.3	302.9	102.9	65.2
Hydnocarpus wightiana	146.2	64.7	53.0	90.2	39.7	53.2	26.5	10.1	58.9	23.5	7.91	63.1	286.4	122.5	57.0
Hymenodictyon excelsum	80.3	28.7	61.1	29.7	11.9	57.2	12.3	2.9	72.7	2.0	0.3	80.0	124.3	43.8	67.7
Peltophorum pterocarpum	152.9	81.1	41.9	32.8	21.7	32.0	22.0	11.1	47.1	14.0	6.3	52.3	221.7	120.3	43.3
Pterocarpus santalinus	19.6	9.2	53.2	8.0	3.4	57.1	7.5	1.6	77.7	8.5	1.6	80.9	43.6	15.9	67.2
Samadera indica	47.8	26.3	42.7	16.0	7.2	52.0	12.5	4.8	58.0	11.5	2.8	72.3	87.8	41.2	56.2
Tectona grandis	113.8	45.5	60.1	14.5	5.8	59.7	7.5	3.0	59.5	8.5	2.8	66.2	140.3	57.2	61.4
F	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
CD (0.05)	2.59	2.56	2.44	2.58	2.51	2.34	2.57	2.52	2.81	2.67	2.41	2.78	2.43	2.62	2.74
S.Em ±	1.23	1.22	1.16	1.22	1.21	1.16	1.26	1.21	1.34	1.28	1.31	1.29	1.16	1.28	1.32

** Significant at 1 per cent level

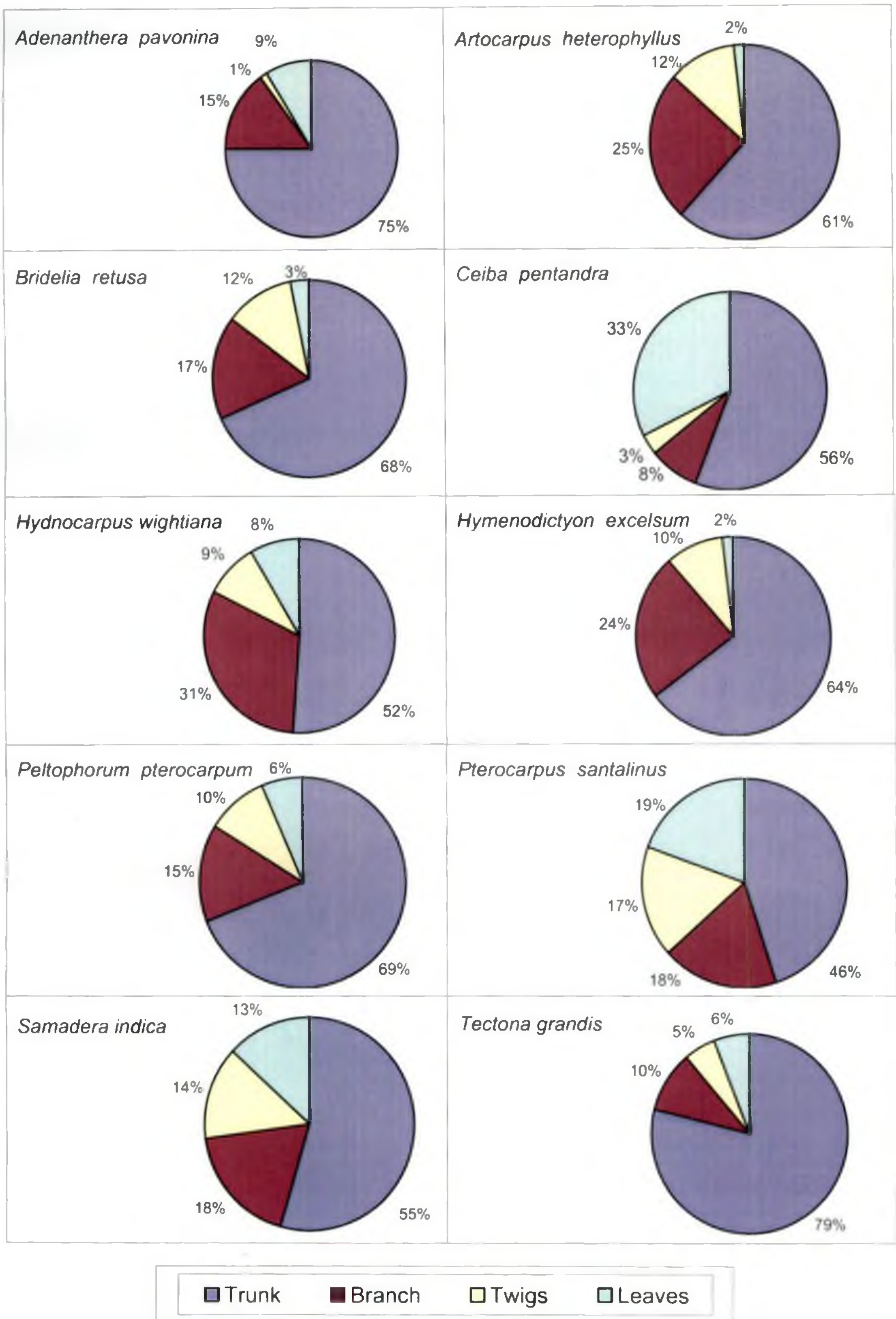


Figure 7. Percentage contribution of various components to total biomass (fresh weight basis)

