CARBON SEQUESTRATION POTENTIAL OF SOME IMPORTANT TREES IN SOUTH GUJARAT

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Carbon sequestration potential of some important trees in South Gujarat

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ABSTRACT

The present investigation entitled "Carbon sequestration potential of some important trees in South Gujarat" was conducted at the Instructional Farm, ASPEE College of Horticulture and Forestry, Navsari Agricultural University, Navsari to evaluate Biomass and carbon sequestration potential of some important trees of South Gujarat. The study involved assessment of morphology, carbon sequestration potential and soil carbon sequestration in the aboveground components of seven important tree species. They were 23 years old. The *Mytragyna parvifolia* and *Terminalia arjuna* were planted at 10.0 x 2.5 m spacing while other tree species were planted at 5.0 m x 5.0 m spacing.

During the course of investigation, various morphological parameters (tree height, clear bole height, diameter at breast height, girth at breast height and volume) above ground carbon sequestration and soil carbon sequestration (soil organic carbon) were studied.

It was noticed that maximum tree height (18.32 m), clear bole height (9.68 m), volume (8.85 m^3/tree) and above ground carbon sequestration (904.83 kg/tree) were attained by T_3: *Terminalia arjuna*. However, maximum diameter at breast height (90.67 cm) and girth at breast height (284.69 cm) were recorded in T_6: *Mangifera indica*.

The maximum above ground carbon content in bark, twig, leaf and stem (58.19 %, 65.40 %, 66.70 % and 68.06 %, respectively) were recorded in T_7 : *Manilkara achras*. Soil organic carbon content was reported significantly higher in T_4 : *Albizia procera* (1.80 and 0.95 %, respectively at 0-15 and 15-30 cm depth of soil).

Among the five forestry tree species *Terminalia arjuna* performed best with respect to tree height, clear bole height, volume and above ground carbon sequestration. While, in case of two horticulture tree species *Mangifera indica* recorded significantly highest DBH and GBH whereas carbon content in bark, twig, leaf and stem were recorded higher in *Manilkara achras*. The *Albizia procera* was found to contribute the highest soil organic carbon.

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CERTIFICATE

This is to certify that the thesis entitled **"Carbon sequestration potential of some important trees in South Gujarat"** submitted by **Mr. Navnitkumar Maganlal Patel** in partial fulfilment of the requirements for the award of the degree of **MASTER OF SCIENCE (FORESTRY)** in the subject of **AGROFORESTRY** of Navsari Agricultural University is a record of bona fide research work carried out by him under my guidance and supervision and that the thesis has not been previously formed the basis for the award of any degree, diploma or has been published for other similar title. All the assistance and help received during the course of the investigation have been duly acknowledged by him.

Tandel M.B

Place : Navsari **(M. B. Tandel)**
Date : 31.12.2012 Major Advisor

DECLARATION

This is to declare that the whole of the research work reported herein the thesis for the partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE** in **FORESTRY** by the undersigned is the result of investigation done by me under guidance and supervision of **Dr. M. B. Tandel**, Assistant Professor (Forestry), ASPEE College of Horticulture and Forestry, Navsari Agricultural University, Navsari and no part of the work has been submitted for any other degree so far.

Place : Navsari

Date : 31.12.2012

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I. INTRODUCTION

Climate change is a topic that has been widely discussed and debated over recent decades. Scientists have reached a general agreement that the lower atmosphere and the Earth's surface are definitely getting warmer. The Intergovernmental Panel on Climate Change (IPCC) reported that a gradual but accelerating increase of atmospheric greenhouse gases has occurred since 1750 as result of human activities and among the anthropogenic greenhouse gases, CO_2 is the most prominent.

Developmental activities and increased transportation activities are increasing the concentration of air pollutants as greenhouse gases, especially CO_2. These are leading to increased atmospheric temperature through the trapping of certain wavelengths of heat radiation in the atmosphere. The increasing carbon emission is of major concerns; it has been well addressed in Kyoto protocol (Ravindranath *et al.* 1997). Tree, shrub, soil and sea water play a crucial role in absorbing atmospheric carbon dioxide. The trees act as major CO_2 sink which captures carbon from the atmosphere and acts as sink, stores the same in the form of fixed biomass during the growth process. Therefore growing trees can be a potential contributor in reducing the concentration of CO_2 in atmosphere by its accumulation in the form of biomass in urban areas. As trees grow and their biomass increases, they absorb carbon from the atmosphere.

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_2 is believed to be the most prominent one (Lorenz and Lal, 2010) accounting for 60% of the total greenhouse effect. The mitigation of global warming entails reducing the atmospheric concentrations of GHGs, particularly CO_2. One of the approaches for reducing CO_2 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), an approach that became popular in the context of the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) allows the use of C sequestration through afforestation and reforestation as a form of GHG-offset activities.

