

**Estimation of Standing State Biomass and  
Carbon Sequestration Potential of Multipurpose  
Tree Species**

**THESIS**

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*By*

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## **CERTIFICATE- I**

This is to certify that the thesis entitled “**Estimation of Standing State Biomass and Carbon Sequestration Potential of Multipurpose Tree Species.**” submitted in partial fulfillment of the requirement for degree of **MASTER OF SCIENCE in FORESTRY (AGRO-FORESTRY)** of the Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur is a record of bonafide research carried out by Shri Jagdish meena, I.D. No. AFP/JB-427/2010, under my supervision. The subject of the thesis has been approved by the Student’s Advisory Committee and the Director of Instruction.

No part of the thesis has been submitted for any other degree or diploma (Certificate awarded etc.). All the assistance and help received during the course of the investigation has been acknowledged by him.

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## CERTIFICATE-II

This is to certify that the thesis entitled “**Estimation of Standing State Biomass and Carbon Sequestration Potential of Multipurpose Tree Species.**” submitted by **Shri Jagdish Meena** to the Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN FORESTRY** in the **Department of Forestry**, has been, after evaluation, approved by the External Examiner and by the Student’s Advisory Committee after an oral examination of the same.

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## ABBREVIATIONS

At the rate of	:	@
And others	:	<i>et al.</i> ,
Centimeter	:	Cm
Critical difference	:	CD
Degree centigrade	:	<sup>0</sup> C
Degree of freedom	:	df
Diameter at breast height	:	dbh
Gram	:	g
Hectare	:	ha
Maximum	:	max
Meter	:	m
Minimum	:	Min
Millimeter	:	mm.
Namely	:	viz.
Per hectare	:	ha <sup>-1</sup>
Percentage	:	%
Quintal	:	q
Standard error of means	:	SEm±
That is	:	<i>i.e.</i>

## INTRODUCTION

Under the present conditions of heavy pressure of human (1210million) and livestock (500million approx.) population, decreasing size of landholdings (0.17 ha per person), acute shortage of fuel wood, fodder, timber and other tree-based products, plantation of Multipurpose Trees (MPTs), especially outside forest has tremendous scope in India. Multiple use trees are capable of producing a range of products and have the capacity to contribute in its specific functions towards the sustainability of yields, an increase in output and/or reduction in inputs, and maintaining the ecological stability of the region. Therefore, Multipurpose Tree species (MPTs) should be introduced in land use systems to exploit their ability to provide the basic needs of people and protect the environment. The paramount importance placed on trees is not merely due to their ability to meet multiple needs, but also due to their long-term sustainability.

The term Multipurpose Trees (MPTs) refers to all woody perennials that are deliberately grown so as to make more than one significant contribution to the production and service functions of land use systems. Multipurpose tree production system is an important forestry activity which aims at the production of timber and other tree products. The benefit from MPTs would include food, water, energy, shelter and raw materials for processing (Chundawat and Gautam, 1993). In addition to wood, the MPTs may also yield fruits, flowers, bark, roots, gums, medicines etc., which may be eaten or utilized for other purposes. In India, Multipurpose Trees are extensively planted to meet the increasing demand for fuel and industrial wood. Many multipurpose trees in different agro-climatic zones of India give excellent fodder and fuel wood.

Madhya Pradesh is blessed with climatic variability and diverse soil types. This provides unique opportunities to the farmers to grow multipurpose trees in marginal and culturable wastelands under various agroforestry practices. Different promising Multipurpose trees viz., *Acacia nilotica*, *Terminalia arjuna*, *Dalbergia sissoo*, *Eucalyptus sps.*, *Albizia lebbek*, *Butea monosperma*,

*Syzygium cumini*, *Madhuca latifolia*, *Mangifera indica*, *Tectona grandis*, *Gmelina arborea*, *Prosopis juliflora*, *Azadirachta indica* etc. found to be suitable for various agroforestry practices in farmers field under different agro-ecological zones of Madhya Pradesh.

There is a growing awareness about woody perennials, playing an important role in sustainability of tropical land use systems and meeting the fuel wood needs of the rural poor. Tree biomass is a non-conventional energy source, play an important role in alleviating the fuel wood crisis. Tree biomass can be defined as the dry matter of organic matter produced by photosynthesis in a standing per unit area and per unit time. The biomass production of tree in different components, viz., stem, branch wood and leaf depends upon number of factors, viz., growth habit of the species, site quality, soil on which trees are growing, age of the tree, management practices, frequent intercultural operations and moisture conservation and its interaction with below ground crops have also contributed towards increasing height and diameter at breast height of trees. MPTS are planted by farmers, especially smallholders, for their day to day needs. However, from the national and community standpoint, trees can be grown to help conserve both the soil and the growing environment. They can greatly reduce fossil fuel requirements for agricultural production and extend the use of fragile environment and marginal lands.

Global warming and associated Climate change is an important environmental issue that has captured the world's attention now a days. Among the Green House Gases (GHGs) contributing to global warming, CO<sub>2</sub> is believed to be the most prominent one (Lorenz and Lal, 2010) accounting for 60% of the total greenhouse effect. Elevated levels of CO<sub>2</sub> and other greenhouse gases in the atmosphere have increased global average surface temperature by 0.6±0.2°C (IPCC, 1999). The mitigation of global warming entails reducing the atmospheric concentrations of GHGs, particularly CO<sub>2</sub>. One of the approaches for reducing CO<sub>2</sub> concentration in the atmosphere is carbon (C) sequestration, the process of removing C from the atmosphere and depositing it in a reservoir. The Land Use, Land Use Change and Forestry (LULUCF) is an approach that

became popular in the context of the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) which allows the use of C sequestration through afforestation and reforestation as a form of GHG-offset activities.

Trees play a vital role in mitigating the diverse effects of environmental degradation and increasing concentration of carbon dioxide in the atmosphere and also its consequences on climate change. Tree promotes sequestration of carbon into soil and plant biomass. Therefore, tree based land use practices could be a viable alternative to store atmospheric carbon dioxide due to their cost effectiveness, high potential of carbon uptake and associated environmental as well as social benefits. (Costa, 1996). Plants capture CO<sub>2</sub> during photosynthesis and transform it to sugar and subsequently to dead organic matter. As the trees grow, they sequester carbon in their tissues, and as the amount of tree biomass increases, the increase in atmospheric CO<sub>2</sub> is mitigated. The area under forests, including part of the area afforested is increasing and currently 67.83 million ha of area is under forest cover. Assuming that the current trend continues, the area under forest cover is projected to reach 72 million ha by 2030. Estimates of carbon stock in Indian forests in both soil and vegetation range from 8.58 to 9.57 Gt C (Ravindranath *et al.*, 2008).

Conceptually trees are considered to be a terrestrial carbon sink (Houghton *et al.*, 1998). Therefore, managed forests can, theoretically, sequester carbon both *in situ* (biomass and soil) and *ex situ* (products). The basic premise of carbon sequestration potential of land use-systems is relatively simple: it revolves around the fundamental biological/ecological processes of photosynthesis, respiration, and decomposition. Essentially, carbon sequestered is the difference between carbon gained by photosynthesis and carbon lost or released by respiration of all components of the ecosystem, and this overall gain or loss of carbon is usually represented by net ecosystem productivity. Most carbon enters the ecosystem via leaves and carbon accumulation is most obvious when it occurs in above ground biomass.

In response to this reality, the need for extending man made forests and agroforests are more felt today than ever before. Tropical fast growing MPTs in this regard assume greater importance on account of their enormous potential to produce biomass and sequester atmospheric C (Kumar, 2003). Moreover, trees significantly contribute to improve the soil C content and there by assist in improving the soil carbon sequestration. By including trees in agricultural production systems, agroforestry can increase the amount of carbon stored in lands devoted to agriculture, while still allowing for growing of food crops (Kursten, 2000). The tree components in agroforestry can be significant sinks of atmospheric carbon due to their fast growth and high productivity. Average sequestration potential in agroforestry has been estimated to be 25 t C ha<sup>-1</sup> over 96 million ha of land in India and 6-15 t C ha<sup>-1</sup> over 75.9 million ha in China (Sathaye and Ravindranath, 1998 and Ravindranath *et al.*, 2008). Agroforestry is an ideal option to increase productivity of wastelands, increase tree cover outside the forest and reduce human pressure on forests under different agro-ecological regions, and is also a viable option to prevent and mitigate climate-change effects.

Keeping all these points in view, the present investigation entitled **“Estimation of Standing State Biomass and Carbon Sequestration Potential of Multipurpose Tree Species ”** has been undertaken with the following objectives:

1. To estimate the above ground biomass of Multipurpose Tree Species.
2. To quantify the fixed carbon in Multipurpose Tree Species.
3. To evaluate carbon sequestration potential of Multipurpose Tree Species.

## REVIEW OF LITERATURE

The present investigation deals with the aboveground biomass production and carbon sequestration potential of multipurpose tree species. For the present study entitled “Estimation of Standing State Biomass and Carbon Sequestration potential of Multipurpose Tree species” an attempt has been made to collect the available literature and is reviewed in this chapter under following heads:

2.1 Biomass production

2.2 Carbon sequestration

### **2.1 Biomass production**

Biomass production is an important consideration in all tropical tree planting programmes and the tree biomass plays a key role in sustainable management and in estimating forest carbon stocks and fluxes of several biogeochemical elements, the amount of energy stored in biomass, and other conventional goods and services. The biomass production by a plant community is the reflection of its capacity to assimilate solar energy under some set of environmental conditions. Different plant communities have different rate of biomass production, based on their efficiency. There is considerable interest in estimating the biomass of trees and forests for both practical forestry issues and scientific purposes. Biomass is defined as mass of live or dead organic matter. Changes in time of vegetation biomass per unit area (biomass density) can be used as an essential climate variable, because they are a direct measure of sequestration or release of carbon between terrestrial ecosystems and the atmosphere. As trees grow and their biomass increases, they absorb carbon from the atmosphere and store it in plant tissues (Mathews *et. al.*, 2000) resulting in growth of different parts. Active absorption of CO<sub>2</sub> from the atmosphere in photosynthetic process and its subsequent storage in the biomass of growing trees or plants is the carbon storage

Chaturvedi (1984) estimated biomass production of *Acacia nilotica*, *Syzygium cumini*, *Prosopis juliflora*, *Dalbergia sissoo* planted at 1.5m x 1.5m in semi arid conditions at Etawah (U.P). It was observed that all species does not grow at the same rate. Regression equations were developed for prediction of biomass of different tree species.

Gurumurti *et al.* (1986) estimated above ground biomass production of *Acacia nilotica* (5264 plants ha<sup>-1</sup>) raised under semi arid non irrigated conditions over 5 years in Gujrat. The total biomass production at 12 and 60 months old trees was 16.0 and 154.0 oven dry t ha<sup>-1</sup> respectively. Out of which the above ground biomass was 10.9 and 110.1 oven dry t ha<sup>-1</sup> respectively.

Tandon *et al.* (1989) studied plantations of *Acacia mearnsii* in an age series of 4, 7 and 10 years recorded the above ground biomass production of 20.4, 27.1 and 151.4 t ha<sup>-1</sup>., respectively for class A trees and 64.8, 45.6 and 21.9 t ha<sup>-1</sup> for class B trees.

Brown *et al.* (1989) estimated the above ground biomass of tropical forests. For estimation of volume, regression equations were developed as a function of diameter at breast height and tree height.

Tandon *et al.* (1991) reported that biomass production in *Populous deltoides*, among different component; bole contributed the maximum (65-73%) in above ground biomass and root contributed between 10 to 21% towards below ground biomass.

Dudley and fowns (1992) developed biomass equations and tested predictions were produced from previously published equations by harvest of 2-years old plantations in Hawaii. Equations of the form  $B = aDBH^b$ , where B is the total above ground biomass, were fitted to harvest data of *Acacia mangium*, *Acacia mearnsii*, *Casuariana equisetifolia*, *Eucalyptus grandis*, *Eucalyptus saligna* and *Leucaena leucocephala*. Equations derived at mountain view, Hawaii, were compared with independent data from Kilohana, Kauai. The following published biomass equations were used:

*Acacia mangium*  $Y = -3.212 + 0.905 \ln(D^2H)$  (Halenda, 1989).

*Eucalyptus grandis*  $Y = 0.069413 \times (D - 2.1472) \times (H - 0.3129)$ , (Schubert *et al.* 1988).

Where Y = Total above ground biomass.

Bargali *et al.* (1992) biomass of 2-8 year-old plantations of *Eucalyptus tereticornis* growing in tarai region of central Himalaya increased from 7.7 Mg ha<sup>-1</sup> in the second year to 126.7 Mg ha<sup>-1</sup> in the 8-year-old plantation

Kushalappa (1993) observed that as DBH of sample trees increased in *Eucalyptus hybrid* plantation, there was a corresponding increase in biomass on per tree basis in all components of trees.

Toky and Bisht (1993) conducted a study to compare the biomass accumulation in 6-yr-old trees of nine important fuel wood species from arid north-western India. The study results showed wide variation in above ground biomass accumulation which varied from 11.6 kg tree<sup>-1</sup> in *Zyziphus mauritiana* to 37.5 kg tree<sup>-1</sup> in *Melia azedarach*.

Malimbwi *et al.* (1994) estimated volume and biomass of the seventeen tree species in the miombo woodland at Kitulangalo forest reserve, various volume equations were developed for estimation of biomass in different parts of the tree on the basis of diameter classes >15 cm and <15 cm.

Pereira *et al.* (1997) destructively sampled the trees of *Acacia mearnsii* to determine biomass of the above-ground parts (leaves, dead and live branches, wood and bark), and regression equations derived for estimating biomass from diameter at breast height (dbh). Using these equations, the biomass was estimated as 158.51 t ha<sup>-1</sup>, 12.3 per cent belonging to the canopy (leaves 4.23, live branches 11.28 and dead branches 4.02 t ha<sup>-1</sup>) and 87.7 per cent belonging to the stems (wood 125, and bark 13.98 t ha<sup>-1</sup>).

Pacholi and Pandey (1998) investigated the biomass production in *Dalbergia sisoo* planted at forest research station, Rarha, Birsa Agricultural University, Ranchi. The above ground biomass of *Dalbergia sisoo* was found

maximum at 2m x 2m spacing (104.6 t ha<sup>-1</sup>) while it decreased with increasing spacing.

Kumar *et al.* (1998) studied total and individual component of biomass production and diameter (D) and height (H) of *Acacia auriculiformis* which was measured in sample trees representing all diameter classes in 9 year old plantations established at 3 spacings (1m x 1m, 1.5m x 1.5m and 2m x 2m) in July 1984, near Ranchi, in Bihar, India. Linear regression equations for predicting biomass production were developed and showed that total and component biomass decreased at wider spacings. The mean annual biomass production rate was highest (16.94 t ha<sup>-1</sup>) at 1.0 x 1.0 m spacing.

Rao *et al.*, (2000) compared the biomass production of 11 multipurpose tree species growing on sandy loam soils in Andhra Pradesh and found that *Dalbergia sissoo* yielded maximum biomass (214.6 Mg ha<sup>-1</sup>) followed by *Leucaena leucocephala* (187.8 Mg ha<sup>-1</sup>) and *Acacia auriculiformis* (162.4 Mg ha<sup>-1</sup>).

Hunter (2001) carried out the study after 37 months of transplanting of *Eucalyptus spp.* and *Dalbergia sissoo*, a biomass and nutrient content determination was made. The *Eucalyptus* had total dry weight averaging 45.3 t ha<sup>-1</sup> while the *Dalbergia sissoo* had an average weight s only 7.6 t ha<sup>-1</sup>.

Subramanian *et al.* (2003) recorded height growth of 8m in five year old teak plantation and further observed that more than 50% of above ground biomass produced at 20 years period (149 t ha<sup>-1</sup>), is accumulated in initial five years period (76.9 t ha<sup>-1</sup>).

Padron and Navarro (2003) estimated above ground biomass of *Prosopis pallida* trees, which were naturally occurring in the north of Peru. A total of trees with diameters at the base between 12 and 48 cm were measured. Allometric equations were developed to estimate biomass. They reported that the obtained results show 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 ( $r=0.95$ ,  $r^2=0.9164$  and  $p=0.000$ ), with the diameters of the tree base.

The equations with the highest level of significance were multiplicative:  $Y = (\text{diameter of the tree base})^2 \times (\text{total height})$ .