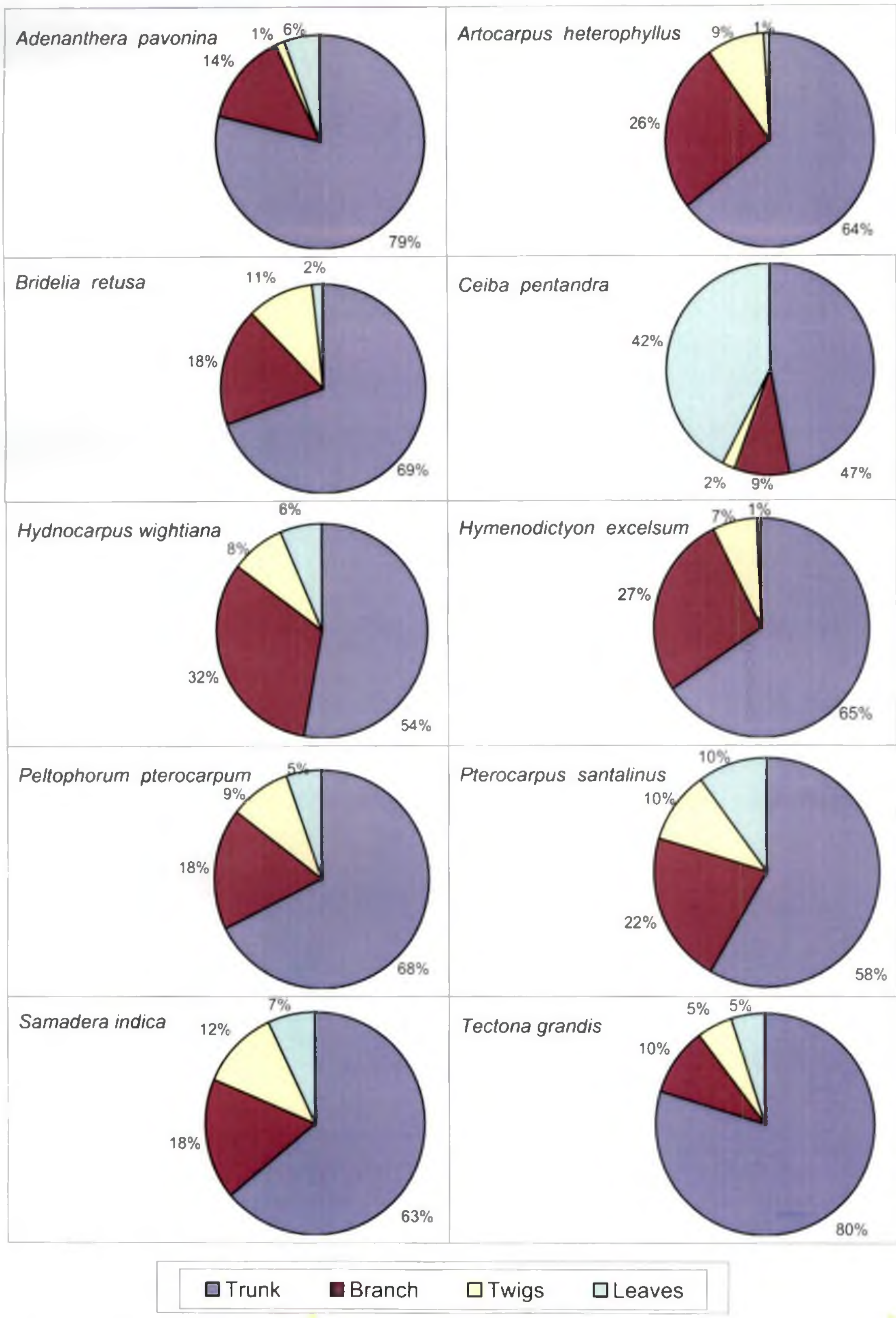


Figure 8. Percentage contribution of various components to total biomass (dry weight basis)

Tectona grandis (5.8 kg) and *Samadera indica* (7.2 kg). In the case of twigs, dry weight was more for *Bridelia retusa* (15.2 kg) and this was followed by *Peltophorum pterocarpum* (11.1 kg). The least dry weight for twigs was that of *Pterocarpus santalinus* (1.6 kg) and *Ceiba pentandra* (2.1 kg). Among all the species studied, the maximum dry leaf biomass was accumulated by *Ceiba pentandra* (43.6 kg) and minimum by *Artocarpus heterophyllus* (0.6 kg). It is very clear from the data that the dry weight of the different components varied significantly with respect to all the species studied.

The data illustrated in Figure 8 indicate that like fresh weight in all the tree species, trunk contributed maximum towards the total dry biomass. The percentage contribution of trunk ranged from 47 per cent in *Ceiba pentandra* to 80 per cent in *Tectona grandis*. With regard to the percentage contribution, trunk was followed by branches in all the tree species except *Ceiba pentandra* where the dry weight of leaves was more than that of branches. Dry weight percentage of branches was highest in case of *Hydnocarpus wightiana* where it was 32 per cent followed by *Hymenodictyon excelsum* (27 %). It could also be seen from the figure that dry weight contribution of branches is least in species like *Ceiba pentandra* (9 %) followed by *Tectona grandis* (10%). Percentage contribution of twigs and leaves are almost similar in the case of *Pterocarpus santalinus* and *Tectona grandis* where it was 10 and 5 per cent respectively. Contribution of twigs to total dry weight was very less in *Adenanthera pavonina* (1%) and is higher in *Samadera indica* (12%). Leaves contributed 42 per cent to total dry weight in the case of *Ceiba pentandra* which is highest and least was recorded for the species *Artocarpus heterophyllus* and *Hymenodictyon excelsum* where it was only 1 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, and bark percentage are furnished in Table 8. The cross sectional views of discs collected from the main stem of various tree species are illustrated in Plates 2a and 2b.

4.3.1 Heartwood percentage

It could be seen from the table that the discs of *Adenanthera pavonina* recorded highest proportion (45.20%) of heartwood in basal portions followed by *Tectona grandis* (41.94%) and *Bridelia retusa* (40.51%). However, the difference between these tree species was not significant. Heartwood percentage recorded by *Samadera indica* (17.69%) and *Peltophorum pterocarpum* (26.89%) was on par. In the disc from middle portion of the trunk, heartwood percentage recorded was maximum for *Tectona grandis* (44.00%) followed by *Bridelia retusa* (38.83%). It could also be seen from the table that the least heartwood percentage was recorded for *Artocarpus heterophyllus* (15.27%) and *Hymenodictyon excelsum* (20.53%). In the disc from top of the trunk, heartwood percentage varied from 14.50 per cent in *Adenanthera pavonina* to 37.35 per cent in *Pterocarpus santalinus*. The species like, *Bridelia retusa, Tectona grandis, Ceiba pentandra, Peltophorum pterocarpum* and *Hymenodictyon excelsum* could be regarded as moderate ones with respect to heartwood percentage in top discs.

4.3.2 Sapwood percentage

In the disc collected from basal portion of the trunk, sapwood percentage recorded was maximum for *Samadera indica* (77.55%) followed by *Peltophorum pterocarpum* (65.81%). *Pterocarpus santalinus* recorded the least (40.41%) followed by *Tectona grandis* (42.58%). In the case of disc collected from middle portion, the variation of the sapwood percentage was from 35.20 per cent in *Tectona grandis* to 75.88 per cent in *Artocarpus heterophyllus* while in the case of top disc, variation was from 35.69 per cent in *Pterocarpus santalinus* to 79.67 per cent in *Samadera indica*. The superiority and inferiority of species with regard to

Table-8 Physical properties of the wood of tree species grown in the arboretum

	Base				Middle				Top			
Tree species	Heart wood %	Sapwood %	Heartwood: Sapwood	Bark %	Heart wood %	Sapwood %	Heartwood: Sapwood	Bark %	Heartwood %	Sapwood %	Heartwood: Sapwood	Bark %
Adenanthera pavonina	45.20	47.80	0.94	6.80	30.70	62.30	0.49	6.90	14.50	78.50	0.18	6.80
Artocarpus heterophyllus	30.46	59.41	0.51	10.13	15.27	75.88	0.20	8.85	16.18	77.45	0.21	6.37
Bridelia retusa	40.51	49.27	0.82	10.22	38.83	50.00	0.78	11.17	37.13	53.31	0.70	9.56
Ceiba pentandra	27.19	62.21	0.44	10.60	29.77	62.60	0.48	7.63	34.93	58.59	0.60	6.48
Hydnocarpus wightiana	35.91	61.80	0.58	2.29	24.87	70.15	0.35	4.97	19.04	74.96	0.25	6.00
Hymenodictyon excelsum	28.84	52.35	0.55	18.81	20.53	58.17	0.35	21.29	23.94	50.53	0.47	25.53
Peltophorum pterocarpum	26.89	65.81	0.41	7.30	28.85	63.40	0.45	7.75	28.07	63.73	0.44	8.20
Pterocarpus santalinus	33.75	40.41	0.82	25.83	32.63	37.54	0.86	29.02	37.35	35.69	1.04	26.95
Samadera indica	17.69	77.55	0.23	4.76	25.45	69.09	0.37	5.45	17.07	79.67	0.21	3.25
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
F	**	**	**	**	**	**	**	**	**	**	**	**
CD (0.05)	2.40	2.48	0.24	2.92	2.52	2.66	0.22	2.84	2.36	2.72	0.21	2.72
S.Em ±	1.14	1.24	0.12	1.39	1.25	1.26	0.12	1.41	1.18	1.31	0.11	1.34