Global carbon is held in a variety of different stocks. Natural stocks include oceans, fossil fuel deposits, the terrestrial system and the atmosphere. In the terrestrial system carbon is sequestered in rocks and sediments, in swamps, wetlands and forests, and in the soils of forests, grasslands and agriculture. About two-thirds of the globe's terrestrial carbon, exclusive of that sequestered in rocks and sediments, is sequestered in the standing forests, forest under-story plants, leaf and forest debris, and in forest soils. In addition, there are some non-natural stocks. For example, long-lived wood products and waste dumps constitute a separate human-created carbon stock. Given increased global timber harvests and manufactured wood products over the past several decades, these carbon stocks are likely to increase as the carbon sequestered in long-lived wood products and waste dumps is probably expanding. A stock that is taking-up carbon is called a "sink" and one that is releasing carbon is called a "source." Shifts or flows of carbon over time from one stock to another, for example, from the atmosphere to the forest, are viewed as carbon "fluxes." Over time, carbon may be transferred from one stock to another. Fossil fuel burning, for example, shifts carbon from fossil fuel deposits to the atmospheric stock. Physical processes also gradually convert some atmospheric carbon into the ocean stock. Biological growth involves the shifting of carbon from one stock to another. Plants fix atmospheric carbon in cell tissues as they grow, thereby transforming carbon from the atmosphere to the biotic system. The amount of carbon stored in any stock may be large, even as the changes in that stock, fluxes, are small or zero. An old-growth forest, which is experiencing little net growth, would have this property. Also, the stock may be small while the fluxes may be significant. Young fast-growing forests tend to be of this type. The potential for agricultural crops and grasses to act as a sink and sequester carbon appears to be limited, due to their short life and limited biomass accumulations. Their role for human management of carbon could increase as we learn more about their potential. How forest ecosystems act as carbon sinks? A carbon sink is defined as a process or an activity that removes greenhouse gases from the atmosphere. Carbon sequestration is the extraction of the atmospheric carbon dioxide and its storage in terrestrial ecosystems for a very long period of time - many thousands of years.

Indian forestry is in a phase of dismal scenario due to heavy pressure of burgeoning human population on land, growing demand of timber, fuel wood, fodder, grazing, encroachment, shifting cultivation, urbanization, industrialization and improper land management. Reduction of forest areas has a great impact on the amount of carbon dioxide stored in the atmosphere, because forest is the great and essential source of world producing oxygen and storing carbon dioxide. A tropical forest, where approximately 50% of the world is living is the richest of terrestrial carbon sinks. During last few decades, the rapid land use and land cover change have resulted in large scale carbon degradation in tropical ecosystems. In response to this reality, the need for extending man made forests and agro forests 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. In fact, the amount of C sequestered in the soil is many folds higher than the aboveground biomass.

Forests play a major role as sinks for atmospheric carbon and it is estimated that each individual on earth is responsible for emission of 3 tones carbon per year, to sequester this much of carbon; we must plant and maintain at least 15 trees per year (Singh, 2007). However, economic parameters have to be considered along with other ecological benefits before deciding on which species would be the best for plantations. Here, we have only considered carbon sequestration and if per year carbon sequestered is the criteria, results show that the area where no plantation was taken up could put on more biomass per year or rather could sequester more carbon per year.

Short rotation tropical plantations that couple intensive management and rapid growth rates are also characterized by high rates of nutrient removal in the harvested biomass, which in turn, raises concerns about long-term site quality and sustainable production. The potential nutrient export, especially with whole tree harvesting may deplete the site nutrient capital (Jorgensen and Wells, 1986; Wang *et al.* 1991).

Keeping the foregoing in view the present investigation entitled "Carbon sequestration potential in some important trees of South Gujarat" was carried out with the following objectives:

i. To assess and compare the aboveground morphology of selected important trees.
ii. To assess above ground carbon sequestration of selected important trees.
iii. To assess the extent of soil carbon sequestration contributed by important trees.

II. REVIEW OF LITERATURE

To have better understanding on the present study, the finding of research work on various aspects of carbon sequestration at various locations in India and abroad have been reviewed briefly as follows.

Tree densities will have varying effects on individual tree component and total system yield. Practically in all experiments, the mean diameter for trees in the stand increased with increasing spacing (Smith, 1986).

Rates of reforestation and afforestation worldwide are likely to grow over the next decades as many countries seek to compensate for the loss of natural forests, and thus the role of plantations in sequestering carbon may also increase (Rotmans and Swart, 1991). Tropical forests harness more carbon than most other ecosystems and roughly 44 times more than agricultural lands. Fast growing trees in short rotation woody crop (SRWC) systems may increasingly meet societal needs ranging from renewable energy to ecosystem services such as carbon sequestration and environmental remediation (Jose, 2009).

Tropical plantations can serve diverse productive, economic, social, political and ecological functions. With their relatively high yields, tropical and subtropical plantations can make substantial contributions to world timber and pulp production (Wadsworth, 1983 and Evans, 1992). Plantations may help in stabilization of rural populations in regions where shifting agriculture is the predominant land use. In combination with subsistence and commercial crops (agroforestry) or cattle (agrosilvopastoral systems), plantations have been used as tools in rural development projects worldwide. Industrial plantations can make developing countries producers of wood-based commodities and at the same time bring about net reductions of atmospheric carbon (Dabas and Bhatia, 1996). If put in context with their other economic, social, and environmental functions, well designed and managed tropical plantations can provide viable alternatives to help reduce levels of atmospheric carbon.

There is considerable interest in estimating the biomass of trees and forests for both practical forestry issues and scientific purposes. Tree biomass plays a key role in sustainable forest management since it is the basis for estimating stocks and fluxes of several biogeochemical elements, the amount of energy stored in biomass, and other conventional goods and services. Trees also play an important role in the global carbon cycle and they are important as potential carbon pools and sinks (Schimel *et al.* 1994).

2.1 Above ground morphology

Dutt and Tyagi (2011) carried out the comparison of eleven *Eucalyptus* species for their morphological characteristics in North Indian topographical condition. They found that the *Eucalyptus grandis* of Bhadrachalam and Saharanpur origins gave significantly good results comparable to *Pinus kasiya* and other *Eucalyptus species*.

Matas and Pukkala (2011) carried out an experiment on comparison of the growth of six *Eucalyptus* species in Angola.