Karmacharya and Singh (2003) the study was carried out in teak plantations (4, 14 and 30 years old), raised in a dry tropical region in northern India, an analysis of the standing crop biomass and above ground net production was made through non-destructive methods. Allometric regressions were developed relating girth to weights of bole wood, bole bark, branch, leaf and inflorescence. The above ground biomass ranged from 25.7 to 76.9 t ha<sup>-1</sup>. The proportion of woody biomass was 56% of the total at 4 years, increasing to 91% of the total by 30 years. On the contrary, the proportion of leaf biomass decreased from 34% of the total at 4 years to 7% by 30 years. Very high aboveground net production was obtained at 4 years (25.6 t ha<sup>-1</sup> year<sup>-1</sup>), but net production decreased with age (14 and 12.9 t ha<sup>-1</sup> year<sup>-1</sup> at 14 and 30 years).

Kale *et al.* (2004) developed linear equations to estimate biomass of five prominent species found in dry deciduous forest at Shivpuri district, Madhya Pradesh, central India, using a non-destructive method. For this, wood samples were taken from the permanent sample plots in all the available girth classes and their biomass values were calculated. Efforts were made to establish the relationship between sample biomass. The following species were taken: *Tectona grandis* and *Miliusa tomentosa*.

Rawat and Negi (2004) estimated the biomass production of *Eucalyptus tereticornis* which varied from 11.9 Mg ha<sup>-1</sup> in three years to 146 Mg ha<sup>-1</sup> in 9 year old plantation in moist regions.

Sah *et al.* (2004) developed volume equations that provide estimates of biomass from measured plants. They developed equations to estimate total above ground biomass of 10 common hardwood tree species in the shrub layer of pine forest of the lower Florida. Many equations that related biomass categories to crown area and height were significant ( $p < 0.05$ ), but the form and variables comprising the best model varied among species.

Thakur and Singh (2005) studied growth and above ground biomass in short rotation *Eucalyptus tereticornis* Sm. Provenances. The higher proportion of aboveground biomass was allocated to bole (60.4-63.3%) followed by branch (12.01-14.46%) and foliage (4.14-4.81%).

Segura and Kanninen (2005) reviewed the volume equations based on the direct measurement of individuals of seven tree species, for the estimation of the tree volume and above ground biomass in a tropical humid forest in northern Costa Rica. They reported that the average total above ground biomass ranged from 4 to 10 Mg/tree. The best fit equations for total above ground biomass that were based on combinations of diameter at breast height and total commercial height as independent variable had  $r^2$  values between 0.77 and 0.87.

Singh and Toky (2005) estimated above ground biomass and net primary productivity in high density (energy) plantations of three important species raised at Hisar in arid India. In 4-year old plantations, with initial plant spacing of 0.6m x 0.6m, *Leucaena leucocephala* showed fairly high net primary productivity ( $33 \text{ t ha}^{-1} \text{ year}^{-1}$ ) closely followed by *Eucalyptus tereticornis* ( $29 \text{ t ha}^{-1} \text{ year}^{-1}$ ). In both species, the values were two fold higher than *Acacia nilotica*. Of the total net productivity 23 to 27% returned to the soil through litter fall. The standing biomass after 4 years was  $112 \text{ t ha}^{-1}$  in *Leucaena leucocephala*,  $96 \text{ t ha}^{-1}$  in *Eucalyptus tereticornis* and  $52 \text{ t ha}^{-1}$  in *Acacia nilotica*. In 8-years old plantations with initial spacing of 2x2m, the net primary productivity was  $25 \text{ t ha}^{-1} \text{ year}^{-1}$  in *Leucaena leucocephala*,  $21 \text{ t ha}^{-1} \text{ year}^{-1}$  in *Eucalyptus tereticornis* and  $14 \text{ t ha}^{-1} \text{ year}^{-1}$  in *Acacia nilotica*; and 38 to 45% of it was returned to the soil through litter fall. After 8 years of growth, biomass was  $126 \text{ t ha}^{-1}$  in *Leucaena leucocephala*,  $102 \text{ t ha}^{-1}$  in *Eucalyptus tereticornis* and  $77 \text{ t ha}^{-1}$  in *Acacia nilotica*.

Roy *et al.* (2006) studied on tree growth and biomass production in eight year old plantation in single line (2m apart) of *Melia azedarach* tree on farm boundaries in a semi arid region (IGFRI, Jhansi, U.P). They observed that maximum number of trees were recorded in the diameter range of more than 22 cm. the trees contributed a total biomass production of  $2101 \text{ t ha}^{-1}$  of which 66,

24 and 10 % were contributed by minor timber, fire wood and fodder respectively. They were also developed biomass prediction equations Based on regression analysis with  $D^2$  dbh and  $D^2 H$ . the relationship of bole and total aerial biomass was found to be strong with all the predictor variables whereas relationship of foliage was strong with  $D^2$  and  $D^2h$  only.

Fang *et al.* (2007) studied biomass production and carbon sequestration potential in Poplar plantation with different management patterns i.e. four planting densities (1111, 833, 625 & 500 stem  $ha^{-1}$ ) and three poplar clones (NL- 80351, I-69 & I-72). Based on the model of total biomass production was significantly different in the plantations. The ranking of the plantation biomass production by planting density was  $1111 > 833 > 625 > 500$  stems  $ha^{-1}$  and by components was stem > root > branch > leaf for all plantations.

Mani and Parthasarathy (2007) studied above-ground biomass estimation in ten tropical dry evergreen forest sites of peninsular India. Two linear regression equations, one using basal area and the other using BA (Basal area) and height were followed. The AGB (Above Ground Biomass) varied from 39.69 to 170.02  $Mg ha^{-1}$  and by method 2; it varied from 73.06 to 173.10  $Mg ha^{-1}$ . The relationship between BA and AGB yielded a positive correlation for all the five sites of inland and coastal areas.

Raizada *et al.* (2007) prepared biomass prediction models for 17 year old having spacing 8mx8m, even aged plantation of *Acacia nilotica* tree, raised on salt affected vertisols of the semi arid tropics in karnataka .They observed that wide variations occurred in the trees sampled by random selection in the plantation with respect to diameter (3.1 to 16cm) and tree height (3.5 to 5.1m). Total above ground biomass ranged from 26.5 to 100.74  $kg tree^{-1}$ . Prediction models with best fit were in the linear form with  $r^2$  values of 0.8261, 0.9162 and 0.8665 for predicting bole, utilizable and total above ground biomass.

Goel and singh (2008) studied on performance of five year old coppice plants of *Dalbergia sisoo* was evaluated for biomass production on a sub-standard soil site. They developed different regression model with various growth

parameters to predict biomass of coppice shoots. Linear regression equation  $y=a+b(d^2h)$  (height and diameter of coppice shoot) was found to be the best predictor of biomass followed by diameter ( $d^2$ ) and height alone because of high value of correlation coefficient ( $p<0.001$ ,  $p<0.01$ ). At the age of 5 year, coppice shoot produced a total of  $13.52 \text{ Mg ha}^{-1}$  above ground biomass with maximum stem wood ( $9.84 \text{ Mg ha}^{-1}$ ), and leaf ( $0.781 \text{ Mg ha}^{-1}$ ) respectively at the density of  $2406 \text{ coppice stems ha}^{-1}$ . Accordingly, biomass allocation to different plant components revealed high proportions of woody biomass (94.3%) and marginal contribution of leafy portion (5.7%). mean annual increment (MAI) on the basis of total above biomass was  $2.70 \text{ Mg ha}^{-1}$  whereas the current annual increment was  $5.75 \text{ Mg ha}^{-1}$ .

Khanduri *et al.* (2008) studied on the assessment of three different teak forest stands was done in 2006 in Mizoram, India. Five diameter classes arbitrarily established for knowing the volume attribute data and population structure, viz., a (10-20 cm), b (20-30 cm), c (30-40 cm), d (40-50 cm), and e (50-60 cm). The volumes of individual trees under different diameter classes, i.e., 10-20, 20-30, 30-40, 40-50, 50-60 and >60cm have been calculated by using the following volume equation adopted from the forest survey of India (FSI, 1996). The general volume equation for teak is as follows:

$$V=0.008690+0.323051D^2 H$$

Where, V is the volume of individual tree, D is the diameter at breast height and H is the height of tree till the last branching.

Rawat *et al.* (2008) observed that the biomass production of *Dalbergia sissoo* plantations ranged from  $83.56 \text{ kg tree}^{-1}$  to  $1516 \text{ kg tree}^{-1}$ . The percent contribution in biomass production through tree components were in the order of bole>root>branch>bark>leaves.

Chauhan *et al.* (2009) conducted a study on the biomass and carbon allocation in different parts (viz., stem, branch, bark, root) of thirteen agroforestry tree species having spacing  $6\text{m} \times 3\text{m}$  (36 plant of each species) during 2003-06 on the agroforestry research farm (Ladhowal) of PAU, Ludhiana, India. They

reported that the biomass accumulation through stem was highest in *Acrocarpus fraxinifolius* (22.35 kg) which was statistically at par with *Populous deltoids* (18.92 kg) and *Eucalyptus teriticornis* (16.16 kg). there was no statistical difference in below ground biomass of different tree species. The highest tree stem carbon storage at the plantation level was found in *Acrocarpus fraxinifolius* ( $6.05 \text{ t ha}^{-1}$ ), while the lowest was *Syzigium cumini* ( $0.73 \text{ t ha}^{-1}$ ). They also observed that the carbon content of biomass component had relatively little influence on total carbon storage compared to the relative biomass in each tree component stem alone though was the largest store house of carbon but little and roots in the short rotation tree species play a major role in carbon sequestration in the soil reservoir.

Umrao *et al.* (2010) conducted a study on the productivity status of ten year old silvipasture system in red lateritic soil of chattisgarh plains in marginal wasteland area at Baronda Research Farm, Indira Gandhi Agriculture University, Raipur in the year 2002-03. The experiment was carried out on four Multipurpose tree species Viz., *Dalbergia sisoo*, *Gmelina arborea*, *Pongamia pinnata* and *Terminalia arjuna*, planted at 5x5m spacing in July 1992. They stated that among all four species, *Dalbergia sissoo* and *Gmelina arborea* considered as more biomass producing species in the silvipasture system. The overall dry matter production was found in order of *Dalbergia sisoo* (45.18 kg/tree), *Gmelina arborea* (36.97 kg/tree), *Pongamia pinnata* (26.74 kg/tree) and *Terminalia arjuna* (23.12 kg/tree).

Kumar *et al.* (2011) conducted a study to estimate the biomass production and nutrient removal by eight year old poplar plantation raised at different spacing in a replicated randomized block design having three spacing of 5x4m, 10x2.5m, and 15x2.5m. They observed that biomass of all the plants parts decreased with increasing tree spacing except that the differences between 10x2.5m and 15x2.5m spacing in respect of leaves and branches biomass were not significant. The total tree biomass including litter fall was higher in 5x4m ( $415 \text{ t ha}^{-1}$ ) followed by 10x2.5m ( $330 \text{ t ha}^{-1}$ ) and 15x2.5m ( $192 \text{ t ha}^{-1}$ ) spacing.

## 2.2 Carbon sequestration

Carbon sequestration is naturally taking up of atmospheric carbon dioxide by forests, agro-ecosystems, oceans and grasslands during photosynthesis. Most terrestrial carbon storage is in tree trunks, branches, foliage and roots which is often biomass. While all living plants matter absorbs CO<sub>2</sub> as part of photosynthesis, trees process significantly more than smaller plants due to their large size and extensive root structure. In essence, trees, as kings of plants world, have much more “woody biomass” to store CO<sub>2</sub> than smaller plants, and as a result are considered nature’s most efficient “Carbon Sinks”.

The carbon sequestration process involved in individual tree is an important concern in environmental system. The carbon sequestration in tree represents the balance between the process of photosynthesis and respiration which uses and releases CO<sub>2</sub> respectively. The process of carbon sequestration is the most rapid during the early stage of the life of tree while, as tree reaches maturity the above two processes become increasingly similar. Additionally, the rate of carbon sequestration is less particularly in over mature stage of the tree. Hence, the tree or forest expands the capacity of carbon sequestration also increases and vice-versa (Sedjo *et al.*, 2003).

Carbon sequestration is the process of removing carbon from the atmosphere and depositing it in a reservoir. It entails the transfer of atmospheric C, especially CO<sub>2</sub>, and its secure storage in long-lived pools. Aboveground C storage is the incorporation of C into plant matter either in the harvested product, or in the parts remaining on site in a living form. The amount of biomass, and subsequently C, that is stored depend to a great deal apart from the nature of plant itself on the properties of the soil on which it grows, with higher concentrations of organic matter (OM), nutrients, and good soil structure, leading to greater biomass production (Nair *et al.*, 2010). Aboveground carbon Sequestration is the direct manifestations of above ground biomass production (Nair *et al.*, 2010). A large number of ecological and management factors influence the rate at which this fundamental process proceeds. Tree plantations, especially in the tropics, play an important role in carbon sequestration through

the accumulation of carbon in the wood and increase in soil carbon storage. However, there is a large variation in the carbon sequestration potential of different plantation species and there are varying estimates of the carbon sequestration rates of common plantation species (FAO, 2003 and Negi and Chauhan, 2002). Carbon sequestration potential depends upon the biological productivity, which in turn depends upon interaction between species, climate, topography and management practices imposed. Thus carbon sequestration potential varies from place to place, which need to be worked out on region to region and species to species basis.

For calculation of carbon accumulation by plantation species, only stem biomass values were used, because most leaves and a great portion of the branches are expected to turnover every year, i.e., they represent only short-term carbon storage. Average stem biomass increments were converted to total carbon content by assuming that biomass is approximately 50% carbon (Brown *et al.*, 1986). Most researchers estimated carbon by assuming the carbon content of dry biomass to be the constant 50% by weight. (Brown, 1997, Montagini and porras, 1998).

Lugo *et al.*(1988) compared the carbon sequestration among different plantations of tropics and reported that 5-16 year old Eucalyptus plantation stored highest carbon (4.5-14 Mg C ha<sup>-1</sup> yr<sup>-1</sup>) followed by 5-30 old tropical pines (3-12 Mg C ha<sup>-1</sup> yr<sup>-1</sup>) while lowest amount of 2-4 Mg C ha<sup>-1</sup> yr<sup>-1</sup> was reported in 25-75 year old teak plantation.

Schroeder (1992) studied the carbon storage potential of short rotation tropical tree plantations. Mean long term carbon storage over multiple rotations was calculated for several commonly grown species, including *Pinus caribaea*, *Leucaena spp.*, *Casuarina spp.*, *P. patula*, *Cupressus lucitanica*, *Cassia siamea*, *Acacia spp.* and *Azadirachta indica*. Rotation length, and hence the potential to accumulate biomass was shown to be a key factor in the ability of plantations to remove carbon from the atmosphere over the long-term.

Botkin *et al.* (1993) field measures of trees and shrub dimensions were used with established biomass equations in a stratified, two-stage cluster sampling design to estimate above ground oven dry woody biomass and carbon storage of the eastern deciduous forest of North America. Biomass averaged  $8.1 \pm 1.4 \text{ kg/m}^2$  and totaled  $18.1 \pm 3.1$  giga tons. Carbon storage averaged  $3.6 \pm 0.6 \text{ kg/m}^2$  and totaled  $8.1 \pm 1.4$  giga tons.

Chaturvedi (1994) estimated that one tonne of carbon could be sequestered by 2.2 tonne of wood.

Negi and Chauhan (2002) conducted a study on carbon sequestration potential for natural sal forest aged 67 years and estimated carbon storage  $5.45 \text{ t C ha}^{-1} \text{ year}^{-1}$ .

Kraenzel *et al.* (2003) estimated the carbon storage of harvestable teak plantations of Panama. Above and belowground biomass and tissue carbon content of 20 years-old teak trees were measured. A regression relating diameter at breast height (DBH) to total tree carbon storage was constructed and used to estimate plantation level tree carbon storage, which averaged  $120 \text{ t C ha}^{-1}$ . Litter, undergrowth and soil compartments were estimated to contain 3.4, 2.6 and  $225 \text{ t C ha}^{-1}$ , respectively. The soil carbon was a one-time measurement, not an estimate of soil C plantations estimated to be  $351 \text{ t C ha}^{-1}$ .

Pande (2003) estimated  $446.06 \text{ M t C}$  for above ground and below ground components of forest vegetation and  $167.83 \text{ M t C}$  for forest soil for Madhya Pradesh. Forest type wise, it ranges from  $2.74 \text{ M t C}$  for Scrub forest vegetation to  $363.01 \text{ M t C}$  for dense forest vegetation and  $1.12 \text{ M t C}$  in scrub forest soil to  $149.85 \text{ M t C}$  in dense forest soil.