** Significant at 1 per cent level

Adenanthera pavonina

Artocarpus heterophyllus

Bridelia retusa

Ceiba pentandra

Hydnocarpus wightiana

Plate 2a.A view of stem discs of tree species selected for the study

Hymenodictyon excelsum

Peltophorum pterocarpum

Pterocarpus santalinus

Samadera indica

Tectona grandis

Plate 2b.A view of stem discs of tree species selected for the study

sapwood percentage in the base, middle and top discs are evident from the data furnished in above table.

4.3.3 Heartwood - Sapwood ratio

The observations furnished in Table 8 revealed that in disc from the base of trunk, highest heartwood - sapwood ratio of 0.98 was recorded for *Tectona grandis* closely followed by *Adenanthera pavonina* (0.94). The ratio was the minimum for *Samadera indica* (0.23). The ratio of heartwood - sapwood decreased in the order: *Tectona grandis* > *Adenanthera pavonina* > *Bridelia retusa* = *Pterocarpus santalinus* > *Hydnocarpus wightiana* > *Hymenodictyon excelsum* > *Artocarpus heterophyllus* > *Ceiba pentandra* > *Peltophorum pterocarpum* > *Samadera indica.*

In the disc from the middle of the trunk of the tree species, highest heartwood - sapwood ratio was recorded in *Tectona grandis* (1.25) followed by *Pterocarpus santalinus* (0.86). *Artocarpus heterophyllus* (0.20) stood lowest with regard to this parameter. In the disc collected from top of the trunk, highest heartwood - sapwood ratio was seen in *Pterocarpus santalinus* (1.04) followed by *Tectona grandis* (0.93) and the ratio was the least for *Adenanthera pavonina* (0.18).

4.3.4 Bark percentage

Disc of *Pterocarpus santalinus* recorded maximum bark percentage (25.83%) followed by *Hymenodictyon excelsum* (18.81%) when collected from the basal portion of the tree. *Hydnocarpus wightiana* recorded minimum bark percentage (2.29%) followed by *Samadera indica* where it was 4.76 per cent. With regard to middle portion of the trees, *Pterocarpus santalinus* recorded the maximum bark percentage (29.02%) followed by *Hymenodictyon excelsum* (21.29%). *Hydnocarpus wightiana* recorded minimum bark percentage of 4.97

per cent with regard to middle portion. The discs from the top portion of the tree species of *Pterocarpus santalinus, Tectona grandis* and *Hymenodictyon excelsum* stood top in the list while species like *Samadera indica, Hydnocarpus wightiana* and *Artocarpus heterophyllus* stood bottom in the list with regard to bark percentage.

4.4 Calorific value and specific gravity of wood of tree species grown in the arboretum

The observations related to calorific value and specific gravity of wood of tree species grown in arboretum are furnished in Table 9 and illustrated in Figures 9 and 10.

Close perusal of the data indicate that calorific values of wood significantly varied between different species. It could be seen from the data that the basal portion of the trunk of *Pterocarpus santalinus* recorded highest calorific value (7143.63 cal.g^{-1}) followed by *Ceiba pentandra* (7088.75 cal.g^{-1}). *Samadera indica* has the least calorific value of 3593.01 cal.g^{-1} followed by *Bridelia retusa* (3643.78 cal.g^{-1}). In the middle portion of trunk, *Pterocarpus santalinus* recorded the highest calorific value (6025.07 cal.g^{-1}) followed by *Hydnocarpus wightiana* (4723.10 cal.g^{-1}) and *Adenanthera pavonina* (4367.60 cal.g^{-1}) while *Ceiba pentandra* has the least (3345.36 cal.g^{-1}). With regard to the top portions of trunk, *Pterocarpus santalinus* recorded highest calorific value (6837.50 cal.g^{-1}) followed by *Adenanthera pavonina* (4572.57 cal.g^{-1}), while the least calorific value was recorded for *Ceiba pentandra* (2926.29 cal.g^{-1}).

The data furnished in this table also revealed that the mean calorific value varied from 3626.85 to 6668.73 cal.g^{-1} in various tree species studied. The mean calorific value was maximum for *Pterocarpus santalinus* (6668.73 cal.g^{-1}) followed by *Hydnocarpus wightiana* (4810.11 cal.g^{-1}) and *Ceiba pentandra* (4453.47 cal. g^{-1}). Least average calorific value was that of *Samadera indica*

Table-9 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	
Adenanthera pavonina	4057.45	4367.60	4572.57	4332.54	0.52
Artocarpus heterophyllus	3848.28	3595.56	4261.15	3901.66	0.76
Bridelia retusa	3643.78	3541.73	4209.03	3798.18	0.76
Ceiba pentandra	7088.75	3345.36	2926.29	4453.47	0.28
Hydnocarpus wightiana	4776.13	4723.10	4931.10	4810.11	0.85
Hymenodictyon excelsum	4370.56	4108.77	4008.27	4162.53	0.96
Peltophorum pterocarpum	4261.73	4107.41	3027.64	3798.93	0.49
Pterocarpus santalinus	7143.63	6025.07	6837.50	6668.73	0.14
Samadera indica	3593.01	3590.74	3696.79	3626.85	2.14
Tectona grandis	4367.91	4366.01	4413.48	4382.47	0.44
F	**	**	**		*
CD (0.02)	2.46	2.66	2.68		1.12
S.Em ±	1.17	1.27	1.28		0.53