Species included *Eucalyptus saligna* Sm., *E. camaldulensis* Dehnh., *E. macarthurii* H. Deane & Maiden, *E. resinifera* Sm., *E. siderophloia* Benth., and *E. grandis* Hill ex. Maiden. The *E. saligna* had the highest stand volume at 43 years (1427 m^3 ha^{-1}) followed by *E. grandis* (1006 m^3 ha^{-1}) while *E. macarthurii* and *E. camaldulensis* had the lowest stand volume (423 and 511m^3 ha^{-1}, resp.). Using X-ray analyses of increment cores, it was possible to study the temporal development of the stand characteristics. An analysis of the mean annual increment showed that the optimal rotation length for most of the studied *Eucalypts* is around 22 years with the exception of *E. resinifera*, for which 12 – 15 years is the best. *E. saligna* had the highest maximum mean annual increment (MMAI) of 37 m^3 ha^{-1} attained at 22 years of age. *E. grandis* reached its MMAI of 25 m^3 ha^{-1} at 28 years.

Abubakar *et al.* (2011) reported variations in the leaf, morphological and anatomical features of *Moringa oleifera* L. accessions from Northern Nigeria. The highest leaf length range (58.85 - 61.75 cm) and leaflet length (34.55 - 37.25 cm) were recorded by 16BAU and 5ZRKD, respectively, while the highest leaflet width (1.85 - 1.87 mm) by 12BDZM. The accession showing the highest leaf area in all the samples studied was 2JHJG (3.45 mm^2). The accession collected from Argungun in Kebbi State (3ARKB) gave the highest stomatal length (30.80 μm) on its adaxial surface, while lowest stomatal width was shown by 6GZKN (14.01 μm) on its abaxial surface. The highest and lowest epidermal cell width of 32.60 μm/16.80 μm in the adaxial / abaxial surfaces was found in 16BAU and 2JHJG as well 3ARKB, respectively.

Safavi (2011) carried out an experiment to estimate genetic parameters and relationship among morphological traits studied on 12 poplar clones. The investigated variables included the Plant Height (PH), Height Volume Growth (HVG), Diameter at Breast Height (DBH), Volume Growth of Diameter at Breast Height (VGDBH), Bulk of Produce Hectare (BPH), Blade Length (BL), Blade Width (BW), Petiole Length (PL) and Petiole Diagonal (PD). Combined variance analysis showed a significant variation among genotypes for the traits PH, HVG, DBH, VGDBH, BPH, BL, BW, PL and PD. High correlation were found among the PH, HVG, DBH, BPH and BL. Heritability was high for BL, PD, PL, BW, PH, HVG and VGDBH. High genetic gain was observed for HVG, PD, BL, PL and PH. The effects of year and year X genotype showed significant effects.

Dhillon and Sidhu (2010) conducted a clonal trial by planting 17 poplar clones at village Dhindsa (Jallandhar) in central-plain region of Punjab. No clone was significantly superior to control for any growth trait at the age of 4 and 6 year. Clone IN-CSb was promising one with significantly higher volume (0.56) m^3/tree at 8-year age. The phenotypic and genotypic coefficients of variation were relatively low with maximum values for volume (27.17 - 32.13 % and 7.96 - 10.46 %) and the minimum for tree height (7.98 - 9.33 % and 1.69 -3.78 %). The broad sense heritability and genetic advance were relatively higher at 8-year age.

Sandhu *et al.* (2010) studied genetic relationships of sixteen accessions of *Dendrocalamus strictus* Roxb. on the basis of morphological characters and RAPD markers. Considerable variability was found among the accessions analyzed, yet, no significant relationship exhibited between genetic variation estimated by morphological and RAPD characters. The analysis of genetic relationship in *Dendrocalamus strictus* using morphological and RAPD banding data can be useful for framing plant improvement, conservation and management strategies.

Tikader and Dandin (2008) conducted a field experiment on leaf morphology and venation pattern in 4 Indian Mulberry species i.e., *Morus indica, M. alba, M. laevigata* and *M. serrata* of the family Moraceae. The leaf size of Morus species varied and a wide range i.e., *M. indica* (120.00 - 234.00 cm^2), *M. alba* (168.00 - 253.00 cm^2), *M. laevigata* (204.00 - 480.00 cm^2) and *M. serrata* (168.00-272.00 cm^2). Number of strands ending into petiole is more or less similar in all species, which ranges from 3 - 5 but the venation pattern is thick in case of *M. laevigata* and *M. serrata*. The areole number/mm^2 varies from 1.54 - 5.20 and areole size from 0.18 - 0.65/mm^2 in different species. The areole number is higher in *M. laevigata* and *M. serrata* and lower in *M. indica* and *M. alba*. The leaf morphological characters, the foliar venation pattern, areole formation, number of veins ending into petiole and veins/areole are the important features for identification of different *Morus* species at the vegetative stage. The minor venation, which ramifies into lamina also indicates the leaf quality i.e., palatability to silkworm.

Sadian and Pieber (2007) studied morphological variation of walnut in Mediterranean climate. Forty varieties were selected from Austria, Germany, Check Cslavakia, United State, Hungary and France and evaluated that the significant correlation was observed between number of fruits per tree with total yield per tree, mean weight of single fruit per tree and the flowering duration.

Kumar *et al.* (2006) studied eleven morphological characters *viz.*, plant height, collar diameter, plant fresh weight, shoot fresh weight, leaf fresh weight, plant dry weight, shoot dry weight, root dry weight, leaf dry weight and first leaf initiation among ten accessions of *Jatropha curcas* L. Significant variation was observed among all the characters. Heritability (broad sense) estimates exhibited high value for plant height and collar diameter whereas it was very low for the rest of the characters.