Lasco and Pulhin (2003) estimated carbon stocks and rate of sequestration of various forest ecosystems in the Philippines. Carbon density ranges widely from less than  $5 \text{ t ha}^{-1}$  to more than  $200 \text{ t ha}^{-1}$  in the following order: old growth forests > secondary forest > mossy forest > mangrove forest > pine forest > tree plantation > agroforestry farm > brush lands > grasslands. Carbon sequestration ranges from less than  $1 \text{ t ha}^{-1} \text{ yr}^{-1}$  in natural forests to more than  $15$

t ha<sup>-1</sup> yr<sup>-1</sup> in some tree plantations. It was estimated that Philippine forest lands are a net sink of green house gases (GHG) absorbing 107 Mt CO<sub>2</sub> which was equal to the total Philippine GHG emissions.

Ganeshaiyah *et al.* (2003) carbon content of 54 plant species was estimated by two methods. First by ash content method and secondly by regression equation derived between carbon and Ca content (%). In the oven dried plant components (leaves, bark and wood) were burnt in electric furnace at 400 °C temperature. Ash content left after burning was weighed and carbon was calculated by using the following equation:

$$\text{Carbon\%} = 100 - (\text{Ash weight} - \text{oven dry weight}).$$

Value of carbon calculated and regression equations were developed between carbon and calcium.

Swamy *et al.* (2003) study was carried out to observe biomass, carbon storage variations in 1 to 6 year old plantations of *Gmelina arborea*. Growth parameters (Dbh, total height and number of branches) varied significantly due to difference in age and site quality, but tree density showed nonsignificant variation. Stand biomass ranged from 3.94(1-year old) to 53.67 Mg ha<sup>-1</sup>(6- year old) and stand carbon in 6-year old plantations ranged from 24.12 to 31.12 Mg ha<sup>-1</sup> at different site. Among tree components, the stem wood accounted for maximum C (56.25% at site 1) followed by branches (19.8% at site 3), roots (18.51% at site 2), and foliage (7.01% at site 3). Mean annual C accretion at 6 years age of plantation was highest in site 3 and it was 0.35, 2.66, 0.965 and 0.87 Mg ha<sup>-1</sup> for leaf, stem, branches and roots, respectively.

Lal and Singh (2004) reviewed that annual productivity has increased from 0.7 m<sup>3</sup> per hectare in 1985 to 1.37 m<sup>3</sup> per hectare in 1995. Increase in annual productivity directly indicates an increase in forest biomass and hence higher carbon sequestration potential. The carbon pool for the Indian forests is estimated to be 2026.72 Mt for the year 1995. Estimates of annual carbon uptake increment suggest that our forests and plantations have been able to remove at least 0.125Gt of CO<sub>2</sub> from the atmosphere in the year 1995.

Kaur *et al.*(2004) the study was carried out on about six year old tree species of *Acacia nilotica*, *Dalbergia sissoo* and *Prosopis juliflora* in the main plots of a split-plot experiment with two species of grasses, *Desmostachya bipinnata* and *Sporobolus marginatus*, in the sub plots. The total carbon storage in the trees 1.18 to 18.55 Mg C ha<sup>-1</sup> and carbon input in net primary production varied between 0.98 to 6.50 Mg C ha<sup>-1</sup> yr<sup>-1</sup>. Carbon flux in net primary productivity increased significantly due to integration of *Prosopis juliflora* and *Dalbergia sissoo* with grasses.

Montagnini and Nair (2004) average carbon storage by agroforestry practices has been estimated as 9, 21, 50 and 63 Mg C ha<sup>-1</sup> in semiarid, sub-humid, humid and temperate regions.

Hooda *et al.* (2005) reported about C Sequestration potential of tree species planted on farmlands viz., planting of poplar, Eucalyptus and Teak have shown the potential in the range of 1.42 to 2.85 t C ha<sup>-1</sup> yr<sup>-1</sup>.

Houghton (2005) estimation of carbon emissions from tropical deforestation have focused on the uncertainty in rates of deforestation. The changes more likely represent improved information than real on the ground changes in carbon storage. In either case, however, the data have a significant effect on current estimates of carbon emissions from the tropics and, hence, on understanding the global carbon balance.

Swamy and Puri (2005) evaluated Growth, biomass productivity and C-sequestration of *Gmelina arborea* in sole stands and agroforestry system, was established in abandoned agricultural land. At 5 years, total stand biomass in agrisilviculture system was 14.1 Mg ha<sup>-1</sup> while the plantations had 35% higher biomass than agrisilviculture system. Differential allocation of Biomass and C storage was observed in stands and relatively more C was allocated in above ground components in plantations compared to agrisilviculture system. Over the 5 years of study, trees had 3.5 Mg ha<sup>-1</sup> more C than agrisilviculture system.

Evrendilek *et al.* (2006) studied the above ground biomass, above ground litter fall and leaf litter decomposition of five indigenous tree stands (pure stands of *Abies ciliata*, *P. nigra* and *C. libani*) in eastern Mediterranean evergreen needle leaf forest of Turkey. Mean C stock of the conifer forests was estimated as  $97.8 \pm 79 \text{ Mg C ha}^{-1}$  consisting of  $83.0 \pm 67 \text{ Mg C ha}^{-1}$  in the above ground and  $14.8 \pm 12 \text{ Mg C ha}^{-1}$  in the below ground biomass.

Manhas *et al.* (2006) the total carbon stock (wood only) for India was 1085.06 and 1083.69 Mt in 1984 and 1994 respectively. The average carbon stock for the country was  $24.94 \text{ t C ha}^{-1}$  in 1984 and  $24.54 \text{ t C ha}^{-1}$  in 1994. *Shorea robusta* forests stocked  $24.07 \text{ t C ha}^{-1}$  in 1984 and  $22.66 \text{ t C ha}^{-1}$  in 1994, *Tectona grandis* forests stocked  $11.11 \text{ t C ha}^{-1}$  in 1984 and  $11.25 \text{ t C ha}^{-1}$  in 1994. In west Bengal, total carbon stock of *Shorea robusta* and *Tectona grandis* were 5.49 Mt in 1984 and 6.19 Mt in 1994, and 0.29 Mt in 1984 and 0.30 Mt in 1994, respectively.

Gera *et al.* (2006) reported that in Punjab, among agroforestry model adopted by farmers, maximum C Sequestration potential on annual basis has been estimated for planted forests of poplar (*Populous deltoids*) as block ( $4.42 \text{ t c ha}^{-1}$ ), followed by poplar bund planting ( $2.46 \text{ t c ha}^{-1}$ ) and Eucalyptus (*Eucalyptus tereticornis*) bund planting ( $2.15 \text{ t c ha}^{-1}$ ).

Kirby and Potvin (2007) worked with a community in eastern Panama to determine the average above and below ground C stocks of three lands-use types in their territory: managed forest, agroforests and pasture. They examine evidence for a functional relationship between tree species diversity and C storage in each land use type, and also explored how the use of particular tree species by community members could affect C storage. They found that managed forests stored an average of  $335 \text{ Mg C ha}^{-1}$ , traditional agroforests an average of  $145 \text{ Mg C ha}^{-1}$ , and pastures an average of  $46 \text{ Mg C ha}^{-1}$  including all vegetation based C stocks and soil C to 40 cm depth.

Ramachandran *et al.* (2007) estimated total above and below ground biomass carbon stock in kolli hills in different forest types is 2.74 Tg of which the semi arid evergreen forest contributed 22%, the deciduous forest contributed to the maximum of 57% and the other forest types contributed 21%. Vegetation biomass carbon density of 0.60 Tg ha<sup>-1</sup> in semi evergreen forests, 1.57 Tg ha<sup>-1</sup> in deciduous forests, 0.35 Tg ha<sup>-1</sup> in secondary deciduous forests, 0.22 Tg ha<sup>-1</sup> in thorn forests and 0.01 Tg ha<sup>-1</sup> in Euphorbia forests was recorded. This estimate is similar to the average carbon density of the tropical forests.

Ravindranath *et al.* (2007) reported an average sequestration potential of 2.23 t C ha<sup>-1</sup> yr<sup>-1</sup>, for short rotation plantation interventions involving tree species such as *Eucalyptus hybrid*, *Casuariana equisetifolia*, *Acacia nilotica*, and *Gmelina arborea*, planted for the purpose of fuel wood, industrial wood and poles.

Alamgir and Al-Amin (2008) developed allometric models for estimate biomass, organic carbon stock in the forest vegetation. Model using above ground biomass alone was found to be the best predictor of biomass organic carbon stock in trees because of high coefficient of determination ( $r^2$  is 0.73697 and 0.87703 for > 5 cm to <15 cm and >15cm DBH range , respectively) and significance of regression ( $p$  is 0.000 for each DBH range) Coefficients for both DBH range.

Jana *et al.* (2009) studied percentage of carbon content (except root) in the aboveground biomass of *Shorea robusta*, *Albizzia lebbeck*, *Tectona grandis* and *Artocarpus integrifolia* were 47.45, 47.12, 45.45 and 43.33, respectively. The Total aboveground biomass carbon stock per hectare as estimated for *Shorea robusta*, *Albizzia lebbeck*, *Tectona grandis* and *Artocarpus integrifolia* were 5.22, 6.26, 7.97 and 7.28 t C ha<sup>-1</sup>, respectively in these forest stands. The annual carbon sequestration rate from ambient air were estimated at 8.97 t C ha<sup>-1</sup> by *Shorea robusta*, 11.97 t C ha<sup>-1</sup> by *Albizzia lebbeck*, 2.07 t C ha<sup>-1</sup> by *Tectona grandis* and 3.33 t C ha<sup>-1</sup> by *Artocarpus integrifolia*.

Dhruw *et al.* (2009) studied the storage and sequestration of carbon in leguminous trees (*Cassia siamiae* and *Dalbergia sissoo*) vs. non-leguminous tree (*Tectona grandis*) in red lateritic soil of Chhattisgarh and found that carbon sequestration by leguminous trees was higher than the non-leguminous trees. The Carbon concentrations of different components of eight-year-old trees were found to be 39.3-42.55, 41.06-43.3 and 40.74- 46.5 and 44.4-45.3% in leaves, branches, stems and roots, respectively. The total storage of carbon ranged from 1354.7 to 3079.86 kg ha<sup>-1</sup>. They also stated that the fast growing trees have more potential to capture and store atmospheric CO<sub>2</sub> at faster rate in comparison to slow growing tree species.

Baishya *et al.* (2009) compared tree aboveground biomass (AGB) distribution and carbon storage in different DBH (diameter at breast height) classes between natural semi-evergreen forest and sal plantation forest in the humid tropical region of northeast India. The natural forest had lower AGB (323.9 Mg ha<sup>-1</sup>) than the plantation forest (406.4 Mg ha<sup>-1</sup>). About 49% of the AGB was present in > 60 cm dbh trees in the natural forest against 24% in the plantation forest. The carbon storage was highest in 60-80 cm and 40-60 cm dbh classes in the natural forest and plantation forest, respectively.

Dogra *et al.* (2009) studied on above ground productivity and carbon sequestration potential of *Eucalyptus hybrid* in Punjab. Developed logarithmic model with two variables (Diameter at breast height and tree height), proved best fit for predicting weight of timber and other tree components, and prediction equation to estimate the amount of carbon sequestered and CO<sub>2</sub> absorbed. They stated that *Eucalyptus hybrid* has been planted in Punjab in linear strips along roads and canals, in small forest blocks and on farmers field in association with agricultural crops under agroforestry systems; such tree planting practices have expanded the opportunity to increase wood production and slow down CO<sub>2</sub> concentration from the atmosphere. Based on sampled trees, *Eucalyptus hybrids* grown under Punjab's climatic conditions attained an average air dry timber density of 550±28 kg m<sup>-3</sup>.

Derwisch *et al.* (2009) reviewed that tropical tree plantations may play an important role in mitigating CO<sub>2</sub> emissions through their potential to capture and sequester carbon from the atmosphere. The objectives of the study were to measure the carbon storage potential of 1-2 and 10 years old *Tectona grandis* plantations. The average above ground C storage ranged from 2.9 Mg C ha<sup>-1</sup> in the 1-year old plantations to 40.7 Mg C ha<sup>-1</sup> in the 10 year old plantations. Using regression analysis they estimated the potential above ground C storage of the *Tectona grandis* plantation over a 20 year rotation period. The CO<sub>2</sub> storage over this period amounted to 191.1 Mg CO<sub>2</sub> ha<sup>-1</sup>.

Singh and Lodhiyal (2009) reported that agroforestry systems can play an important role in carbon mitigation programme through carbon sequestration and can reduce the pressure on existing natural forests by providing fuel, fodder, timber and wood products to the farmers.

Mir (2010) conducted a study to estimate above ground biomass and rate of carbon sequestration in *Tectona grandis*, *Madhuca indica*, *Dalbergia sissoo*, *Acacia nilotica*, and *Azadirachta indica* at Allahabad. The study result shown that *Madhuca indica* have maximum above ground biomass followed by *Azadirachta indica*, *Dalbergia sissoo*, *Tectona grandis* and *Acacia nilotica* with 398.84, 306.86, 261.46, 237.78, and 179.86 kg tree<sup>-1</sup> respectively. The percent carbon content in above ground biomass of *Tectona grandis*, *Madhuca indica*, *Dalbergia sissoo*, *Acacia nilotica*, and *Azadirachta indica* recorded were 50.12%, 54.22%, 55.02%, 56.48%, and 51.00% respectively. The total carbon sequestration rate obtained from above ground biomass of *Tectona grandis*, *Madhuca indica*, *Dalbergia sissoo*, *Acacia nilotica*, and *Azadirachta indica* were 11.94, 20.84, 14.35, 10.13, and 15.67 kg tree<sup>-1</sup> respectively.

Hussain (2010) a series of experiment was conducted to assess carbon sequestration potential of selected fast growing tree species viz., *Populus deltoids*, *Bombax ceiba*, *Eucalyptus hybrid*, *Leucaena leucocephala*, and *Bauhinia variegata* commonly found in natural and social forests of India. The experiment result concluded as the maximum above ground biomass was

recorded in *Bombax ceiba* (144.19 kg tree<sup>-1</sup>) followed by *Bauhinia variegata* with a value of 54.58 kg tree<sup>-1</sup> and the least biomass was found in *Leucaena leucocephala* (26.82 kg tree<sup>-1</sup>). The maximum fixed carbon was recorded in *Leucaena leucocephala* (51.01%) followed by *Bauhinia variegata* with a value of 47.75% and the minimum fixed carbon was recorded in *Bombax ceiba* (43.42%). The maximum carbon sequestration was recorded in *Bombax ceiba* (58.95 kg tree<sup>-1</sup>) followed by *Bauhinia variegata* with a value of 26.02 kg tree<sup>-1</sup> and the minimum carbon sequestration was recorded in *Leucaena leucocephala* (13.66 kg tree<sup>-1</sup>). However, *Leucaena leucocephala* was found to be the most efficient carbon sequester followed by *Bauhinia variegata*, which might be due to nitrogen fixing ability of these two species.

Madhusudanan (2010) conducted a study on carbon sequestration potential in the above ground biomass of selected multipurpose tree species in South Gujarat during August 2008 to March 2010, at the Instructional farm, ASPEE College of Horticulture and Forestry, Navsari Agricultural University, Navsari. The study involved assessment of biomass, nutrient accumulation and carbon sequestration potential in the aboveground components of 4 multipurpose tree species (MPTs) of 20-year stand age viz. *Casuarina equisetifolia*, *Eucalyptus tereticornis*, *Gmelina arborea* and *Albizia procera*. The trees were established at 2.5 x 2.5 m spacing in a randomized block design with four replications.

Aboveground biomass accumulation studies revealed considerable variation among the species. Among the four species *Albizia procera* showed highest biomass which was at par with *Casuarina equisetifolia*. This was followed by *Eucalyptus tereticornis*; *Gmelina arborea* invariably recorded the least aboveground biomass. The percentage contribution of various components to above ground biomass was in the order: stem wood > branch wood > twig > leaves. Among the biomass components stem wood constituted the bulk of the biomass (65.59-79.21%) and leaves represented the lowest (1.65-3%). Stand biomass accumulation also followed a trend similar to mean tree accumulation.

For instance, *Albizia procera* registered highest biomass production (379.86 Mg ha<sup>-1</sup>) which was at par with *Casuarina equisetifolia* (371.70 Mg ha<sup>-1</sup>).