** Significant at 1 per cent level

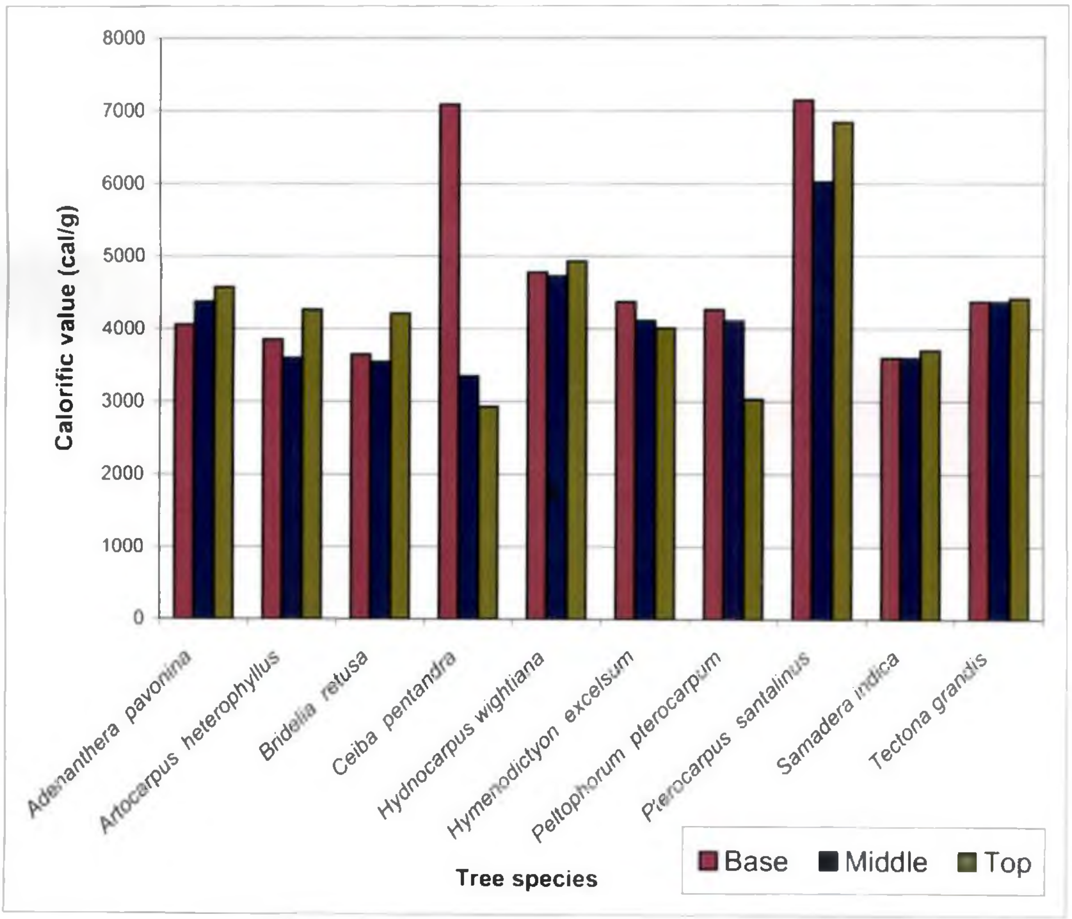


Figure. 9 Calorific value of wood of tree species grown in the arboretum

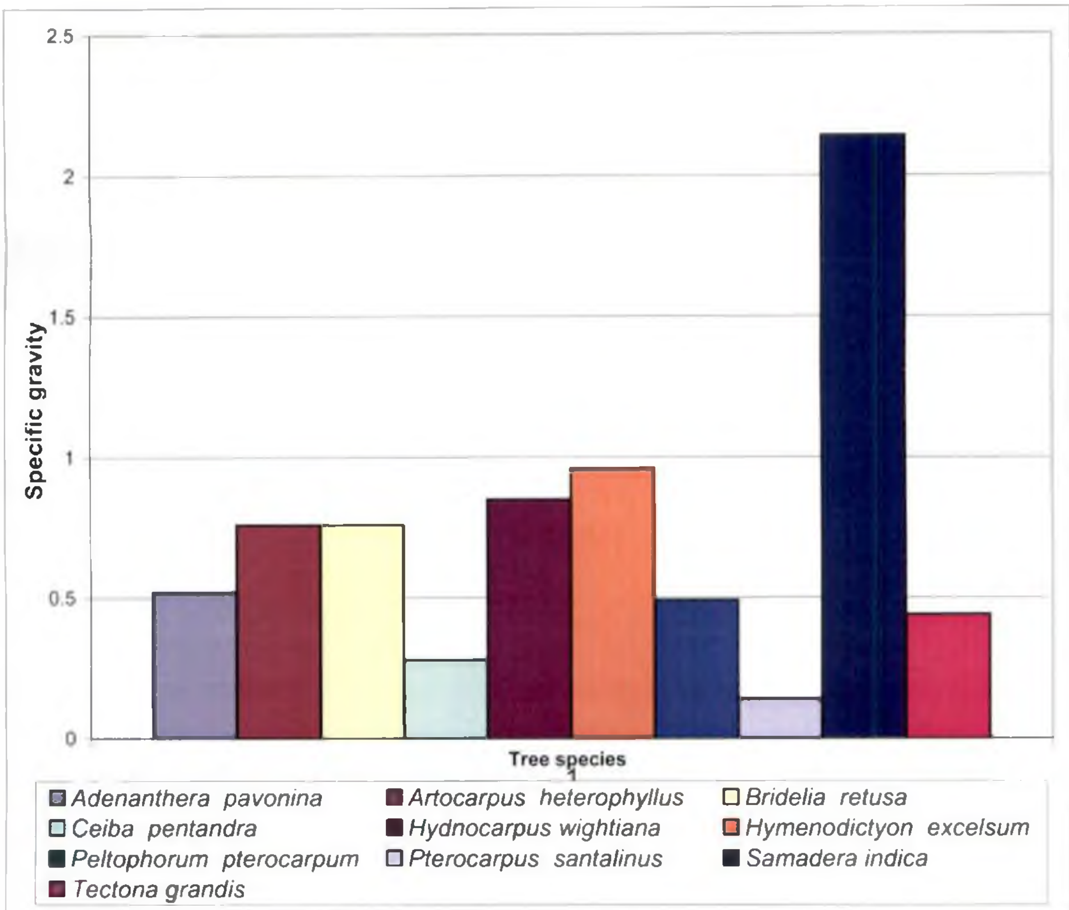


Figure.10 Specific gravity of wood of tree species grown in the arboretum

(3626.85 cal.g^{-1}) which was followed by *Bridelia retusa* (3798.18 cal.g^{-1}). In trees, the calorific values are decreasing in the order: *Pterocarpus santalinus* > *Hydnocarpus wightiana* > *Ceiba pentandra* > *Tectona grandis* > *Adenanthera pavonina* > *Hymenodictyon excelsum* > *Artocarpus heterophyllus* > *Peltophorum pterocarpum* > *Bridelia retusa* > *Samadera indica.*

The data furnished in Table 9 indicate that the specific gravity of wood of various tree species ranged from 0.14 in *Pterocarpus santalinus* to 2.14 in *Samadera indica*. Other species viz., *Adenanthera pavonina, Artocarpus heterophyllus, Bridelia retusa, Ceiba pentandra, Hydnocarpus wightiana, Hymenodictyon excelsum, Peltophorum pterocarpum* and *Tectona grandis* recorded a specific gravity of 0.52, 0.76, 0.76, 0.28, 0.85, 0.96, 0.49 and 0.44 respectively.

4.4 Leaf nutrient concentration of tree species grown in the arboretum

It is evident from Table 10 that among all the tree species, leaf nitrogen content was significantly highest in *Adenanthera pavonina* (2.34%) followed by *Pterocarpus santalinus* (2.16%) and *Artocarpus heterophyllus* (2.13%). On the other hand, *Tectona grandis* recorded minimum (1.07%) nitrogen concentration in the leaf tissues. The nitrogen concentration in the leaf samples of tree species is decreasing in the order: *Adenanthera pavonina* > *Pterocarpus santalinus* > *Artocarpus heterophyllus* > *Bridelia retusa* > *Samadera indica* > *Hymenodictyon excelsum* > *Hydnocarpus wightiana* > *Peltophorum pterocarpum* > *Ceiba pentandra* > *Tectona grandis* (Figure 11).