Ginwal *et al.* (2005) studied the seed source variation of *Jatropha curcas* L. collected from ten different locations with respect to morphology, germination and seedling growth. The study revealed that performance of Chhindwara seed source was better as compared to other sources.

Dogra and Sharma (2005) studied on sixteen accessions of *Eucalyptus* species and provenances established in Ferozpur Forest Division of Punjab in 1982 to evaluate differences in growth and yield. Highest basal area (29.50 *mV* h) was reported in Laura provenance of *Eucalyptus tereticornis*. Mean annual increment was again highest in Laura provenance.

Sheela *et al.* (2004) studied morphological and biochemical traits of selected accessions of bird pepper *(Capsicum frutescens* L.) and stated that the plant height, primary branches per plant and plant spread of different accessions ranged from 41.90 to 75.70 cm, 3.80 to 6.90, and 33.00 to 49.10 cm, respectively. Fruit length and girth varied from 1.66 to 5.08 cm and 1.67 to 3.84 cm, respectively, with the highest values for both parameters being recorded in the accession CF 36. Yield per plant ranged from 43.39 to 97.73 g, with the highest being recorded for CF 103, followed by CF 10 and CF 19.

Mohanty and Khurana (2003) analysed morphological variation of selected clones of *Populous ciliate* x *Populus maximowiczii* hybrid and found that the growth potential was maximum in clone CM_2 4-15/91 with height and diameter of 2.11 m and 1.70 cm, respectively. Average leaf blade length was 109 times higher as compared to average maximum leaf width and average nerve length was 5 times to average petiole length.

Mwihomeke *et al.* (2001) conducted a trial involving twenty one provenances from Indonesia and seven local seed sources of *Casuarina junghuhniana* established at Lushoto Tanzania in March, 1971 at 22 and 48 months of age, the following characteristics were assessed: survival, root collar diameter (RCD), diameter at breast height (DBH) and height. At 48 months of age, the four best performing seed sources were: Mt. Brumo; East Java, Mt. Pohen, Bali; Kanyan Agriculture Research Institute, Muguga, Kenya and Mt. Brumo, East Java while the four worst performing ones were: Kapan, Kumpang, Timor; Noelmina river, Timor and Buat, Soe, Timor.

Pathak (1998) conducted a trial of ten *Acacia nilotica* (L.) wild ex Del (Babul) provenances at the Forestry Research Farm of Jawaharlal Nehru Krishi Viswavidyalaya, Jabalpur under rainfed conditions. The four year results showed significant differences between provenances in height, volume index, diameters at base (DB) and diameter at breast height (DBH). Provenance from Firojpur and Jhansi performed best in all the characters studied.

Kumaravelu *et al.* (1995) worked on fourteen provenances of *Eucalyptus tereticornis* Sm. and fifteen provenances of *E. camaldulensis* Dehnh. planted in 1982 at Pudukottai, Tamil Nadu. After 8 years of planting, percentage survival and DBH were recorded for all the provenances. Survival percentage was better in *E. camaldulensis* than *E. tereticornis*. Three provenances of *E. tereticornis viz.*, Laura (10975 + 11953), Mt. Garbine (13013) and Kennedy River (12947) and Five of *Eucalyptus camaldulensis viz.*, Katherine (12181), Richmond (13008), Gibu river (12346), Gilbert river (12963) and 12986 proved promising.

Beltrati (1981) carried out an experiment on morphological and anatomical aspects of seeds and seedlings of *Eucalyptus pilularis* Sm. and *E. umbra* R.T. Baker and found to be similar, with the exception of some anatomical features of the testa and the average length of the fertile seeds, which is significantly different for the two species.

2.2 Carbon sequestration

Chavan and Rasal (2011) worked on aboveground and belowground carbon sequestration potential of *Eucalyptus spp.* from 9th sectors of Aurangabad city. The biomass and total organic carbon of standing trees is estimated by non destructive method. The total standing aboveground biomass and belowground biomass of *Eucalyptus spp.* is 509.01 t ha^{-1} and 132.34 t ha^{-1}, respectively while, total standing biomass of *Eucalyptus spp.* in 2847 ha of Aurangabad is 641.35 t ha^{-1}. The sequestered carbon stalks in aboveground and belowground standing biomass of *Eucalyptus spp.* is 254.50 t ha^{-1} and 66.17 t ha^{-1}, respectively while, total sequestered carbon of *Eucalyptus spp.* in 2847 ha area is 320.67 t ha^{-1}. The average carbon dioxide of *Eucalyptus spp.* intake is 1176.85 t CO_2 in Aurangabad city. The highest carbon sequestration of *Eucalyptus spp.* in sector 6th and 7th it 31.00 % each while, lowest carbon sequestration in 1st sector it (1.00 %).

Kakkar and Nagaraja (2011) conducted a trial to evaluate the C storage potential in *Syzygium cumini, Gmelina arborea, Tectona grandis, Acacia auriculiformis, Dalbergia latifolia, Terminalia chebula* and *Hardwickia binnata* plantations at Hosakote Research Station. The selected species showed mean height (m) of 6.202, 10.007, 4.645, 10.739, 6.450, 4.969 and 5.860 and mean DBH (m) of 0.213, 0.141, 0.129, 0.116, 0.104 and 0.096. Total C sequestrated (t ha^{-1}) in above selected species was found to be 2.94, 19.28, 5.31, 21.30, 7.67, 7.70 and 5.35, respectively. *Acacia auriculiformis* followed by *Gmelina arborea* recorded highest C sequestered. It is evident that closer spacing and fast growing species sequester more C.