Aboveground C- sequestration also followed a similar trend with biomass accretion among the species. *Albizia procera* showed highest C-sequestration potential (189.92 Mg C ha<sup>-1</sup>) which was at par with *Casuarina equisetifolia* (185.852 Mg C ha<sup>-1</sup>) closely followed by *Eucalyptus tereticornis* (114.36 Mg C ha<sup>-1</sup>). Component contribution to carbon sequestration on mean tree basis and per hectare basis showed similar trends as biomass partitioning. All the MPTs showed the following trend of component contribution: stem>branch>twig>leaves. The carbon allocated in the stems varied from 65.59% (*Gmelina arborea*) to 79.21% (*Albizia procera*).

Gera *et al.* (2010) studied on the opportunities for carbon sequestration benefits from growing trees of medicinal importance, viz., Aonla, Arjun, Bahera, Neem, Padam, Reeta, on farmlands at Haryana under forestry CDM project; involves afforestation and reforestation which offer opportunities for CO<sub>2</sub> mitigation by removal of accumulated CO<sub>2</sub> from atmosphere and sequester it in vegetation soil and wood products. The study results show that plantation of tree species of medicinal importance as Aonla, Arjun, Jamun, Harar, Neem and Reeta has shown significantly large sequestration potential in the range of 3.05 to 11.01 tons of CO<sub>2</sub> ha<sup>-1</sup> yr<sup>-1</sup>.

Kaul *et al.* (2010) reported a net annual carbon sequestration for short rotation fast growing Poplar (8 Mg C ha<sup>-1</sup> yr<sup>-1</sup>) and Eucalyptus (6 Mg C ha<sup>-1</sup> yr<sup>-1</sup>) plantations followed by moderate growing teak forests (2 Mg C ha<sup>-1</sup> yr<sup>-1</sup>) and slow growing long rotation sal forests (1 Mg C ha<sup>-1</sup> yr<sup>-1</sup>). He also added that due to fast growth rate and adaptability to range of environments, short rotation plantations, in addition to carbon storage rapidly produce biomass for energy and contribute to reduce green house gas emissions.

Gera *et al.* (2011) studied on the carbon sequestration potential of selected plantation interventions in terai region of Uttarakhand, with the objectives to assess their carbon sequestration potential, and cost-effectiveness

exclusive and inclusive of carbon benefits. The results of study have shown a wide range of sequestration potential with varied from 0.74 t c ha<sup>-1</sup> yr<sup>-1</sup> in case of Aonla Block plantation, 2.34 t c ha<sup>-1</sup> yr<sup>-1</sup> for Triphala block plantation, calculated for the assessment period 2008-38. However, with the wood products scenario, the maximum sequestration potential was observed for poplar block plantation (2.41 t c ha<sup>-1</sup> yr<sup>-1</sup>), closely followed by Eucalyptus block (1.73 t c ha<sup>-1</sup> yr<sup>-1</sup>), while Teak block plantation showed sequestration potential of 1.50 t c ha<sup>-1</sup> yr<sup>-1</sup>.

## **MATERIALS AND METHODS**

The present investigation entitled “Estimation of Standing State Biomass and Carbon Sequestration Potential of Multipurpose Tree Species” was conducted on 24 years old stand age of MPTs at dusty acre farm, under AICRP on Agroforestry, Department of forestry, JNKVV, Jabalpur during 2011-12. The materials used and the methods employed during the course of investigation are presented in this chapter under the appropriate heads.

### **3.1 Experimental site**

The field experiment was conducted at Dusty Acres Research Farm, Department of Forestry, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur.

### **3.2 Climate and weather conditions of Jabalpur**

Jabalpur is situated at 23°9' North latitude and 79°58' East longitudes with an altitude of 411.78 meters above the mean sea level. The climate of the locality is semi-arid and tropical, with hot dry summer and cool dry winter. It is classified as "Kymore Plateau and Satpura Hills" agro-climate zone, as per norm of National Agricultural Research Project. As per recent classification of National Bureau of Soil Survey and Land use planning (NBSSLUP), Nagpur, this area belongs to agro-ecological region number 10, named as Central High Lands (Malwa and Bundelkhand), sub-region number 10.1, named as hot sub-humid (dry) eco-region (Malwa Plateau, Vindhayan Scarpland and Narmada Valley).

The mean annual rainfall of Jabalpur based on last 20 years data which was 1350 mm which is mostly received from south-west monsoon between mid June to end of September with little occasional rainfall of 75 mm during other months. The mean monthly minimum temperature varies between 8.2 to 8.7 °C in December and January, and maximum temperature varies between 45.5 to 46.4°C during May and June, respectively. January is the coldest month of the year with minimum temperature being 3°C. Generally relative humidity remains very low during summer (15 to 30%); moderate (60 to 75%) during winter and it attains high value (80 to 95%) during rainy season.

### 3.3 Experimental details

The present study was undertaken on 24 Years old five Multipurpose Tree Species, planted during 1988. The selection of trees for estimation of the biomass production and carbon sequestration was done on the basis of dbh, which was recorded for each individual tree species from block of Multipurpose trees stands and mean value was worked out to select the representative trees in a stand of MPTs. Five trees were selected those represent the average dbh of each Multipurpose tree stand.

Five wood samples from stem of selected multipurpose tree species were taken, those have almost same size for determination of specific gravity, moisture content and fixed carbon % in multipurpose trees. The field experiment was conducted in randomized block design.

Treatment : 5 (Multipurpose Tree Species)

T<sub>1</sub> : *Acacia nilotica*

T<sub>2</sub> : *Albizia lebbek*

T<sub>3</sub> : *Dalbergia sissoo*

T<sub>4</sub> : *Eucalyptus tereticornis*

T<sub>5</sub> : *Terminalia arjuna*

Design	:	RBD
Number of replications	:	Five
Year of experimentation	:	2011-12
Plot size (block plantation of trees)	:	400 m <sup>2</sup> .

### 3.4 Description of the selected Multipurpose Trees

#### 3.4.1 *Acacia nilotica*

Common name: Bbabul

Family: Mimosaceae (Leguminosae)

Scientific name: *Acacia nilotica* (L.) Willd. ex Delile

*Acacia nilotica* is a very useful multipurpose tree and it is a tropical, perennial tree species, 2.5–10 (–20) m tall, single-stemmed, deciduous tree; root system deep and extensive; trunk straight, up to 100 cm in diameter; bark rough and longitudinally fissured, 1–1.5 cm thick, grey to brownish black, younger stems grey-brown and smooth; crown flattened or rounded. It is widely cultivated in the Indian subcontinent and it is now widely planted on farms throughout the plains and can also grow on saline, sodic or alkaline soils. It is recommended for agroforestry in arid and semiarid areas and for erosion control. Being easy to propagate by seed, fast growing, nitrogen fixing, tolerant of poor soils and arid conditions it will always have a role to play in the reclamation of degraded areas where fuel and timber supplies are lacking.

#### Uses

*Acacia nilotica* is a truly multipurpose tree, widely used as a timber, source of fodder, tannin and gum, and as a fence, shade and fuel tree. The dark brown heartwood is nearly twice as hard as teak and very shock resistant; the wood is dense, heavy, termite resistant, and water repellent and is used widely in constructions, for railway sleepers, tool handles, carts and boat construction. The heartwood is especially valued for both firewood and charcoal. It has a calorific value of 4950 kcal per kg. The leaves and pods are an excellent fodder, rich in protein. The flowers yield a honey of good quality. The bark of slender branches yields a fibre which is used for the manufacture of paper or is made into coarse ropes in India. The bark, gum, leaves and pods are used in many traditional medicines, possessing anti-inflammatory properties.

### **3.4.2 *Albizia lebbbeck***

Common name: black siris, Indian siris, koko, lebbek

Family: Fabaceae

Scientific name: *Albizia lebbbeck* (L.) Benth

*Albizia lebbbeck* is a large, fast-growing deciduous tree that generally reaches 10 to 20 m in height and 30 to 60 cm dbh. Native to Pakistan, India, Bangladesh, Andaman Islands, Burma, S China, NE Thailand, and Malaysia; Found in deciduous and semi-deciduous monsoon forests, and rainforests in its native habitat, and in a variety of situations in the humid and semi-arid tropics and subtropics. It prefers well-drained soils of moderate to high fertility. It can grow on less fertile soils, but is not adapted to heavy clay or waterlogged soils. It is adapted over a wide range of pH from acid to alkaline, and also tolerates moderate soil salinity. It is very drought tolerant, being found in areas with rainfall as low as 300 - 400 mm/yr.

#### **Uses**

It is a nitrogen-fixing tree, with value for shade, quality hardwood (cabinet, veneer, and construction), fuel-wood and charcoal, and honey (source of nectar and pollen); proposed as alternative forage to *Leucaena leucocephala* in more acid soils. The extensive, shallow root system makes it a good soil binder and suited to soil conservation and erosion control. Various parts of the tree are used in folk remedies for many ailments. It is also used as an ornamental and avenue tree, and sometimes as a shade tree in coffee and tea. The bark contains saponins and tannins, used for making soap and in tanning, respectively.

### **3.4.3 *Dalbergia sissoo***

Common name: shisham, sisam, sissoo, sissu Indian rosewood

Family: Fabaceae

Scientific name: *Dalbergia sissoo* Roxb. ex DC.

*Dalbergia sissoo* known as Shisham is an erect, medium to large-sized deciduous tree, native to the Indian Subcontinent, growing up to 25 m in height and

80 cm dbh with a light crown which reproduces by seeds and suckers under favourable conditions. It is primarily found growing along river banks below 900 m elevation, but can range naturally up to 1300 m. It can withstand average annual rainfall up to 2000 mm and droughts of 3-4 months. *D. sissoo* grows well in a wide range of soil types, from pure sand and gravel to rich alluvial soil of riverbanks.

In its native countries of India and Pakistan, *D. sissoo* has been widely planted outside its natural range. It has been established in irrigated plantations, along roadsides and canals, and around farms and orchards as windbreaks. Shisham is best known internationally as a premier timber species of the rosewood genus. However, Shisham is also an important fuel wood, shade, and shelter. With its multiple products, tolerance of light, frosts and long dry seasons, this species deserves greater consideration for tree farming, reforestation and agroforestry applications.

### **Uses**

Young branches and foliage form an excellent fodder with a dry-matter content of 32.46%, crude protein 2.7-24.1%. The foliage has normally been used as emergency feed when other fodder sources fail. The species is fast growing, hence suitable for firewood. The calorific value of the sapwood and heartwood of 'excellent' fuel wood is reported to be 4,908 kcal/kg and 5,181 kcal/kg respectively. As a fuel wood it is grown on a 10 to 15-year rotation. Shisham wood makes excellent charcoal for heating and cooking.

*Dalbergia sissoo* is one of the most useful timber species of India. The heartwood is very hard and close grained with a specific gravity of 0.62-0.82. It is used for high-quality furniture, cabinets, decorative veneer, marine and aircraft grade plywood, ornamental turnery, carving, engraving, tool handles and sporting goods. Its root wood is used for tobacco pipes. Sulphate pulp from wood is used in producing writing and printing paper. Oil obtained from the seeds is used to cure skin diseases. The powdered wood, applied externally as a paste, is reportedly used to treat leprosy and skin diseases.

Due to its vigorous reproduction through suckers, it is useful for stabilizing eroding sites. It is therefore found in a variety of wastelands, like in south Asia, where it is known as a colonizing species. As shisham tree fix atmospheric N<sub>2</sub> therefore it improves soil fertility. Heavy litter fall decomposes to enrich the soil with nitrogen, phosphorus and organic carbon. It may be planted as one component of a multitier home garden system, where it contributes several products.

#### **3.4.4 *Eucalyptus tereticornis***

Common name: Eucalypt

Family: Myrtaceae

Scientific name: *Eucalyptus tereticornis* Smith

*Eucalyptus tereticornis* (Mysore Gum) is a fast growing exotic species that has been planted almost all over India for large scale afforestation and plantation programme. It is ideally suited for pulp and paper industry and also finds many other uses like fuel and charcoal, essential oil and timber production.

#### **Uses**

Eucalypt is a very good substitute for firewood because of its calorific value and moderate burning qualities. Eucalypt wood gives good charcoal that fulfills the fuel wood or charcoal requirement of rural small scale industries by eucalyptus plantation. Its poles are good for transmission purposes and are also used in construction of dwelling houses, work sheds and in mines\ . Considering the cost of eucalypt timber, it is found to be quite economical to use in low cost houses; as mine timber and in other construction purposes. It is also being used as furniture wood. One of the most important uses of eucalypt wood so far has been in the paper and pulp industry. The demand for paper and pulp is going to increase many fold in India and eucalypt, being one of the good pulpwood materials, will be in continuing demand.

### **3.4.5 *Terminalia arjuna***

Common name: Arjuna, Arjun Tree

Family: Combretaceae

Scientific name: *Terminalia arjuna* (Roxb.) Wight & Arn.

*Terminalia arjuna* is the large size deciduous tree, is common throughout India especially in the sub Himalayan tracts and Eastern India. It is mainly grown on the banks of the rivers and streams. The height of the Arjuna tree reaches up to 60 - 85 feet. It has a buttressed trunk and a vast spreading crown from which the branches drop downwards.

#### **Uses:**

The Arjuna is one of the species whose leaves are fed on by the *Antheraea paphia* moth which produces the tassar silk (Tussah), a wild silk of commercial importance. The Bark of Arjuna tree contains calcium salts, magnesium salts, and glucoside has been used in traditional Ayurvedic herbalism Juice of its leaf is used to cure dysentery and earache. Its wood is used in boat and house building as it is very hard. Its wood is also used in the making of the agricultural implements and weapons too. It is grown in the cities and towns for the purpose of shade.

### **3.5 Observations recorded**

#### **3.5.1 Tree Height (m)**

The total heights of individual standing multipurpose trees in each stand were measured from the ground level to the tip of the leading shoot with the help of a 30 m long measuring tape. It is expressed in meter.

#### **3.5.2 Diameter at Breast Height (cm)**

For determination of Diameter at breast height (dbh), Circumference(C) of individual standing trees were measured with the help of measuring tape at 1.37 m

height from ground level and circumference was converted into dbh by using the following relation ( $dbh=C/3.14$ ). It is expressed in cm.

### 3.5.3 Basal area (m<sup>2</sup>)

Basal area of selected trees in a multipurpose tree stand was calculated by using the following formula:

$$\text{Basal area} = 0.00007854 \times (\text{dbh})^2$$

### 3.5.4 Tree volume (m<sup>3</sup>)

The above ground volume of selected standing trees was calculated by using basal area and tree height in the following relation:

$$\text{Volume of standing tree} = \text{Basal area} \times \text{Tree height}$$

### 3.5.5 Moisture content (%)

Moisture content was determined by taking the fresh weight of wood samples of selected tree species. Oven dry weight of samples was determined at 105 °C in a hot air oven for a period until a constant weight of wood samples was achieved. The relation used is as follows:

$$\text{Moisture content (\%)} = \frac{\text{Fresh weight (g)} - \text{Oven dry weight (g)}}{\text{Fresh weight (g)}} \times 100$$

### 3.5.6 Specific gravity

Specific gravity was calculated by using the formula:

$$\text{Specific gravity} = \frac{\text{Oven dry weight of wood sample}}{\text{Green volume of that wood sample}}$$

(Negi *et al.*, 2003; Mani *et al.*, 2007; and Jana *et al.*, 2009)

### 3.5.7 Above Ground Biomass of trees (Kg/tree)

Stand biomass (above ground) of trees was estimated by using formula i.e.

$$\text{Biomass (kg/tree)} = \text{Volume of tree} \times \text{specific gravity}$$

(Negi *et al.*, 2003 Mani *et al.*, 2007 and Jana *et al.*, 2009)

### 3.5.8 Ash content (%)

Ash content was determined by calculating the ash content of wood samples of each tree species. For this, the oven dried wood samples were completely burned to get ash. The relation used for determination of ash content is as follows:

$$\text{Ash content (\%)} = \frac{\text{Weight of ash}}{\text{Oven dry weight}} \times 100$$

(Jana *et al.*, 2009)

### 3.5.9 Fixed carbon (%)

Fixed carbon mainly contributes to carbon storage. It is determined by detecting moisture content and ash content from 100 as percentage and remainder is assumed as the pure or fixed carbon. The relation was used as follows:

$$\text{Fixed carbon (\%)} = 100 - (\text{Ash content\%} + \text{Moisture content \%})$$

(Ganeshiah *et al.*, 2003)

### 3.5.10 Carbon sequestration (kg/tree)

The total biomass carbon storage was calculated by using the following formula:

$$\text{Carbon sequestration (kg C tree}^{-1}\text{)} = \text{biomass of tree} \times \text{carbon content (\%)}$$

(Jana *et al.*, 2009)

### 3.5.11 Determination of weight of CO<sub>2</sub> sequestered in the tree (kg/tree)

CO<sub>2</sub> is composed of one molecule of carbon and two molecules of oxygen. The atomic weight of carbon, oxygen and carbon dioxide is 12.001115, 15.9994 and 43.999915 respectively. The ratio of atomic weight of CO<sub>2</sub> to C is 3.6663. Therefore, to determine the weight of carbon dioxide sequestered in the tree by multiply the weight of carbon in the tree by 3.6663.