The phosphorus content was found to be maximum (0.22%) in *Artocarpus heterophyllus* followed by *Bridelia retusa* (0.21%). However, the difference between these two species was not statistically significant. The lowest concentration of phosphorus was found in the leaves of *Ceiba pentandra* (0.03%) followed by *Tectona grandis* (0.04 %). Here also the difference between these two

Table-10 Leaf nutrient concentration of tree species grown in the arboretum

Tree species	Nitrogen (%)	Phosphorus (%)	Potassium (%)
Adenanthera pavonina	2.34	0.18	0.45
Artocarpus heterophyllus	2.13	0.22	0.24
Bridelia retusa	2.01	0.21	0.29
Ceiba pentandra	1.11	0.03	0.32
Hydnocarpus wightiana	1.56	0.15	0.37
Hymenodictyon excelsum	1.62	0.14	0.33
Peltophorum pterocarpum	1.23	0.09	0.28
Pterocarpus santalinus	2.16	0.13	0.26
Samadera indica	1.98	0.19	0.31
Tectona grandis	1.07	0.04	0.84
F	*	*	*
CD (0.05)	0.56	0.15	0.29
S.Em ±	0.27	0.07	0.14

* Significant at 5 per cent level

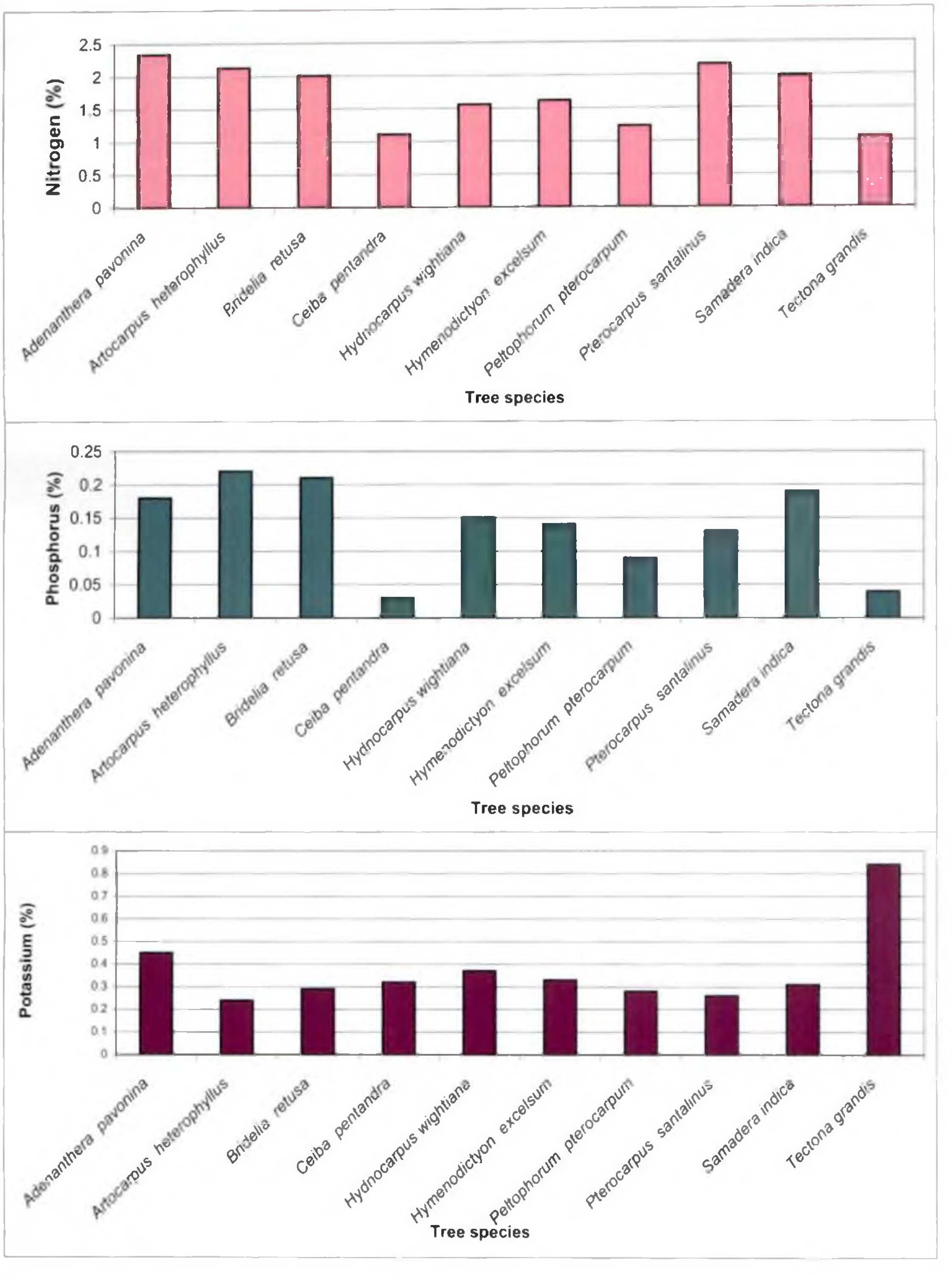


Figure 11.Leaf nutrient concentration of tree species grown in the arboretum

species was not significantly different in their P content.

From the data it is clear that the potassium content ranged from 0.24 per cent in *Artocarpus heterophyllus* to 0.84 per cent in *Tectona grandis*. With regard to higher potassium content, *Tectona grandis, Adenanthera pavonina* and *Hydnocarpus wightiana* were on par while with regard to lower potassium content, species like *Artocarpus heterophyllus*, *Pterocarpus santalinus*, *Peltophorum pterocarpum* and *Bridelia retusa* were on par.

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 depleting at a fast rate 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. For this purpose choice of species is one of the important criteria as no relevant information on these aspects of many tree species are available. The proper choice of tree species for a specific location for maximum benefits is the need of the day. Keeping in view of this consideration, the present series of investigations were taken up in the College of Forestry, Kerala Agricultural university, Vellanikkara to generate some valuable data based on which fast growing tree species with high biomass production and better wood qualities could be screened and further multiplied in the college nursery for large scale production of seedlings for distribution to farmers for farm forestry and general afforestation programmes. Important findings of the studies 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, *Tectona grandis*, *Ceiba pentandra* and *Artocarpus heterophyllus* were found fast growing in terms of height and commercial bole height. Height increment varied from 6m in *Samadera indica* to 16.5m in *Tectona grandis* and girth from 28.9cm in *Samadera indica* to 94.8cm in *Ceiba pentandra*. In the present study, *Samadera* *indica* was found to be poor in terms of growth behaviour as it showed lowest increment with respect to height, commercial bole height and girth. *Peltophorum pterocarpum* and *Tectona grandis* produced maximum number of primary branches of 60.0 and 32.8 respectively at the end of the study *i.e.* in 2008 while *Ceiba pentandra* produced only 13.5 numbers of primary branches which was lowest among the species studied even though it showed good height and girth increment. *Artocarpus heterophyllus* recorded 6.1m increment in mean spread and this was found to be superior. The observations recorded in the present study revealed that the maximum volume increment of 1.124 cu. m was recorded by *Ceiba pentandra* and hence this could be identified as a superior species with respect to volume increment whereas *Samadera indica* as inferior in which volume increment during this period was only 0.036 cu. m. Species like *Bridelia retusa* and *Tectona grandis* recorded comparatively good volume increment of respectively 0.497 cu. m and 0.435 cu. m.