Nath and Das (2011) studied C estimate in aboveground vegetation of bamboo farming system and studied that it was ranged from 6.51 (2004) to 8.95 (2007) Mg ha^{-1} with 87.00 %, 9.00 % and 4.00 % of the total C stored in culm, branch and leaf, respectively. The study also elucidated that the rate of C sequestration was 1.20 - 1.46 Mg $ha^{-1}yr^{-1}$, with a mean of 1.32 Mg $ha^{-1}yr^{-1}$.

Rizvi *et al.* (2011) studied the assessment of C storage vis-a-vis CO_2 assimilation by poplar plantations in agroforestry. The C storage was found to be 27.00 – 32.00 t ha^{-1} in boundary system, whereas it was 66.00 – 83.00 t ha^{-1} in agrisilviculture system at a rotation period of 7 years in the two districts *viz.*, Yamunanagar and Saharanpur of North-Western India. From the study it is clear that poplar plantations make important contributions towards atmospheric CO_2 assimilation and hence play a significant role in the mitigation of atmospheric accumulation of greenhouse gases.

Sudha *et al.* (2010) conducted an experiment on development of an agroforestry sequestration project in Khammam district of India. Technical potential for afforestation was determined considering the various land use options. For estimating the technical potential, culturable wastelands, fallow and marginal croplands were considered for Eucalyptus clonal plantations. The baseline carbon stock was estimated to be 45.33 t C/ha. The additional carbon sequestration potential under the project scenario for 30 years is estimated to be 12.82 t C/ha/year inclusive of harvest regimes and carbon emissions due to biomass burning and fertilizer application. The project scenario though has a higher benefit cost ratio compared to baseline scenario, initial investment cost is high. Investment barrier exists for adopting agroforestry in the district.

Borah and Chandra (2010) conducted an experiment on carbon sequestration potential of selected bamboo species at Jorhat district of Assam; three bamboo species mainly *Bambusa balcooa* (Bhaluka), *B. tulda* (Jati) and *B. nutans* (Mokal) are widely grown. Highest above ground carbon stock was calculated for *B. balcooa* (234.17 t ha^{-1}) followed by *B. tulda* (86.99 t ha^{-1}) and *B. nutans* (63.25 t ha^{-1}).

Prasad *et al.* (2010) revealed that the carbon content varied significantly among tree species (38.28 - 42.07 %) as well as tree components (35.86 - 44.55 %). The carbon content in different tree species was in the order of *E. tereticornis* = *A. indica* = *A. nilotica* = *B. monosperma* = *A. procera* = *D. sissoo* = *E. officinalis* = *A. pendula*. The order of carbon content in tree-components was branch = stem > root > foliage > stem bark = branch bark. Among all the studied tree species, *A. procera* was found to be the most efficient in capturing C (127.74 kg C/tree) and removing CO_2 from the atmosphere (46.83 kg/tree/year) while, *A. pendula* the least with corresponding values of carbon (8.22 kg C/tree) and CO_2 (3.01 kg/tree/year), respectively. Positive correlation existed between carbon content and tree growth attributes (height and DBH).

Gupta (2009) realized that more efforts on plantation in poorly stocked forest areas i.e. "Open canopy" and "Scrub" forests - which can help in sequestering more carbon as well. Also by using wood preservation treatments, the service life of wood used in the district can be increased to 3.07 times.

Phanikumar *et al.* (2009) studied on C sequestration with special reference to agroforestry in cold deserts of Ladakh revealed that the Nubra Valley (Trans-Himalayan region) is covered with more than 5,75,000 agroforestry plantations (Willow and Poplar). These species have been found to sequest more than 75,000 t of C. Every year these plantations are contributing 400 t of leaf litter to the ground, which is one of the best sources of SOC.

Walsh *et al.* (2008) studied on tree growth in farm forestry *Eucalyptus* plantations in the low to medium rainfall (450.00 – 700.00 mm y^{-1}) regions of New South Wales, Australia, in an attempt to estimate the productivity of the plantations. The species measured include *Eucalyptus camaldulensis, E. botryoides, E. globulus, E. albens, E. polyanthemos, E. microcarpa, E. melliodora, E. sideroxylon, E. crebra* and *Corymbia maculata.* At the age 10 year, mean dominant height (100 tallest trees per ha) ranged from 7.50 to 18.80 m, mean top basal area (thickest 100 stems ha^{-1}) from 1.50 to 9.20 m^2 ha^{-1}, volume from 9.50 to 125.90 m^3 ha^{-1}, total above ground biomass from 12.50 to 105.80 t ha^{-1} and mean carbon density (above ground) from 11.20 to 35.20 t ha^{-1}.

Koul and Panwar (2008) concluded that location-specific land-use systems need to be prioritized taking both C sequestration potential and socio-economic needs into account. It was found that in the Terai zone of West Bengal, fallow land and agricultural field sequester 5.86 % and 4.73 % C, respectively as compared to the natural forest of *Shorea robusta*. However, agroforestry systems *viz.*, tea garden and agrihorticulture contributed 24.24 % and 9.09 % C, respectively. Study further suggested that the potential of C storage of tree + crop-based system can be further increased using improved planting materials of perennial components.

Ramachandran *et al.* (2007) conducted an experiment on C stock in a natural forest area of Kolli hills, part of the Eastern Ghats of Tamil Nadu and reported that the biomass C estimated is 2.74 Tg and the soil C is 3.48 Tg. The average biomass C density recorded in tropical degraded forests was from 63.33 to 156.00 t ha^{-1} and 70.00 t ha^{-1}.