### 3.5.12 Determination the weight of CO<sub>2</sub> sequestered in the tree per year (kg/tree)

It can be determined by using following relation:

Total weight of carbon dioxide sequestered in the tree / Total age of tree

### 3.6. Statistical analysis

The experimental data were subjected to statistical analysis by ANOVA technique and critical difference test. Treatment effect and other factors were determined by F test as outlined by **Fisher and Yates (1963)**

**Table 3.1 ANOVA table (RBD)**

Source of variation	Degree of freedom	Sum of square	Mean sum of square	F (cal.)	F (tab.) at 5%
Due to replication	(r-1)	SSR	MSSR= SSR/ (r-1)	MSSR/ MSSE	
Due to treatments	(t-1)	SST	MSST=SST/(t-1)	MSST/MSSE	
Due to error	(t-1)(r-1)	SSE	MSSE=SSE/(t-1)(r-1)		
Total	rt-1	TSS			

Where,

t= number of treatments

r= number of replications

SST = Sum of Square due to treatment

MSSR = Mean Sum of Square due to replications

MSST = Mean Sum of Square due to treatment

MSSE = Mean Sum of Square due to error

TSS = Total Sum of Square

$F_{cal}$  = calculated value of F

$F_{tab}$  = value of F from variance ratio table

The standard error of the differences ( $SED_{\pm}$ ) will be calculated by using following expression:

$$SED (\pm) = \sqrt{2 \times MSE / r}$$

The critical difference (CD) was calculated to test the differences of treatment. The CD was calculated using the following relation:

$$CD (5\%) = SED (\pm) \times t$$

t = 5% tabulated value at error degree of freedom (16) i.e. 3.01

## RESULTS

The present chapter deals with the findings of the investigation regarding biomass and carbon sequestration potential of 24 years old stand age of multipurpose tree species, was carried out during the year 2011-2012 at dusty acre farm, Department of forestry, college of agriculture, J.N.K.V.V, Jabalpur. The results obtained in the present investigation have been summarized in the form of tables and figures along with appendix. Data on various parameters studied were subjected to statistical analysis in order to draw the valid conclusions of results which have been presented in succeeding pages. The results obtained have been described in this chapter under the following subheadings.

### 4.1 Tree Height (m)

It was observed that the tree height varies significantly within different multipurpose tree species. Data presented in table 4.1 and figure 4.1 revealed that highest average tree height was observed for *Eucalyptus tereticornis* followed by with a value of 22.52 m, while the lowest average height was recorded in *Dalbergia sissoo* with a value of 13.78 m.

Table 4.1 Average Height of the different multipurpose tree species.

Treatments (Tree species)	Average height (m)
<i>Acacia nilotica</i> (T <sub>1</sub> )	15.18
<i>Albizia lebbbeck</i> (T <sub>2</sub> )	18.76
<i>Dalbergia sissoo</i> (T <sub>3</sub> )	13.78
<i>Eucalyptus tereticornis</i> (T <sub>4</sub> )	22.52
<i>Terminalia arjuna</i> (T <sub>5</sub> )	15.70

F Test = S  
SED ( $\pm$ ) = 0.8470  
CD (5%) = 1.7533

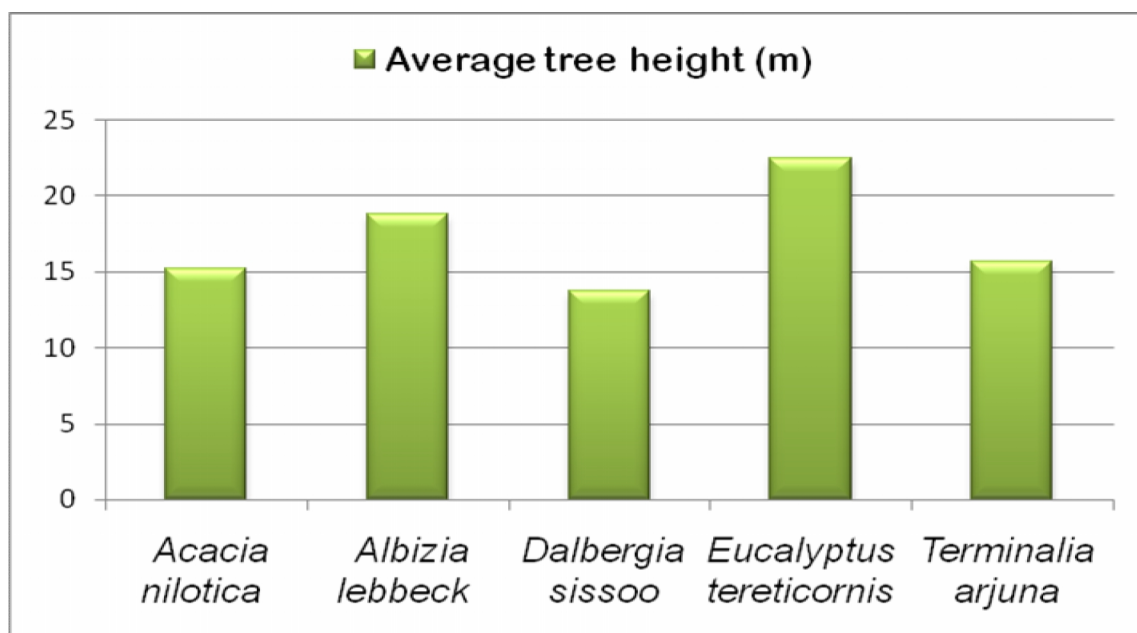


Fig.4.1. Average height of different multipurpose tree species

#### 4.2 Diameter at Breast Height (cm)

It was observed that the tree diameter at breast height varies significantly with different multipurpose tree species. From table 4.2 and figure 4.2 it was observed that the maximum average diameter at breast height was in *Albizia lebbeck* (28.70cm) followed by *Acacia nilotica* (26.36 cm). Minimum average diameter was recorded in *Terminalia arjuna* (24.30 cm) and in remaining two species viz., *Eucalyptus tereticornis* and *Dalbergia sissoo*, dbh was 25.60 cm and 25.24 cm respectively. Diameter at breast height is an important parameter for estimating the basal area of tree as it directly correlated with volume, biomass production of tree.

Table 4.2 Average diameter at breast height of different multipurpose tree species

Treatments (Tree species)	Average diameter at breast height (cm)
<i>Acacia nilotica</i> (T <sub>1</sub> )	26.36
<i>Albizia lebbek</i> (T <sub>2</sub> )	28.70
<i>Dalbergia sissoo</i> (T <sub>3</sub> )	25.24
<i>Eucalyptus tereticornis</i> (T <sub>4</sub> )	25.60
<i>Terminalia arjuna</i> (T <sub>5</sub> )	24.30

F Test = S

SED (±) = 0.4908

CD (5%) = 1.0160

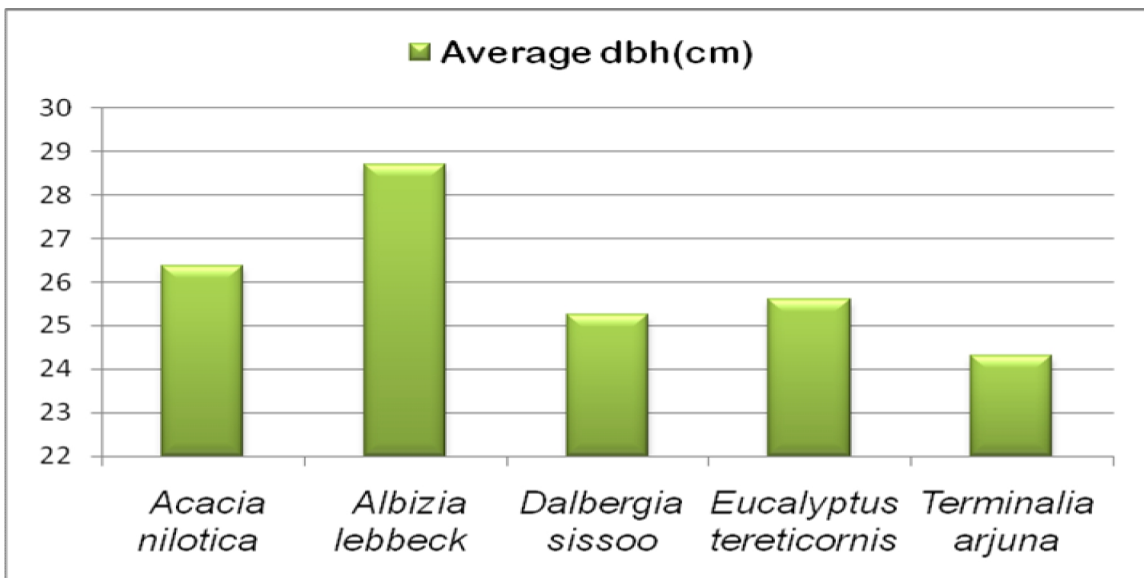


Fig.4.2. Average diameter at breast height of different multipurpose tree species

### 4.3 Basal Area (m<sup>2</sup>)

It was observed that the basal area varies significantly with different multipurpose tree species. From table 4.3 and figure 4.3 it was observed that the maximum basal area was in *Albizia lebbeck* (0.065m<sup>2</sup>) followed by *Acacia nilotica* (0.055m<sup>2</sup>). Minimum basal area was recorded in *Terminalia arjuna* (0.046 m<sup>2</sup>). In remaining two species viz., *Dalbergia sissoo* and *Eucalyptus tereticornis*, basal area was 0.050 m<sup>2</sup> and 0.051 m<sup>2</sup> respectively. Basal area is an important parameter for estimating the volume of tree as it is directly correlated with biomass production of tree.

Table 4.3 Average basal area of different multipurpose tree species

Treatments (Tree species)	Average Basal Area (m <sup>2</sup> )
<i>Acacia nilotica</i> (T <sub>1</sub> )	0.055
<i>Albizia lebbeck</i> (T <sub>2</sub> )	0.065
<i>Dalbergia sissoo</i> (T <sub>3</sub> )	0.050
<i>Eucalyptus tereticornis</i> (T <sub>4</sub> )	0.051
<i>Terminalia arjuna</i> (T <sub>5</sub> )	0.046

F Test = S

SED (±) = 0.0020

CD (5%) = 0.0042

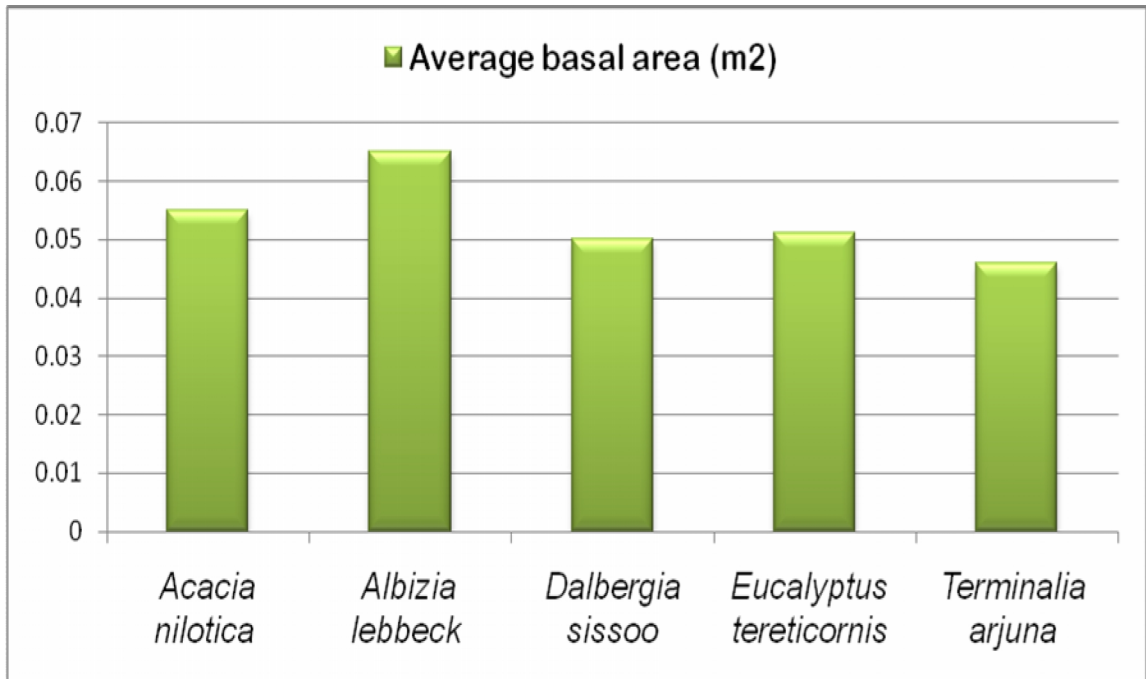


Fig.4.3. Average basal area of different multipurpose tree species

#### 4.4 Volume (m<sup>3</sup> / tree)

It was observed that the volume varies significantly with different multipurpose tree species. It is evident from table 4.4 and figure 4.4 that the trees with maximum height and basal area have maximum volume. The maximum volume was found in *Albizia lebbeck* (1.22 m<sup>3</sup>) followed by *Eucalyptus tereticornis* (1.16 m<sup>3</sup>) while minimum was found in *Dalbergia sissoo* (0.69 m<sup>3</sup>) and in remaining two specie viz *Acacia nilotica* and *Terminalia arjuna*, the volume was 0.83 m<sup>3</sup> and 0.73 m<sup>3</sup> / tree respectively.

Table 4.4 Average volume of different multipurpose tree species

Treatments (Tree species)	Average Volume (m <sup>3</sup> / tree)
<i>Acacia nilotica</i> (T <sub>1</sub> )	0.83
<i>Albizia lebeck</i> (T <sub>2</sub> )	1.22
<i>Dalbergia sissoo</i> (T <sub>3</sub> )	0.69
<i>Eucalyptus tereticornis</i> (T <sub>4</sub> )	1.16
<i>Terminalia arjuna</i> (T <sub>5</sub> )	0.73

F Test = S

SED (±) = 0.0732

CD (5%) = 0.1516

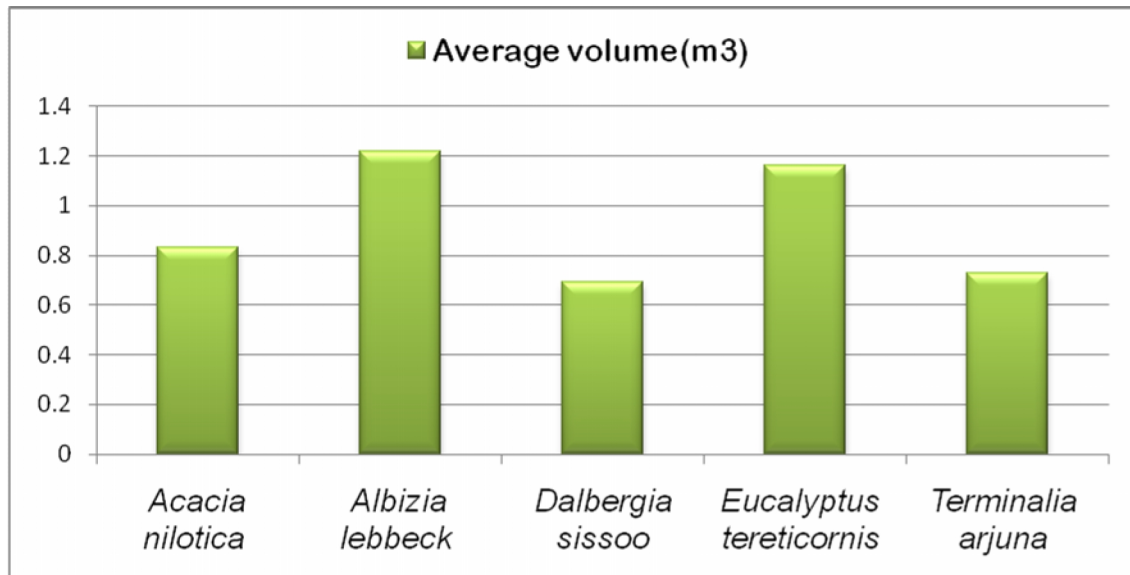


Fig.4.4. Average volume of different multipurpose tree species

#### 4.5 Specific gravity

It was observed that the specific gravity varies significantly with different multipurpose tree species. It is revealed from table 4.5 and figure 4.5 that the highest specific gravity was recorded in *Eucalyptus tereticornis* with 0.716 followed by *Dalbergia sissoo* with 0.686. While minimum was found in *Albizia lebbeck* with 0.582. The specific gravity of remaining two species viz. *Acacia nilotica* and *Terminalia arjuna* recorded was 0.662 and 0.616 respectively.