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. The above studies showed that growth of teak was poor when grown in both acidic and sandy loam soils. However, in present study, teak was grown in Ultisols and growth was found promising. It is also evident that the growth rates of some 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 consistent and uniform even beyond their juvenile stage.

The present study revealed that the height and girth measurements were significantly different between the species during the entire course of study. Jisha (2006) also reported similar findings with regard to growth behaviour of tree species. 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. Gupta (2006) reported that, there is significant difference among species studied in terms of height and girth increment. Shono *et al.* (2007) from their studies reported that the growth performance of 45 native species, which were planted in degraded areas of Singapore, were significantly affected by nature of species, site and interaction between species and site quality. This study clearly shows that the nature of species should be taken into account while considering its growth performance. It is a well known fact that by nature, *Samadera indica* is a small tree and in most of the studies it is identified as a poor species with respect to growth. A study was conducted in Gujarat by Jaimini and Tikka (2001) to evaluate the survival, growth and biomass production of 15 multipurpose tree species and reported that crown spread was maximum for *Albizia lebbek.* Gupta (2006) reported that *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. These two findings are in agreement with the results of present study where species like *Artocarpus hirsutus* and *Peltophorum pterocarpum* were identified as superior ones with respect to mean spread and number of primary branches produced and hence can be planted as avenue and shade trees in social forestry programmes. The relationship of height and growth with volume was reported by Kumar *et al.* (2005). They found that siris (*Albizia lebbek*) gave maximum yield in terms of volume as it was having maximum height and girth. Piotto (2007) also used MAI as an index to compare the growth performance of the species. These reports are in agreement with the observations made in the present study.

Pinyopusarerk *et al.* (2005) conducted a study in a 48-month old provenance trail of *Casuarina junghuhniana* planted in Kanchanaburi, Thailand to assess the variation in growth and branching characteristics and the study revealed that there were significant differences in growth parameters in relation to seed sources. Influence of different site characters on the growth rate of *Calamus merrillii* in different plantations of Philippines were studied by Abasolo (2006) and reported that growth rate was highly affected by soil pH, organic matter, nitrogen, phosphorus and potassium content compared to other characters. These results were supporting the present findings also. These factors could highly affect the growth rate of all the species either in a positive or negative way. The present study thus revealed that growth rate was obviously dependent not only on one site parameter but on the inter-relationship of all other related characters. The results of the present study showed that generally, *Tectona grandis, Ceiba pentandra, Bridelia retusa, Artocarpus heterophyllus* and *Peltophorum pterocarpum* could be considered as fast growing tree species under Vellanikkara conditions.

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

From the present study, it is evident that *Ceiba pentandra* produced maximum biomass of 302.9 kg in terms of total fresh weight of the whole trees. The total dry weight of the trees ranged from 15.9 kg in *Pterocarpus santalinus* to 178.0 kg in *Adenanthera pavonina*. Species like *Bridelia retusa, Hydnocarpus wightiana* and *Peltophorum pterocarpum* recorded a biomass production of 141.4 kg, 122.5 kg and 120.3 kg respectively in terms of total dry weight. Kumar *et al.* (1998) studied the biomass accumulation of nine multipurpose trees grown in Thiruvazhamkunnu, Kerala and reported that when trees were felled at 8.8 years of age, rate of biomass accumulation was highest for *Acacia auriculiformis* and least for *Leucaena leucocephala*. Vidyasagaran (2003) also reported similar findings and stated that, above ground biomass of *Casuarina equesitifolia* increased nine times from 2nd to 9th year in the plantations of central Kerala. 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. In their study, basal area and biomass production were estimated from the height and gbh data. Above studies showed that height and girth of the trees could highly affect the biomass accumulation. These reports are in agreement with the observations made in the present study where *Ceiba pentandra* produced maximum biomass which also showed good height and girth increment and this species can be planted as a fuel wood tree in agro/social forestry programmes.

Pterocarpus santalinus on an average produced 43.6 kg/plant of fresh biomass in the present study which is relatively low compared to other tree species. Gopikumar (2000) has also made similar observations by conducting experiment in similar conditions where *Artocarpus hirsutus* was reported to produce lesser biomass compared to *Albizia falcataria*. In the present study fresh and dry weights recorded for *Tectona grandis* was 140.3 and 57.2 kg respectively which show better performance of this species compared to many other species. It is also evident better biomass accumulation by *Tectona grandis* at the age of 17 years compared to early reports made by other workers. Singh and Gupta (1993) reported that *Tectona grandis* yielded 111.34 kg/plant at 30 years of age. They have stated that the lower productivity of *Tectona grandis* may be due to the fact that this species is performing better when grown in humid conditions instead of semi arid conditions. This is true considering the observations of present study also where it was grown under humid conditions.

The percentage contribution of trunk in terms of dry weight was ranging from 47 in *Ceiba pentandra* to 80 per cent in *Tectona grandis*. The contribution of branches ranged from 9.0 per cent in *Ceiba pentandra* to 32 per cent in

Hymenodictyon excelsum while twigs ranged from 1.0 per cent in *Adenanthera pavonina* to 12 per cent in *Samadera indica.* The range of leaf percentage contribution was from 1 per cent in *Artocarpus heterophyllus* and *Hymenodictyon excelsum* to 42 per cent in *Ceiba pentandra.* It is also evident from the present study that in all the species, trunk contributed maximum proportion of tree biomass followed by branches except in the case of *Ceiba pentandra* where the dry weight of leaves was more than that of branches. Rana *et al.* (1989) studied biomass production and its relative allocation to various components in *Shorea robusta* grown in central Himalaya and reported that 61.3 per cent biomass was allocated to the bole and 10.5 per cent to the branches. In a similar type of study, Wang *et al.* (1991) observed that *Casuarina equisetifolia* accumulated 70.8 per cent biomass in its bole, 17.4 per cent in the branches and 10.9 per cent in the leaves. Gupta (2006) from his study conducted in College of Forestry, Vellanikkara, reported that trunk accounted maximum biomass production followed by branches. In another study, Navas (2006) also reported that the percentage contribution of various components to above ground biomass was in the order: bole> branch> twig> fruit> leaves> bark. All these reports are in agreement with the observations made in the present study. It is interesting to note from the present study that contribution of leaves to total biomass was very high in *Ceiba pentandra* indicating the use of this species as a shade tree.