Arroja *et al.* (2006) conducted a study to develop a framework for estimation of C sequestration in the forest of *E. globulus*, a fast growing species and found that *E. globulus* forest sector was a C sink, but the magnitude of the C sequestration differs substantially depending on the accounting approach used. The contribution of the forest ecosystem was smaller than the aggregated contribution of wood products in use and in landfills.

Dey (2005) studied the global concern on increasing levels of greenhouse gases specifically carbon dioxide in the atmosphere. In this context, carbon sequestration through managed rubber plantation is gaining importance. Rubber plantation has been expanding in the North East (NE) region and covers an area of 51,510 ha. In this study, the carbon stock of rubber plantation in the NE region has been estimated and results indicated that an average carbon store in rubber plantation is around 136 tonnes/ha, out of which 92.70 t C/ha is contributed by soil and 2.40 t C/ha addition through litter fall and undergrowth vegetation. About seven million tonnes of carbon is store in the rubber plantations of this region. On completion of projected area of 4,50,000 ha the carbon store would be around nine times higher than the present value. This study reflects the immense ecological value that rubber plantations provide, by storing carbon despite low productivity in these marginal lands.

Rawat and Negi (2004) estimated the biomass production of *Eucalyptus tereticornis* and found that it varied from 11.90 t ha^{-1} in three years to 146.00 t ha^{-1} in 9 year old plantation in moist regions. In dry tropical region it varied from 5.65 t ha^{-1} in 5 year old plantation to 135.50 t ha^{-1} in 9 year old plantations.

Rai and Sharma (2003) work on the conversion of land from forest to other usage is a threat to land-use sustenance and contributes negatively to climate change. Land-use/cover changes have caused a significant release of CO_2, to the atmosphere from the terrestrial biota and soils. Soil is a major source of atmospheric CO_2. In the event of growing threats of global warming due to greenhouse gas emissions, reducing CO_2 emission by sequestering C in the soil is of prime importance. Adoption of

C sequestration measures in the soil can considerably reduce the rise in atmospheric CO_2 level. Practices such as improved crop productivity and conservation tillage may be warranted to mitigate their carbon sequestration benefits. The purpose of this paper is to present an overview of measured rates of soil respiration from land-use/cover change to define the annual global CO_2 flux.

Singh *et al.* (2003) revealed that high vegetation status in Gujarat resulted greater carbon stock compared to that Rajasthan. Carbon in the form of vegetation biomass ranged from 1.96 to 2.83 Mg ha^{-1} in Gujarat and 0.24 to 1.73 Mg ha^{-1} in Rajasthan. Soil carbon was 3.60 to 6.38 Mg ha^{-1} as compared to 1.13 to 5.18 Mg ha^{-1} Rajasthan being lowest in the sandy area of Mokal and Ramgarh. The potential of carbon sequestration in the CARs has been worked out to be 6.13 Mg ha^{-1} yr^{-1}. With this sequestration potential the CARs should be able to meet the local need for fuel fodder and small timber.

Wullschleger *et al.* (2002) studied on enhancement of soil C sequestration on phosphate mine lands in Florida by planting short-rotation bioenergy crops and showed that yield estimates for 2 year and 6 month old *E. grandis* planted in single rows varied from 10.00 to 16.00 dry t of biomass per acre. In addition to providing a C neutral option for mitigating rising CO_2 in the atmosphere, an important opportunity exists for promoting soil C sequestration as a result of restoration.

Jha *et al.* (2001) reported that approximately 260 million ha land in India have biological potential of some use.

The carbon store in forest land is higher than agricultural lands followed by pastures and barren land. Intensive technology inputs to strengthen forest conservation could lead to effective Green House Gases stabilization in our country. The variety of soils occurring in India offers different potential for carbon sequestration. The paper deals with the global carbon store in soil and vegetation, global carbon exchange between forest and atmosphere, organic carbon store in some Indian soils, soil carbon store under different land uses, soil carbon store in plantation and natural forest in India and carbon sequestration in wastelands etc.

Rao *et al.* (2000) conducted an experiment with 11 multipurpose tree species in red sandy loam soils. The results showed that *Dalbergia sissoo* yielded maximum biomass (214.60 t ha^{-1}) followed by *Leucaena leucocephala* (187.80 t ha^{-1}) and *Acacia auriculiformis* (162.40 t ha^{-1}). Mean annual biomass production (MABP) was also maximum for *D. sissoo* (23.80 t ha^{-1}) followed by *L. leucocephala* (20.90 t ha^{-1}) and *A. auriculiformis* (18.00 t ha^{-1}). Foliage yield was maximum for *L. leucocephala* (16.80 t ha^{-1}) followed by *A. auriculiformis* (12.00 t ha^{-1}) and *Eucalyptus camaldulensis* (9.90 t ha^{-1}).

Townsend *et al.* (1996) studied spatial and temporal patterns in terrestrial C storage due to deposition of fossil fuel nitrogen and revealed that the vegetation type has a pronounced effect on C uptake; the combination of high C : N ratios and long lifetimes in wood may create a significant sink in forests, but much of the nitrogen falls on cultivated areas and grasslands, where there is limited capacity for long term C storage. Study also showed that net C uptake due to deposition of fossil-fuel N to be between 0.30 and 1.30 Pg C yr^{-1} [1 Pg = 10^{15} g], depending on the fraction of C allocated to wood.