Table 4.5 Average specific gravity of different multipurpose tree species

<b>Treatments (Tree species)</b>	<b>Specific gravity</b>
<i>Acacia nilotica</i> (T <sub>1</sub> )	0.66
<i>Albizia lebbeck</i> (T <sub>2</sub> )	0.58
<i>Dalbergia sissoo</i> (T <sub>3</sub> )	0.69
<i>Eucalyptus tereticornis</i> (T <sub>4</sub> )	0.72
<i>Terminalia arjuna</i> (T <sub>5</sub> )	0.62

F Test = S

SED ( $\pm$ ) = 0.0047

CD (5%) = 0.0098

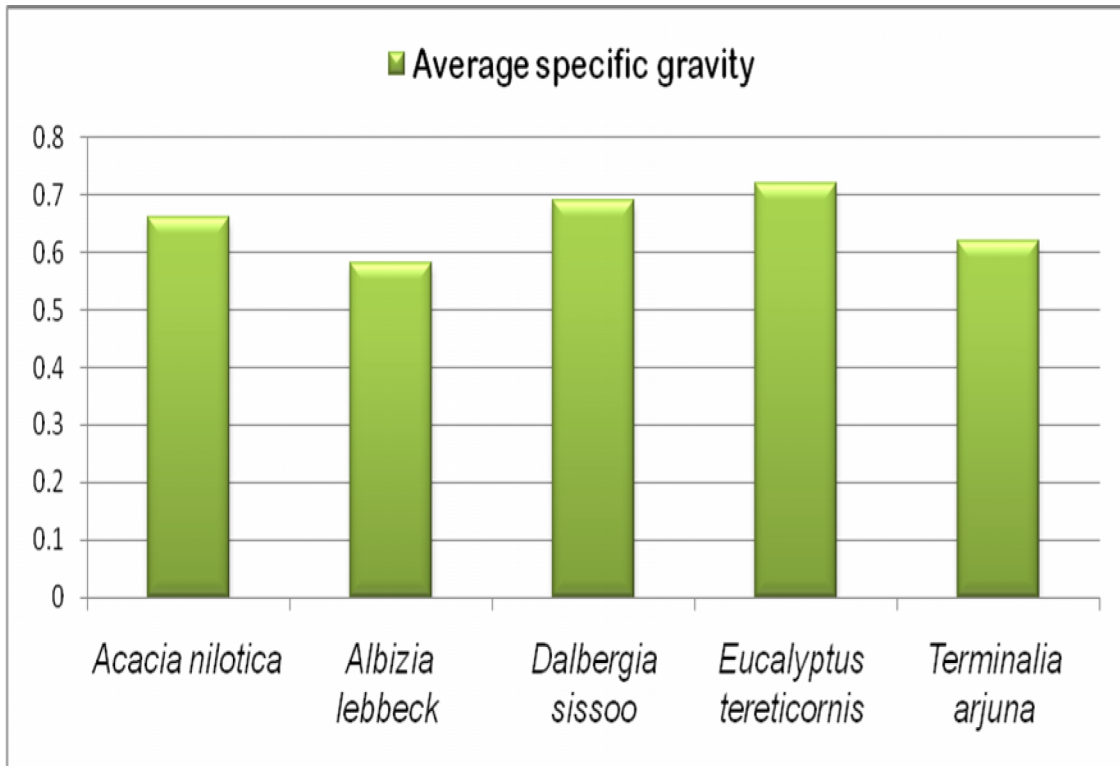


Fig.4.5. Average specific gravity of different multipurpose tree species

#### 4.6 Above ground biomass (kg/tree)

It was observed that the above ground biomass varies significantly with different multipurpose tree species.

Table 4.6 and figure 4.6 revealed that the above ground biomass was highest in *Eucalyptus tereticornis* with 827.12 kg /tree followed by *Albizia lebbeck* with 709.22 kg/tree. The minimum above ground biomass was found in *Terminalia arjuna* with 450.80 kg/tree. The above ground biomass of remaining two species viz. *Acacia nilotica* and *Dalbergia sissoo* was 550.58 and 472.14 kg/tree respectively.

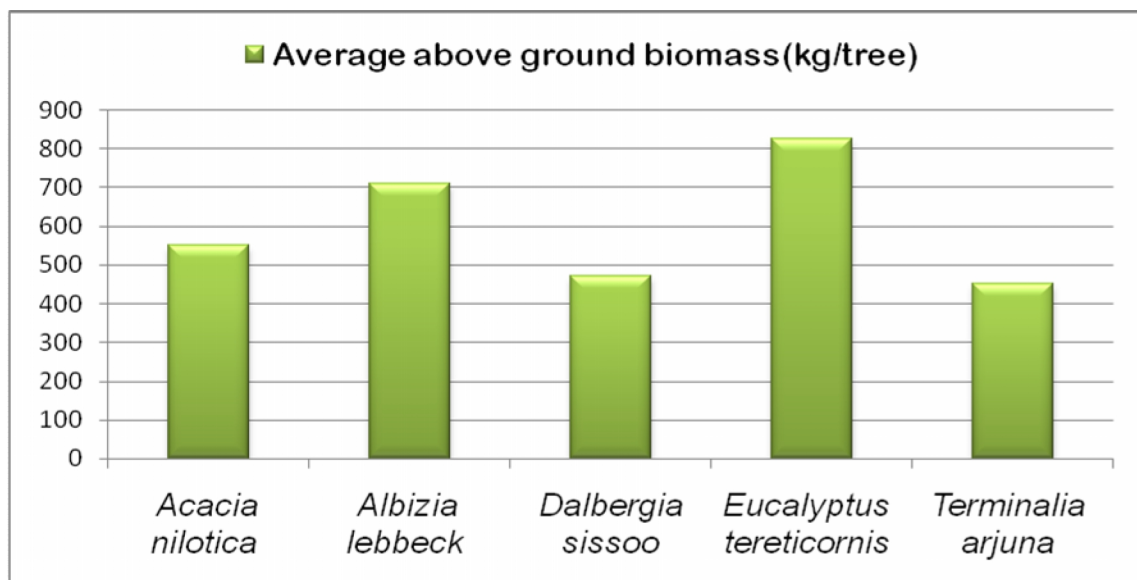
**Table 4.6 Average above ground biomass of different multipurpose tree species**

<b>Treatments (Tree species)</b>	<b>Average Biomass (kg/tree)</b>
<i>Acacia nilotica</i> (T <sub>1</sub> )	550.58
<i>Albizia lebbek</i> (T <sub>2</sub> )	709.22
<i>Dalbergia sissoo</i> (T <sub>3</sub> )	472.14
<i>Eucalyptus tereticornis</i> (T <sub>4</sub> )	827.12
<i>Terminalia arjuna</i> (T <sub>5</sub> )	450.80

F Test = S

SED (±) = 47.9338

CD (5%) = 99.2230



**Fig.4.6. Average above ground biomass of different multipurpose tree species**

#### 4.7 Moisture content (%)

It was observed that the moisture content percentage varies significantly with different multipurpose tree species. It was observed from the table 4.7 and figure 4.7 that maximum moisture content was found in *Eucalyptus tereticornis* with 48.47 % followed by *Acacia nilotica* with 46.21% and minimum moisture content was found in *Albizia lebbeck* with 42.10%. The moisture content of remaining of two species *Terminalia arjuna* and *Dalbergia sissoo* was 43.16 % and 42.49 % respectively.

**Table 4.7 Average moisture content % of different multipurpose tree**

<b>Treatments (Tree species)</b>	<b>Average Moisture content (%)</b>
<i>Acacia nilotica</i> (T <sub>1</sub> )	46.21
<i>Albizia lebbeck</i> (T <sub>2</sub> )	42.10
<i>Dalbergia sissoo</i> (T <sub>3</sub> )	42.49
<i>Eucalyptus tereticornis</i> (T <sub>4</sub> )	48.47
<i>Terminalia arjuna</i> (T <sub>5</sub> )	43.16

F Test = S

SED ( $\pm$ ) = 0.3281

CD (5%) = 0.6792

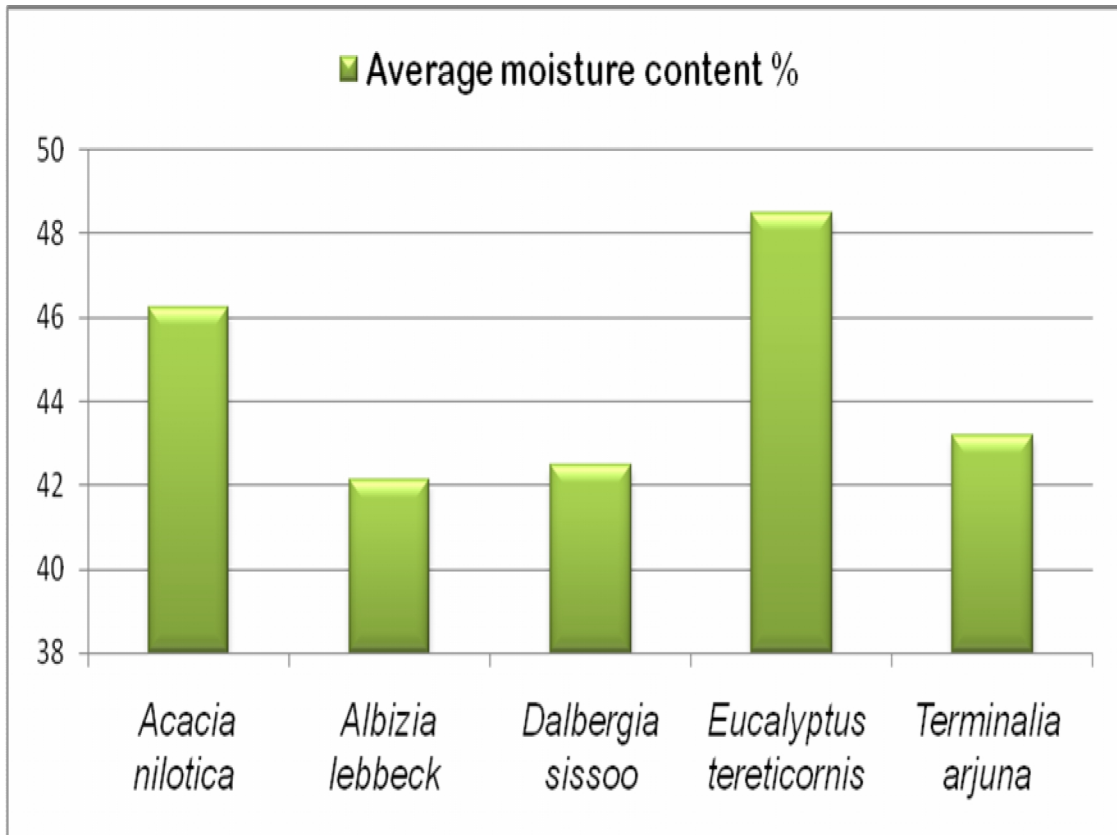


Fig.4.7. Average moisture content % of different multipurpose tree species

#### 4.8 Ash content (%)

It was observed that the ash content percentage varies significantly with different multipurpose tree species. From table 4.8 and figure 4.8 it was observed that ash content was highest in *Eucalyptus tereticornis* with 2.78% followed by *Acacia nilotica* with 2.38% and minimum was found in *Albizia lebbeck* with 1.22%. The ash content of remaining two species viz., *Terminalia arjuna* and *Dalbergia sissoo* was 1.78% and 1.58 % respectively.

Table 4.8 Average ash content % of different multipurpose tree

Treatments (Tree species)	Average ash content %
<i>Acacia nilotica</i> (T <sub>1</sub> )	2.38
<i>Albizia lebbek</i> (T <sub>2</sub> )	1.22
<i>Dalbergia sissoo</i> (T <sub>3</sub> )	1.58
<i>Eucalyptus tereticornis</i> (T <sub>4</sub> )	2.78
<i>Terminalia arjuna</i> (T <sub>5</sub> )	1.78

F Test = S  
 SED (±) = 0.0523  
 CD (5%) = 0.1083

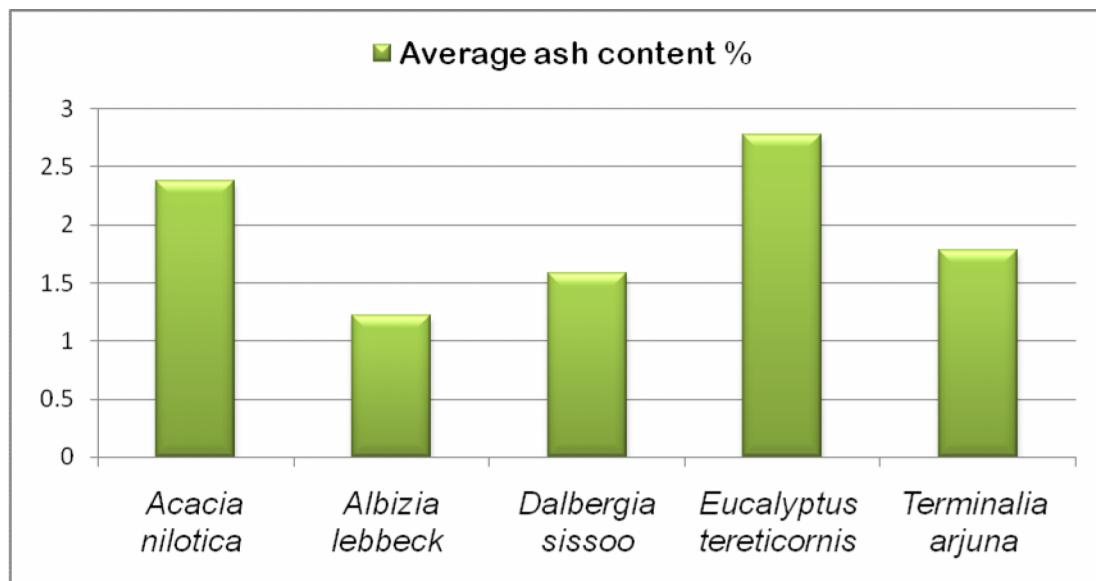


Fig.4.8. Average ash content % of different multipurpose tree species

#### 4.9 Fixed carbon percentage

It was observed that the fixed carbon percentage varies significantly with different multipurpose tree species.

Table 4.9 and figure 4.9 revealed that the fixed carbon % was highest in *Albizia lebbeck* with 56.68 % followed by *Dalbergia sissoo* with 55.93% and minimum fixed carbon% was found in *Eucalyptus tereticornis* with 48.75%. The fixed carbon % of remaining two species viz. *Terminalia arjuna* and *Acacia nilotica* was 55.06% and 51.41% respectively.