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

From the observations, it is clear that the heartwood percentage recorded was high in species like *Adenanthera pavonina, Tectona grandis* and *Pterocarpus santalinus* discs when collected from different portions of trees like base, middle and top respectively. However, *Tectona grandis, Bridelia retusa* and *Pterocarpus santalinus* have recorded good heartwood percentage in all the portions. Suitability of tree species for timber purpose would be considered based on the content of more of heartwood making such wood harder and more resistant to insect and pest attacks. *Tectona grandis* showed highest heartwood percentage of 44.00 per cent and lowest sapwood percentage of 35.20 per cent when discs were collected from middle portions of tree. That is one of the reasons why *Tectona grandis* is considered as a good timber. Tamolang and Rocafort (1987) studied the physico-mechanical properties and possible uses of eleven plantation grown timber species and recommended *Tectona grandis* as one of the good species for construction purposes. *Tectona grandis* is however, considered as one of the most important standard timber species of the world. It is used extensively in India for making doors and window frames, furniture, columns and beams. It is very resistant to termite attacks. Langat and Kariuki (2004) studied the variation in heartwood proportion and basic density between provenances of *Eucalyptus grandis* in Kenya. The study indicated large variations between provenances for the two properties assessed and also reported that the average heartwood proportion decreased with height. In present study *Adenanthera pavonina* showed more or less similar trend. From the result it is also apparent that sapwood percentage recorded was high in case of *Samadera indica, Artocarpus heterophyllus* and *Peltophorum pterocarpum.* In tree species viz., *Tectona grandis, Pterocarpus santalinus* and *Hymenodictyon excelsum* bark percentage is higher in the top portions of the wood compared to other species. This may be for giving better protection to sapwood and growing tissues particularly towards the actively growing top portion of the tree.

The basal portion of the trunk of *Pterocarpus santalinus* recorded highest calorific value (7143.63 $cal.g^{-1}$) followed by *Ceiba pentandra* (7088.75 $cal.g^{-1}$) and *Hydnocarpus wightiana* (4776.13$cal.g^{-1}$). *Samadera indica* has the least calorific value of 3593.01 $cal.g^{-1}$ followed by *Bridelia retusa* (3643.78 $cal.g^{-1}$). In the middle portion of trunk, *Pterocarpus santalinus* recorded the highest calorific value (6025.07 $cal.g^{-1}$) followed by *Hydnocarpus wightiana* (4723.10 $cal.g^{-1}$) while *Ceiba pentandra* has the least (3345.36 cal.g^{-1}). With regard to the top portions of trunk of all the ten tree species, *Pterocarpus santalinus* recorded highest calorific value (6837.50 cal.g^{-1}) followed by *Adenanthera pavonina* (4572.57 cal.g^{-1}). Based on the mean calorific values, *Pterocarpus santalinus, Hydnocarpus wightiana, Ceiba pentandra, Tectona grandis* and *Adenanthera pavonina* could be classified under high calorific value class indicating the use of these species and their branches as fuel wood trees also in agro/social forestry programmes.

Shanavas and Kumar (2003) have reported the calorific values of 45 important fuelwood tree species grown in Kerala. Based on the 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 recorded 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. Haufa and Wojciechowska (1986) reported that moisture content of wood have negative correlation with fuel wood value. Gupta (2006) also reported high calorific values for bottom portion of trees and calorific value decreased with rise in moisture content.

The specific gravity of wood of various tree species ranged from 0.14 in *Pterocarpus santalinus* to 2.14 in *Samadera indica*. The species viz., *Adenanthera pavonina, Artocarpus heterophyllus, Bridelia retusa, Ceiba pentandra, Hydnocarpus wightiana, Hymenodictyon excelsum, Peltophorum pterocarpum* and *Tectona grandis* recorded a specific gravity of 0.52, 0.76, 0.76, 0.28, 0.85, 0.96, 0.49 and 0.44 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 Bhat *et al.* (1999), Shukla *et al.* (1990) and Sahri *et al.* (1998). This may be due to the fact that in the present study, samples were taken from trees which are not fully matured. Gupta (2006) conducted a similar study in College of Forestry, Vellanikkara and reported the lower specific gravity for the wood of most of the tree species. He has also reported that this is due to lack of full maturity of trees. Study conducted by Robert and Espen (1992) revealed that the wood specific gravity of *Cieba pentandra* exhibited marked variability with tree age. In the present study, the 17 year old *Ceiba pentandra* recorded less specific gravity which may be due to less age of the tree. Damodaran and Chacko (1999) reported that wood specific gravity is a variable which changes with positions in a tree and it decreased from bottom to top along the tree height. In the present study, samples collected from the top portion of the trees for estimating the specific gravity indicated low value. Shanavas and Kumar (2003) stated that ash content had a negative correlation with heat of combustion but specific gravity exerted a positive influence. In present study, *Pterocarpus santalinus* have less ash content and that may be the reason for this species to show high calorific value and low wood specific gravity. But in *Samadera indica* it was vice-versa.

5.4 Tissue nutrient concentration

Tissue nitrogen content was highest in *Adenanthera pavonina* (2.34%) followed by *Pterocarpus santalinus* (2.16%) and *Artocarpus heterophyllus* (2.13%). On the other hand, *Tectona grandis* recorded minimum (1.07%) nitrogen content in the leaf tissues. The phosphorus content was found to be maximum (0.22%) in *Artocarpus heterophyllus* followed by *Bridelia retusa* (0.21%). However, a close perusal of data revealed that the difference between these two species was not statistically significant. The lowest concentration of phosphorus was found in the leaves of *Ceiba pentandra* (0.03%) followed by *Tectona grandis* (0.04%). From the data it is clear that the potassium content ranged from 0.24 per cent in *Artocarpus* *heterophyllus* to 0.84 per cent in *Tectona grandis*. With regard to higher potassium content, tree species like *Tectona grandis, Adenanthera pavonina* and *Hydnocarpus wightiana* were on par while with regard to lower potassium content, species like *Artocarpus heterophyllus*, *Pterocarpus santalinus*, *Peltophorum pterocarpum* and *Bridelia retusa* were on par. The above trends clearly indicate that tissue nutrient concentration varied significantly between different species.

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 (2000). Gupta (2006) from the studies conducted at Vellanikkara reported that *Ailanthus triphysa* recorded significantly highest leaf tissue content of nitrogen and phosphorus while potassium content was found to be the maximum in *Tectona grandis*. He has reported the scope of selecting tree species for nutrient content in leaf tissues based on his studies using 10 different species. Singh and Singh (2007) reported that foliage nutrient content varied significantly with stand age and the level of N and K increased showing positive correlation with stand age, while P did not show significant correlation. Results also showed that, some of the nutrients decreased after 12 years, particularly in 19 year old stand.

It could be well established from the above discussion that the leaf biomass of most of the tree species contain considerable amount of nutrients, particularly nitrogen, phosphorus and potassium. These leaves could be very well used as a good manure as a good 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. 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, biomass production, wood properties and tissue nutrient content before recommending for commercial cultivation under social/agroforestry programme or even for general afforestation in the state.