2.3 Soil Organic Carbon

Dinakaran *et al.* (2011) studied the soil organic carbon (SOC) dynamics in two types of tropical ground cover. Higher rupee values during monsoon seen in the present study (in both the covers) are attributed to higher biomass production which increased fresh inputs into soil. In both the covers, correlation ($R^2 > 0.60$) was seen between BGB (belowground biomass) and MBC (microbial biomass carbon). DOC (dissolved organic carbon) in both the covers showed higher values during monsoon coinciding with biomass production. Results of ANOVA showed significant differences ($P < 0.05$) in the measured parameters of both types of ground cover, indicating functional differences. Higher SOC values (15.60 –23.20 g kg^{-1}) in herbaceous cover indicated larger inputs of dead organic matter coming from the death of ephemerals. Lesser and relatively stable quantities of SOC (7.80 – 9.80 g kg^{-1}) in grass cover have been attributed to lower inputs and/or uniformity in their proportion of expenditure of fixed carbon.

Madhusudanan *et al.* (2011) investigated that biomass production and carbon sequestration potential of four fast growing multipurpose tree species *viz., Albizia procera, Casuarina equisetifolia, Eucalyptus tereticornis* and *Gmelina arborea* at 20 years stand age. Above ground C sequestration potential, of the four MPTs studied showed wide variation Among the four species studied, *A. procera* and *C. equisetifolia* recorded higher C sequestration potential, which was 189.93 Mg ha^{-1} and 185.85 Mg ha^{-1}, respectively. Except *G. arborea* all the tree species recorded high C sequestration, which is comparable to the earlier recorded values for tropical forests. Enhanced soil C storage (0 - 30 cm) was also found under trees compared to treeless open.

Xu *et al.* (2011) stated that data scarcity often prevents the estimate of regional (or national) scale soil organic carbon (SOC) stock and its spatial distribution. They estimated the national SOC stock at 383 ± 38 Tg for the near-surface of 0 – 10 cm depth; 1016 ± 118 Tg for 0 – 30 cm depth; and 1474 ± 181 Tg for 0 – 50 cm depth.

Burger *et al.* (2010) studied that how soil organic carbon (SOC) influences the solute transport? To monitor the water and solution movement in soil, anion bromide has been used as a tracer. They were interested in the transport process of nitrate, because of its relevance concerning the issue of nitrogen contamination of groundwater. The study investigated soils under two different types of land use with different carbon contents. The first land use was a pair of soils under apple orchards. The second land use was permanent pasture grazed by sheep. Generally, soil properties improve with soil carbon management. This study showed the converse for the aspect of surface applied solutes under conditions where there would be the likelihood of surface ponding of water.

Chandran *et al.* (2009) conducted an experiment in semi-arid tropics of India and noted that the quasi-equilibrium value (QEV) of SOC decreased from 1.78 to 0.68 % in the first 30.00 cm, when the soils are used for agriculture instead of retaining them as forest. It is found that the highest threshold value of SOC is observed in forest system, followed by horticultural and the lowest in agricultural system.

Nair *et al.* (2009) reported higher soil C stock under deeper soil profiles in tree based agroforestry systems compared to treeless agricultural or pasture systems under similar ecological settings. However, the SOC content in any system is dependent upon a large number of location and system-specific factors such as climate, soil type, vegetation and management practices.

Zhanga *et al.* (2008) stated that SOC storage and SOC density by the SPS (soil profile statistics) and the GST-2D (GIS-based planar soil type) methods, which were lower than the GST-3D (GIS-based three-dimensional soil type) mainly due to the underestimation of soil acreage. Of the four geomorphologic units represented in the study area, the complex landforms with slopes greater than 18.2° covered more than 30.00 %. There is a relatively big difference (> 6.00 %) between planimetric projection area and surface area in this region, making the effect of landform on the estimate of SOC an important factor to be considered. However, such thresholds (30.00 % and 18.2°) as terrain descriptor boundaries need to be further verified in other mountainous regions.

Qiu *et al.* (2006) estimated the soil organic carbon (SOC) storage in North east of China; identify its balance situation and changing trends under current cropping systems. The model predicted results revealed that (1) Total SOC storage in agricultural lands in Heilongjiang, Jilin and Liaoning provinces in Northeast of China is about 1243.48 × 106 t (0 - 30cm soil layer), respectively occupying 58.4, 25.5 and 16.1%; (2) Under the current cultivation systems, SOC is in a negative balance with carbon losing at a high rate of 31.22 × 106 t a^{-1} (respectively 59.3, 25.9 and 14.80 % in Heilongjiang, Jilin and Liaoning provinces) and 2.05 t ha^{-1} a^{-1}, the situation is more serious in Heilongjiang and Jilin provinces; and (3) Protective cultivations, such as manuring, returning more residue of crop to the field, adopting no-till, are very useful for the accumulation of SOC in these regions.

Bellamy *et al.* (2005) revealed that soil is an important part of the biosphere in sequestering C and has a higher potential to store C compared to vegetation and atmosphere and thus play a vital role in the global C cycle.

Singh (2005) studied on soil organic carbon dynamics with three year litter dynamics in *Emblica officinalis*, *Hardwickia binata* and *Colophospermum mopane* based agroforestry systems. Soil carbon content decreased with time in control plot with a loss of SOC by 56.00 % during the study period. However, integration of trees allowed a loss of SOC only by 3.20 % in *E. officinalis*, 22.00 % in *H. binata* and 35.50 % in *C. mopane* plots, indicating greater sequestration of carbon in *E. officinalis* plot and least in *C. mopane* plot. The study further suggested that integration of tree in agricultural land is an important strategy to sequester carbon not only in the form of biomass but also in soil and may therefore maintain soil productivity.

Montagnini and Nair (2004) studied on an important role of trees in soil C sequestration with an increase in the number of trees (high tree density) in a system, the overall biomass production per unit area of land will be higher, which in turn may promote more C storage in soils.