Table 4.9 Average fixed carbon % of different multipurpose tree

Treatments (Tree species)	Average fixed carbon %
<i>Acacia nilotica</i> (T <sub>1</sub> )	51.41
<i>Albizia lebbeck</i> (T <sub>2</sub> )	56.68
<i>Dalbergia sissoo</i> (T <sub>3</sub> )	55.93
<i>Eucalyptus tereticornis</i> (T <sub>4</sub> )	48.75
<i>Terminalia arjuna</i> (T <sub>5</sub> )	55.06

F Test = S

SED (±) = 0.3334

CD (5%) = 0.6902

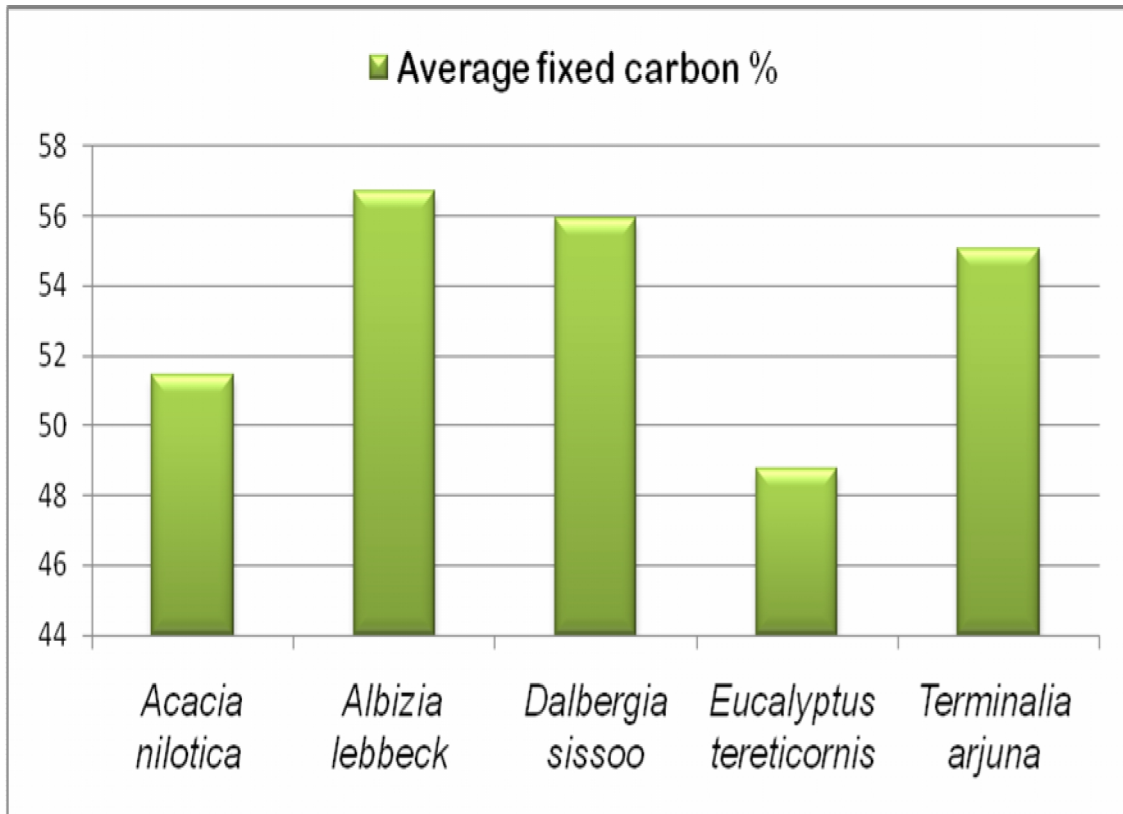


Fig.4.9. Average fixed carbon % of different multipurpose tree species

#### 4.10 Carbon sequestration potential (kg/tree)

It was observed that the carbon sequestration varies significantly with different multipurpose tree species. From table 4.10 and figure 4.10 it was confirmed that the amount of carbon sequestered was highest in *Eucalyptus tereticornis* with 403.40 kg/tree followed by *Albizia lebbeck* with 401.91 kg/tree. The lowest amount of carbon sequestration was observed in *Terminalia arjuna* with 248.45 kg/tree. The amount of carbon sequestered in remaining two species viz., *Acacia nilotica* and *Dalbergia sissoo* was 283.06 kg/tree and 264.09 kg/tree respectively.

Table 4.10 Average carbon sequestration potential of different multipurpose tree

Treatments (Tree species)	Average Carbon sequestration potential (kg/tree)
<i>Acacia nilotica</i> (T <sub>1</sub> )	283.06
<i>Albizia lebbeck</i> (T <sub>2</sub> )	401.91
<i>Dalbergia sissoo</i> (T <sub>3</sub> )	264.09
<i>Eucalyptus tereticornis</i> (T <sub>4</sub> )	403.40
<i>Terminalia arjuna</i> (T <sub>5</sub> )	248.45

F-test=S  
 SED (±) = 25.8700  
 CD (5%) = 53.5509

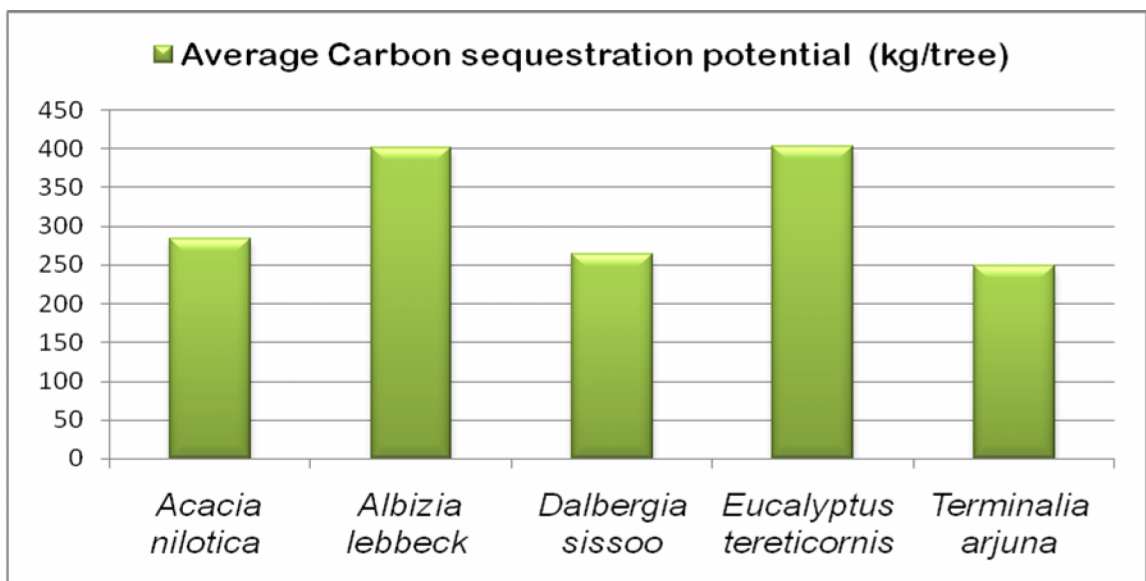


Fig.4.10. Average carbon sequestration of different multipurpose tree species

#### 4.11 Weight of CO<sub>2</sub> sequestered (kg) by tree species

It was observed that the total weight of carbon dioxide that was sequestering by tree species varies significantly with different multipurpose tree species.

From table 4.11 and figure 4.11 it was observed that the amount of carbon dioxide sequestered was highest in *Eucalyptus tereticornis* with 1478.85 kg/tree followed by *Albizia lebbeck* with 1473.37 kg/tree. The lowest amount of carbon dioxide sequestration was observed in *Terminalia arjuna* with 910.83 kg/tree. The amount of carbon dioxide sequestered in remaining two species viz., *Acacia nilotica* and *Dalbergia sissoo* was 1037.68 kg/tree and 968.17 kg/tree respectively.

Table 4.11 average weight of carbon dioxide sequestered (kg) by different multipurpose trees

Treatments (Tree species)	Average weight of CO <sub>2</sub> sequestered (kg/tree)
<i>Acacia nilotica</i> (T <sub>1</sub> )	1037.68
<i>Albizia lebbeck</i> (T <sub>2</sub> )	1473.37
<i>Dalbergia sissoo</i> (T <sub>3</sub> )	968.17
<i>Eucalyptus tereticornis</i> (T <sub>4</sub> )	1478.85
<i>Terminalia arjuna</i> (T <sub>5</sub> )	910.83

F Test = S

SED (±) = 94.8418

CD (5%) = 196.3227

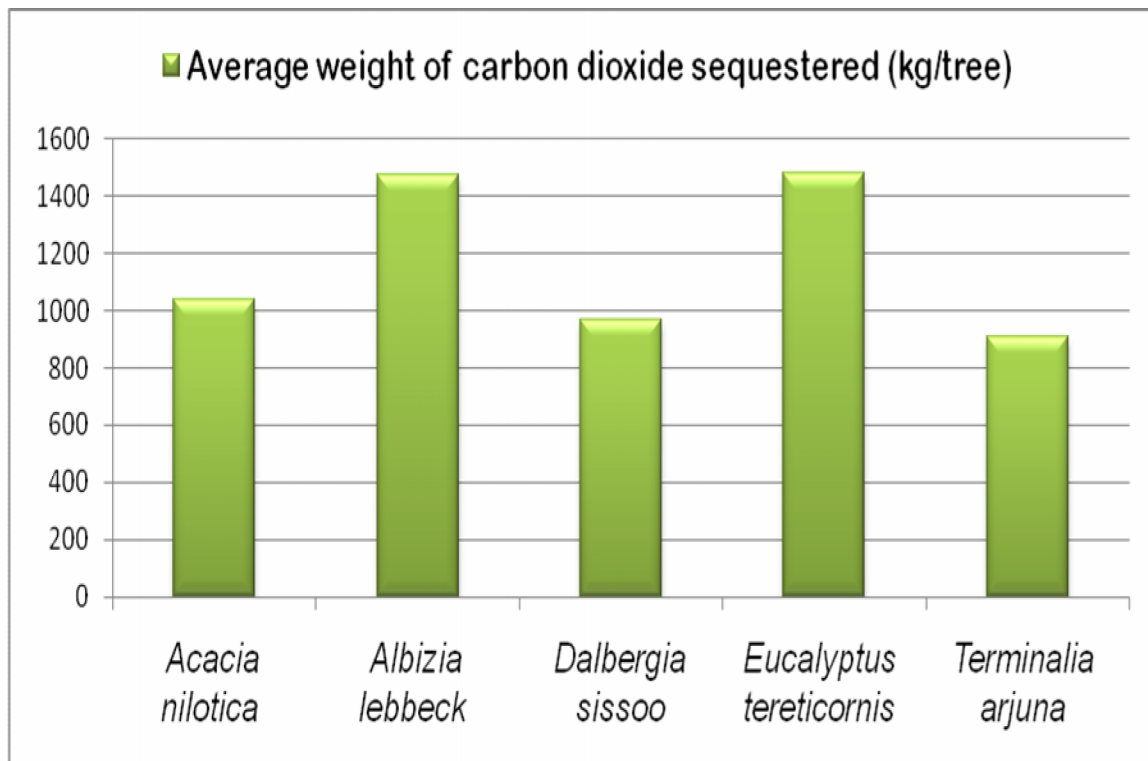


Fig.4.11. Average weight of carbon dioxide sequestered by different multipurpose trees

#### 4.12 Weight of CO<sub>2</sub> sequestered (kg) per year by tree species

It was observed that the weight of CO<sub>2</sub> sequestered per year per tree varies significantly with different multipurpose tree species.

From table 4.12 and figure 4.12 it was observed that the average weight of carbon dioxide sequestered per year was highest in *Eucalyptus tereticornis* with 61.61 kg/tree followed by *Albizia lebbeck* with 61.39 kg/tree. The lowest amount of carbon dioxide sequestration per year was observed in *Terminalia arjuna* with 37.95 kg/tree. The amount of carbon dioxide sequestered per year in remaining two species viz., *Acacia nilotica* and *Dalbergia sissoo* was 43.23 kg/tree and 40.34 kg/tree respectively.

Table 4.12 Average weight of carbon dioxide sequestered (kg) per year by different multipurpose trees

Treatments (Tree species)	Average weight of CO <sub>2</sub> sequestered per year (kg/tree)
<i>Acacia nilotica</i> (T <sub>1</sub> )	43.23
<i>Albizia lebbeck</i> (T <sub>2</sub> )	61.39
<i>Dalbergia sissoo</i> (T <sub>3</sub> )	40.34
<i>Eucalyptus tereticornis</i> (T <sub>4</sub> )	61.61
<i>Terminalia arjuna</i> (T <sub>5</sub> )	37.95

F Test = S  
 SED (±) = 3.9522  
 CD (5%) = 8.1812

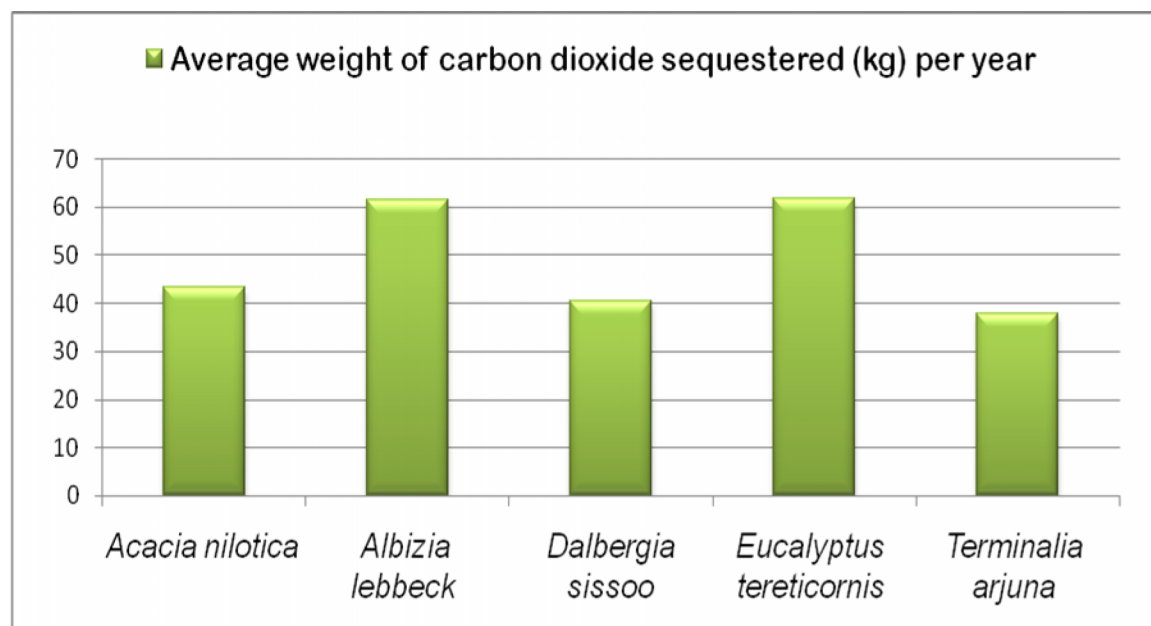


Fig.4.12. Average weight of carbon dioxide sequestered (kg) per year by different multipurpose trees

## DISCUSSION

An investigation on “Estimation of Standing State Biomass and Carbon Sequestration Potential of Multipurpose Tree Species” was taken up to estimate the aboveground biomass and carbon sequestration potential of different MPTs. Planting trees, especially fast-growing multipurpose trees help to remove carbon significantly from the cycle and sequester within the wood (biomass) itself. Multipurpose tree can also reduce the pressure on natural forests by providing the much needed fuel and fodder requirements of the peoples and can reduce a significant amount of atmospheric carbon through carbon sequestration in the standing biomass. The information gathered from present study will help us to assess the contribution of different multipurpose trees to the increasingly important ecosystem service of carbon fixation and storage. In the present scenario of global warming and associated climate change, this study assumes more relevance as trees are important sinks for atmospheric carbon i.e. carbon dioxide, since roughly 50% of their standing biomass is carbon itself (Ravindranath et al., 1997). The findings of present investigation have focused on some interesting facts, which are critically discussed here in this chapter with the support of data and established scientific facts, reported by other research workers. Hence, these are also briefly discussed here.

Tall trees have high woody biomass, support many leaves and increase carbon fixation which can ultimately sequester more of carbon and act as the sink of carbon for long time. Therefore, helps in mitigating green house effect and climate change. In the present study the maximum height was observed for *Eucalyptus tereticornis* (22.52 m) that sequester more carbon than other tree species. These results are in conformity with that of Kraenzel *et al* (2003) who have also proved that tall trees have capability of increasing more carbon fixation which directly sequester more carbon.

Diameter at breast height is an important parameter for estimating the basal area of tree as it directly correlated with volume, biomass production of tree. In the present investigation the maximum dbh was recorded in *Albizia*

*lebbeck* (28.70 cm) that has maximum average basal area and volume with a value of 0.065 m<sup>2</sup> and 1.22 m<sup>3</sup> per tree. Availability of volume per unit area is an important information needed to evaluate, monitor and harvest the available natural resources efficiency and for judicious management for future planning. Volume is important for assessment of standing biomass to estimate the degree of carbon sequestration by the trees. Volume to biomass method is considered as the better estimation method of forest tree biomass. (Brown *et al.*, 1997)

The specific gravity was calculated as the oven dry weight of the wood sample (80 °C, for a period up to a constant weight achieved) to green volume of that sample. In the present investigation the maximum specific gravity was observed for *Eucalyptus tereticornis* with a value of 0.716. The same method was adopted by Jana *et al.*, (2007) for estimation of specific gravity of Teak and Sal trees. Wood specific gravity is an important factor in converting tree volume to standing above ground biomass and strongly depends on location, climate and possibly management of stands. The specific gravity of the tree indicates the preparation of the carbon stored in a particular tree species and also highlights the dry biomass/cellulose preparation on fresh weight basis. The specific gravity variability, however, is under genetic control and varies from species to species. (Zobel and Talbert, 1984)

Estimation of above ground biomass is an important aspect of studies on carbon stock and effect of deforestation and sequestration on the global carbon balance. In the present investigation maximum average above ground biomass was observed in *Eucalyptus tereticornis* with a value of 827.12 kg/tree.