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., *Adenanthera pavonina, Artocarpus heterophyllus, Bridelia retusa, Ceiba pentandra, Hydnocarpus wightiana, Hymenodictyon excelsum, Peltophorum pterocarpum, Pterocarpus santalinus, Samadera indica* and *Tectona grandis* grown in the arboretum. The information generated from this 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, *Tectona grandis, Ceiba pentandra*, and *Artocarpus heterophyllus* were found fast growing while *Samadera indica* and *Bridelia retusa* were slow growing. Species like *Adenanthera pavonina, Bridelia retusa* and *Ceiba pentandra* showed a good height increment during initial stage.The height measurements were significantly different between all the species during the entire course of study.

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 commercial bole height was recorded for *Tectona grandis* followed by *Ceiba pentandra.* However, the difference between these species with regard to this parameter was not significant. *Samadera indica* yielded the lowest commercial bole height followed by *Pterocarpus santalinus*.

3. With regard to girth increment, *Ceiba pentandra* and *Bridelia retusa* could be considered as superior while *Samadera indica* and *Hymenodictyon excelsum* as slow growing. Similarly, *Artocarpus heterophyllus* and *Peltophorum*

pterocarpum could be considered as moderately fast growing species with regard to this parameter. *Ceiba pentandra* showed a fast and steady increase in girth during the entire course of experiment. The observed girth in all the species during every year is significantly different.

4. Based on the production of primary branches, *Peltophorum pterocarpum* could be considered as most superior. The minimum number of branches was produced by *Ceiba pentandra*. However, *Ceiba pentandra* started with a fair number of branches in the first year which did not show a significant increment compared to other species.

5. The observations on another growth parameter i.e. spread indicate that the total mean increment was the maximum for *Artocarpus heterophyllus* followed by *Adenanthera pavonina* and *Tectona grandis*. The minimum increment was for *Samadera indica* followed by both *Hymenodictyon excelsum* and *Pterocarpus santalinus*. The data also showed that there is significant difference among the tree species.

6. During the end of the study in 2008, maximum volume was recorded by *Ceiba pentandra* followed by *Bridelia retusa* and *Tectona grandis* while the least was for *Samadera indica* followed by *Pterocarpus santalinus* and *Hymenodictyon excelsum*. Total increment in volume was also the maximum for *Ceiba pentandra* while minimum was for *Samadera indica* during the period from 1994 to 2008. It is also clear from the data that the volume of tree species increased gradually with the increasing age.

7. From the studies conducted to estimate the total biomass production, it is evident that the maximum biomass was produced by *Ceiba pentandra* in terms of fresh and *Adenanthera pavonina* in terms of dry weights.

Pterocarpus santalinus appeared to be most inferior with regard to total biomass production.

8. The dry weight of trunk was the maximum for *Adenanthera pavonina* followed by *Bridelia retusa*. Trunk dry weight was lowest for *Pterocarpus santalinus* followed by *Samadera indica*. Trunk accounted for maximum biomass production followed by branches. The contribution of trunk was followed by branches in all the tree species except *Ceiba pentandra* where the dry weight of leaves was more than that of branches. Leaves contributed 42 per cent to total dry weight in case of *Ceiba pentandra* and least was recorded for the species *Artocarpus heterophyllus* and *Hymenodictyon excelsum*.

9. At the end of the study period, *Adenanthera pavonina, Tectona grandis* and *Pterocarpus santalinus* 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 in most of the species. Higher heartwood - sapwood percentage ratio was found in *Tectona grandis* and *Pterocarpus santalinus*. In general, sapwood percentage recorded was the maximum for *Samadera indica* and *Artocarpus heterophyllus*.

10. *Pterocarpus santalinus* recorded highest mean calorific value followed by *Hydnocarpus wightiana* while *Samadera indica* recorded the least calorific value followed by *Bridelia retusa*.

11. Specific gravity observed was highest in *Samadera indica* followed by *Hymenodictyon excelsum* while it was lowest in *Pterocarpus santalinus* and *Ceiba pentandra*.

12. Tissue nitrogen content was significantly highest in *Adenanthera pavonina*

and lowest in *Tectona grandis*. But the phosphorus content was found to be the maximum in leaves of *Artocarpus heterophyllus* followed by *Bridelia retusa*. However, the difference between these two species was not statistically significant. The lowest concentration of phosphorus was found in the leaves of *Ceiba pentandra*. Leaf tissues of *Tectona grandis* recorded highest potassium content followed by *Adenanthera pavonina* and *Hydnocarpus wightiana* while minimum content was recorded in *Artocarpus heterophyllus*.

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* Originals not seen

EVALUATION OF TREE SPECIES FOR GROWTH, WOOD PROPERTIES AND LEAF NUTRIENT CONTENT

By

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ABSTRACT OF THE THESIS

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ABSTRACT

The present study was conducted in the College of Forestry, Kerala Agricultural University, Vellanikkara to evaluate the growth performance, biomass production, wood properties and leaf nutrient content of the selected tree species grown in the arboretum during the period 2006 to 2008. The species selected for the study includes *Adenanthera pavonina, Artocarpus heterophyllus, Bridelia retusa, Ceiba pentandra, Hydnocarpus wightiana, Hymenodictyon excelsum, Peltophorum pterocarpum, Pterocarpus santalinus, Samadera indica* and *Tectona grandis*. Data related to growth measurements from 1992 to 2006 have been collected from the college department.

The results revealed that the species like *Tectona grandis, Ceiba pentandra* and *Artocarpus heterophyllus* were fast growing in terms of height and girth while *Samadera indica* as slow growing. *Peltophorum pterocarpum* produced highest number of branches. The spread was the maximum for *Artocarpus heterophyllus* followed by *Adenanthera pavonina*. During the end of the study in 2008, maximum volume increment was recorded by *Ceiba pentandra* while the lowest was for *Samadera indica*.

The total biomass production was found to be the maximum for *Ceiba pentandra* in terms of fresh and *Adenanthera pavonina* in terms of dry weight while the lowest total biomass was produced by *Pterocarpus santalinus* in terms of both fresh and dry weights. Trunk accounted for maximum biomass production followed by branches. The contribution of trunk was followed by branches in all the tree species except *Ceiba pentandra* where the dry weight of leaves was more than that of branches. *Adenanthera pavonina, Tectona grandis* and *Pterocarpus santalinus* produced more heartwood percentage compared to other species. Sapwood

percentage recorded was the maximum for *Samadera indica*. *Pterocarpus santalinus*, *Hydnocarpus wightiana* and *Ceiba pentandra* were having high calorific values and hence could be used for fuel wood purpose also. Specific gravity was found to be the maximum for *Samadera indica* and minimum for *Pterocarpus santalinus*. Leaf tissue nitrogen content was significantly highest in *Adenanthera pavonina* followed by *Pterocarpus santalinus*. The phosphorus content was found to be the maximum in *Artocarpus heterophyllus* while minimum in *Ceiba pentandra*. Leaves of *Tectona grandis* recorded the maximum content of potassium while the lowest was for *Artocarpus heterophyllus*.

The present series of investigations indicate the scope of selecting fast growing tree species with high biomass production, better wood qualities and high foliage nutrient content for distribution to farmers for social/agroforestry and even for general afforestation programmes.