Moisture content of wood is defined as the percentage of water in a wood. The moisture content in the given tree species varied significantly and it may be due to difference in density of wood. As the ash content and moisture content percentage have impact on fixation of carbon percentage in the wood. (Ganeshiah *et al.*, 2003). In the present study *Eucalyptus tereticornis* have the maximum moisture content% with a value of 48.47% and maximum ash content % with a value of 2.78% whereas *Albizia lebbeck* has the minimum

moisture content% with a value of 42.10% and minimum ash content % with a value of 1.22%.

Average stem biomass increments were converted to total carbon content by assuming that biomass is approximately 50% carbon (Brown *et al.*, 1986). Most researchers estimated carbon by assuming the carbon content of dry biomass to be the constant 50% by weight. (Brown, 1997, Montagini and porras, 1998). In the present investigation maximum fixed carbon percentage was found in *Albizia lebbeck* with a value of 56.68% whereas minimum fixed carbon percentage was found in *Eucalyptus tereticornis* with a value of 48.75%. Fixed carbon % in the remaining three species viz. *Dalbergia sissoo*, *Terminalia arjuna* and *Acacia nilotica* were 55.93%, 55.06% and 51.40% respectively.

The same finding were also reported by Dhruv *et al.*, (2009) in the *Dalbergia sissoo* with a value of fixed carbon percentage of 53.34% Chauhan *et al.*,(2009) reported fixed carbon percentage in *Acacia nilotica* with a value of 52.36%.

Carbon sequestration can be defined as the removal of CO<sub>2</sub> from atmosphere (source) in to green plants (sink) where it can be stored indefinitely. The maximum amount of Carbon storage in the present investigation was found in the *Eucalyptus tereticornis* with a value of 403.39 kg/tree whereas minimum carbon storage was found *Terminalia arjuna* with a value of 248.45 kg/tree.

## SUMMARY, CONCLUSION AND SUGGESTION FOR FURTHER WORK

### 5.1. SUMMARY

The present investigation entitled “Estimation of Standing State Biomass and Carbon Sequestration Potential of Multipurpose Tree Species” was conducted at dusty acre farm, on 24 years old stand age of multipurpose tree species, under AICRP on Agroforestry, Department of forestry, JNKVV, Jabalpur during 2011-12. The study was carried out to estimate above ground biomass and carbon sequestration in *Acacia nilotica*, *Albizia lebbeck*, *Dalbergia sissoo*, *Eucalyptus tereticornis*, and *Terminalia arjuna*. For statistical analysis Randomized Block Design was used.

From the present investigation it was observed that maximum average tree height was recorded in *Eucalyptus tereticornis* (22.52 m) followed by *Albizia lebbeck* (18.76m). Whereas the minimum average height was observed in *Dalbergia sissoo* with a value of 13.78m.

It was observed that the maximum average diameter at breast height and basal area was recorded in *Albizia lebbeck* with a value of 28.70cm and 0.065m<sup>2</sup> followed by *Acacia nilotica* with a value of 26.36cm and 0.055m<sup>2</sup>. Whereas Minimum average diameter at breast height and basal area was recorded in *Terminalia arjuna* 24.30cm and 0.046 m<sup>2</sup> respectively.

The maximum average volume was recorded in *Albizia lebbeck* with a value of 1.22 m<sup>3</sup> followed by *Eucalyptus tereticornis* with a value of 1.16 m<sup>3</sup>. While minimum average volume was found in *Dalbergia sissoo* with a value of 0.69m<sup>3</sup> per tree.

The highest specific gravity was recorded in *Eucalyptus tereticornis* with a value of 0.716 followed by *Dalbergia sissoo* with a value of 0.686. While minimum was found in *Albizia lebbeck* with 0.582.

The highest average above ground biomass was recorded in *Eucalyptus tereticornis* with 827.12 kg /tree followed by *Albizia lebbeck* with 709.22 kg/tree. While the lowest average above ground biomass was recorded in *Terminalia arjuna* with 450.80 kg/tree.

The maximum moisture content was recorded in *Eucalyptus tereticornis* with a value of 48.47 % followed by *Acacia nilotica* with a value of 46.21% and minimum moisture content was recorded in *Albizia lebbeck* with a value of 42.10%.

It was recorded that ash content was highest in *Eucalyptus tereticornis* with a value of 2.78% followed by *Acacia nilotica* with a value of 2.38% while minimum ash content was recorded in *Albizia lebbeck* with a value of 1.22%.

The maximum fixed carbon content or carbon storage % was recorded in *Albizia lebbeck* with a value of 56.68 % followed by *Dalbergia sissoo* with a value of 55.93% while minimum fixed carbon content was recorded in *Eucalyptus tereticornis* with 48.75%. Whereas maximum amount of carbon sequestered or carbon sequestration rate was recorded in *Eucalyptus tereticornis* with a value of 403.40 kg/tree followed by *Albizia lebbeck* with a value of 401.91 kg/tree up to 24 years. While the lowest amount of carbon sequestration was recorded in *Terminalia arjuna* with 248.45 kg/tree.

It was recorded that the amount of carbon dioxide sequestered was highest in *Eucalyptus tereticornis* with a value of 1478.85 kg/tree followed by *Albizia lebbeck* with a value of 1473.37 kg/tree while the lowest amount of carbon dioxide sequestration was observed in *Terminalia arjuna* with 910.83 kg/tree.

It was recorded that the average weight of carbon dioxide sequestered per year was highest in *Eucalyptus tereticornis* with a value of 61.61 kg/tree followed by *Albizia lebbeck* with a value of 61.39 kg/tree. While the lowest amount of carbon dioxide sequestration per year was recorded in *Terminalia arjuna* with 37.95 kg/tree.

## 5.2 CONCLUSION

From the above results it can be concluded that out of five multipurpose tree species viz. *Acacia nilotica*, *Albizia lebbbeck*, *Dalbergia sissoo*, *Eucalyptus tereticornis*, and *Terminalia arjuna*, the maximum average tree height was recorded in *Eucalyptus tereticornis* with a value of 22.52 m while the maximum average diameter at breast height and basal area was recorded in *Albizia lebbbeck* with a value of 28.70cm and 0.065m<sup>2</sup>. The minimum tree height was recorded *Dalbergia sissoo* with a value of 13.78m and Minimum average diameter at breast height and basal area was recorded in *Terminalia arjuna* with a value of 24.30cm and 0.046 m<sup>2</sup> respectively. Carbon is sequestered in the trees by the photosynthesis and stored as biomass in different parts of the trees. From the above result it can be concluded that the highest average above ground biomass was recorded in *Eucalyptus tereticornis* followed by *Albizia lebbbeck*, *Acacia nilotica*, *Dalbergia sissoo* and *Terminalia arjuna* with a value of 827.12, 709.22, 550.58, 472.14 and 450.80 kg/tree respectively.

The percentage carbon content in above ground biomass of *Albizia lebbbeck*, *Dalbergia sissoo*, *Terminalia arjuna*, *Acacia nilotica*, and *Eucalyptus tereticornis* recorded were 56.68%, 55.93%, 55.06%, 51.41%, and 48.75% respectively. The total carbon sequestration rate obtained from above ground biomass of *Eucalyptus tereticornis*, *Albizia lebbbeck*, *Acacia nilotica*, *Dalbergia sissoo* and *Terminalia arjuna* were 403.40, 401.91, 283.06, 264.09 and 248.45 kg/tree respectively.

It can be concluded that carbon sequestration through above mentioned tree species have potential to play important role in ameliorating global environment problems such as atmospheric accumulation of green house gases and climate change. Therefore plantation of MPTs should be implemented and measures should be taken to protected the sink of carbon and mitigate the green house effect through carbon storage

## **SUGGESTIONS FOR FURTHER WORK**

- An investigation should be conducted on site management practices that enhanced the biomass production and carbon sequestration potential of multipurpose tree species.
- Study should be carried out on importance of multipurpose tree species to improve soil carbon storage and nutrient accumulation beneath multipurpose trees.
- Study should be carried out on Carbon sequestration potential and biomass production of multipurpose tree species under different agroforestry systems.

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## APPENDIX

**ANOVA for Height (m) *Acacia nilotica*, *Albizia lebbbeck*, *Dalbergia sissoo*, *Eucalyptus tereticornis*, *Terminalia arjuna*.**

Source	DF	SS	MSS	F cal	F Tab	Result
Rep	4	6.2584	1.5646	0.8723	3.01	NS
Treatment	4	243.8104	60.9526	33.9833**	3.01	S
Error	16	28.6976	1.7936			
Total	24	278.7664				

**ANOVA for Diameter at breast height (cm) *Acacia nilotica*, *Albizia lebbbeck*, *Dalbergia sissoo*, *Eucalyptus tereticornis*, *Terminalia arjuna*.**

Source	DF	SS	MSS	F cal	F Tab	Result
Rep	4	6.859024	1.71475	2.8469	3.01	NS
Treatment	4	55.2713	13.8178	22.9414**	3.01	S
Error	16	9.6369	0.6023			
Total	24	71.7672				

**ANOVA for Basal Area (m<sup>2</sup>) *Acacia nilotica*, *Albizia lebbbeck*, *Dalbergia sissoo*, *Eucalyptus tereticornis*, *Terminalia arjuna*.**

Source	DF	SS	MSS	F cal	F Tab	Result
Rep	4	0.0001	0.00002	2.5402	3.01	NS
Treatment	4	0.0009	0.0002	23.3175**	3.01	S
Error	16	0.0001	0.00001			
Total	24	0.0012				

**ANOVA for Volume (m<sup>3</sup>) *Acacia nilotica*, *Albizia lebbeck*, *Dalbergia sissoo*, *Eucalyptus tereticornis*, *Terminalia arjuna*.**

Source	DF	SS	MSS	F cal	F Tab	Result
Rep	4	0.0909	0.0227	1.6946	3.01	NS
Treatment	4	1.2089	0.3022	22.5319**	3.01	S
Error	16	0.2146	0.0134			
Total	24	1.5145				

**ANOVA for specific gravity *Acacia nilotica*, *Albizia lebbeck*, *Dalbergia sissoo*, *Eucalyptus tereticornis*, *Terminalia arjuna*.**

Source	DF	SS	MSS	F cal	F Tab	Result
Rep	4	0.00001	3.99	0.0707	3.01	NS
Treatment	4	0.0577	0.01443	255.469**	3.01	S
Error	16	0.0009	0.00005			
Total	24	0.0586				

**ANOVA for biomass (kg/tree) *Acacia nilotica*, *Albizia lebbeck*, *Dalbergia sissoo*, *Eucalyptus tereticornis*, *Terminalia arjuna*.**

Source	DF	SS	MSS	F cal	F Tab	Result
Rep	4	38394.84	9598.7094	1.6710	3.01	NS
Treatment	4	522725.6	130681.394	22.7504**	3.01	S
Error	16	91906.12	5744.1322			
Total	24	653026.5				

**ANOVA for moisture content % *Acacia nilotica*, *Albizia lebbeck*, *Dalbergia sissoo*, *Eucalyptus tereticornis*, *Terminalia arjuna*.**

Source	DF	SS	MSS	F cal	F Tab	Result
Rep	4	0.7222	0.1805	0.6707	3.01	NS
Treatment	4	151.5927	37.8981	140.7742**	3.01	S
Error	16	4.3074	0.2692			
Total	24	156.6224				

**ANOVA for ash content % *Acacia nilotica*, *Albizia lebbeck*, *Dalbergia sissoo*, *Eucalyptus tereticornis*, *Terminalia arjuna*.**

Source	DF	SS	MSS	F cal	F Tab	Result
Rep	4	0.0304	0.0076	1.1094	3.01	NS
Treatment	4	7.8624	1.9656	286.9489**	3.01	S
Error	16	0.1096	0.0068			
Total	24	8.0024				

**ANOVA for fixed carbon % *Acacia nilotica*, *Albizia lebbeck*, *Dalbergia sissoo*, *Eucalyptus tereticornis*, *Terminalia arjuna*.**

Source	DF	SS	MSS	F cal	F Tab	Result
Rep	4	0.62148	0.1553	0.5588	3.01	NS
Treatment	4	227.0327	56.7581	204.1569**	3.01	S
Error	16	4.4482	0.2780			
Total	24	232.1024				

**ANOVA for carbon sequestration *Acacia nilotica*, *Albizia lebbeck*, *Dalbergia sissoo*, *Eucalyptus tereticornis*, *Terminalia arjuna*.**

Source	DF	SS	MSS	F cal	F Tab	Result
Rep	4	10277.78	2569.4445	1.5356	3.01	NS
Treatment	4	116369	29092.249	17.3877**	3.01	S
Error	16	26770.34	1673.1463			
Total	24	153417.1				

**ANOVA for total weight of carbon dioxide sequestration by *Acacia nilotica*, *Albizia lebbeck*, *Dalbergia sissoo*, *Eucalyptus tereticornis*, *Terminalia arjuna* tree species**

Source	DF	SS	MSS	F cal	F Tab	Result
Rep	4	138061.6	34515.3954	1.5348	3.01	NS
Treatment	4	1563806	390951.396	17.3853**	3.01	S
Error	16	359799.3	22487.4593			
Total	24	2061667				

**ANOVA for average weight of carbon dioxide sequestration per year by *Acacia nilotica*, *Albizia lebbeck*, *Dalbergia sissoo*, *Eucalyptus tereticornis*, *Terminalia arjuna* tree species**

Source	DF	SS	MSS	F cal	F Tab	Result
Rep	4	239.6689	59.9172	1.5343	3.01	NS
Treatment	4	2714.158	678.5395	17.3755**	3.01	S
Error	16	624.8241	39.0515			
Total	24	3578.651				

## ABSTRACT

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## ABSTRACT

The present investigation was carried out on five multipurpose tree species with an objective to estimate above ground biomass and carbon sequestration potential in the above ground biomass of selected multipurpose tree species was conducted, at dusty acre farm, under AICRP on Agroforestry, Department of Forestry, College of agriculture, JNKVV, Jabalpur, during 2011-2012. To estimate carbon sequestration potential in five multipurpose tree species viz, *Acacia nilotica*, *Albizia leebek*, *Dalbergia sissoo*, *Eucalyptus tereticornis* and *Terminalia arjuna* at 24-years-stand age, ash content method was used. Aboveground biomass production was observed to be maximum in *Eucalyptus tereticornis* (827.12 kg /tree) which was at par with *Albizia leebek* (709.22 kg/tree). While the minimum above ground biomass was recorded in *Terminalia arjuna* (450.80 kg/tree).

Results of fixed carbon percentage showed *Albizia leebek* and *Dalbergia sissoo* as most suitable multipurpose tree species. The maximum fixed carbon content or carbon storage % was observed in *Albizia leebek* with a value of 56.68 % followed by *Dalbergia sissoo* with a value of 55.93% while minimum fixed carbon content was recorded in *Eucalyptus tereticornis* with 48.75%.

The maximum amount of carbon sequestered or carbon sequestration rate was recorded in *Eucalyptus tereticornis* with a value of 403.40 kg/tree followed by *Albizia leebek* with a value of 401.91 kg/tree up to 24 years. While the lowest amount of carbon sequestration was recorded in *Terminalia arjuna* with 248.45 kg/tree. It was recorded that the amount of carbon dioxide sequestered was highest in *Eucalyptus tereticornis* with a value of 1478.85 kg/tree followed by *Albizia leebek* with a value of 1473.37 kg/tree while the lowest amount of carbon dioxide sequestration was observed in *Terminalia arjuna* with 910.83 kg/tree.

## VITA

The author of this thesis, Jagdish meena was born on 3<sup>rd</sup> August 1987 in village Shekhpura, Distt. Karauli (Rajasthan). After Higher Secondary School Examination he joined in School of Forestry & Environment, SHIATS, Allahabad, U.P. in the year 2006 for his B.Sc. (Forestry) programme and completed the degree during the year 2010 with a CGPA 9.79 out of 10.00 point scale and positioned 3<sup>rd</sup> rank in the batch 2006.

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