Zhou *et al.* (2003) stated that the terrestrial carbon cycle which is an important component in the study of global change. Data from 2473 soil profiles from the second national soil survey were collected. The analytical results showed that the total amount of soil organic carbon is about 92.40 Pg (Pg = 10^{15} g) and that the average carbon density is about 10.53 kg C m^{-3}. The spatial distribution of soil organic carbon was also analyzed and mapped. This study presents basic data and an analysis method for carbon-cycle studies and also provides scientific support for policy making efforts to control CO_2 emissions in China

Resh *et al.* (2002) compared the soil C pools under N-fixers with Eucalyptus non-N-fixer at four tropical sites and observed that the soils beneath N-fixing trees sequestered 0.11 ± 0.07 kg m^{-2} y^{-1} (mean ± one standard error) of total SOC compared with no change under Eucalyptus (0.00 ± 0.07 kg m^{-2} y^{-1}; P=0.02) and attributed the same to greater retention of older soil C under N-fixing trees.

Post and Kwon (2000) observed that maximum rates of C accumulation during the early aggrading stage of perennial vegetation growth, while substantial are usually much less than 100 g C m^{-2} y^{-1}. Average rates of accumulation are similar for forest or grassland establishment: 33.8 g C m^{-2} y^{-1} and 33.2 g C m^{-2} y^{-1}, respectively. These observed rates of soil organic C accumulation, when combined with the small amount of land area involved are insufficient to account for a significant fraction of the missing C in the global carbon cycle as accumulating in the soils of formerly agricultural land.

Batjes (1996) conducted an experiment on the soil C pool comprises SOC estimated at ISSO Pg and soil inorganic C about 750.00 Pg both to 1.00 m depth. This total soil C pool of 2300.00 Pg is three times the atmospheric pool of 770.00 Pg and 3.80 times the vegetation pool of 610.00 Pg. Thus, any change in the soil C pool would have a significant effect on the global C budget.

Aweto (1995) observed a decline in SOC pool under plantation compared with natural forest in Southern Nigeria. The rate of decline in the SOC pool in kg C/ha/yr for 0.00-20.00 cm layer was 392.00 m Teak, 492.00 m in *Gmelina arborea*, 627.00 m in Cashew, 720.00 m in Rubber, 1890.00 m in Oil palm and 1144.00 m in Coffee. The changes in C and N in soils of *G. arborea* in sole stands and agroforestry system established after 5 years in abandoned agricultural land was evaluated by Swamy and Sunil Puri (2005). Total C content in the soil increased significantly under different stands of *G. arborea* after 5 years of planting. However, it decreased with an increase in soil depth.

III. MATERIALS AND METHODS

The investigation on "**Carbon sequestration potential of some important trees in South Gujarat** " was carried out at the Instructional Farm of ASPEE College of Horticulture and Forestry, Navsari Agricultural University, Navsari, Gujarat. The materials and methods employed during the course of investigation are detailed in this chapter under the following main headings.

3.1 Location

The investigation was conducted at Instructional Farm, ASPEE College of Horticulture and Forestry, Navsari Agricultural University, Navsari, situated at an altitude of 12.00 m above mean sea level, at 20^0 58' North latitude and 72^0 54' East latitude.

The experiment site having typical tropical climate characterized by hot summer, moderately cold winter and humid warm monsoon with an average rain fall of 1,355.00 mm, the bulk of which is received in July to August. The meteorological data during course of investigation are given in Appendix – I. The soil is clay in texture (63.00 %), high moisture retention capacity (40.50 %) and low in organic C content (0.26 %), nitrogen content (110.12 kg ha^{-1}) and medium in available phosphorus (30.39 kg ha^{-1}) while rich in potash content (319.60 kg ha^{-1}). It is not having any problem of sodicity as pH (7.86) and EC (1.75 dSm^{-1}) are below the critical limit.

3.2 Experimental details

3.2.1 Location : Instructional Farm,
ASPEE College of Horticulture
and Forestry
Navsari Agricultural University,
Navsari – 396 450

3.2.2 Year of Planting : 1989

3.2.3 Experimental Design: RBD

3.2.4 Replications : Three (3)

3.2.5 Treatments

T_1 : *Tectona grandis*
T_2 : *Mytragyna parvifolia*
T_3 : *Terminalia arjuna*
T_4 : *Albizia procera*
T_5 : *Acacia catechu*
T_6 : *Mangifera indica*
T_7 : *Manilkara achras*

3.3 Observations to be recorded

3.3.1 Above ground morphology

The following morphological observations were recorded during experiment.

3.3.1.1 Tree height (m)

The Ravi Altimeter is a portable instrument for measuring height of the tree. The instrument has an accessory i.e. a foldable bar, which has a separate scale on each of its face. The usual scales are 15, 20, 25, 30 and the per cent. 15, 20, 25 and 30 are the horizontal distance from the tree where the observer must

Plate-I : General view of experimental area

T1 : *Tectona grandis*

T2 : *Mytragyna parvifolia*

T3 : *Terminalia arjuna*

T4 : *Albizia procera*

Plate-I : Contd....

T5 : *Acacia catechu*

T6 : *Mangifera indica*

T7 : *Malinkhara achras*

stand to get height of the tree above the eye level directly from the instrument. Add the eye height from the ground level to the height of the tree above eye level to get total height of the tree. The percent scale gives the height as a percentage of the unit horizontal distance. Usually the height is measured in meters as a unit. Standardization of instrument (Ravi Altimeter): The calibrations of instrument are checked regularly by measuring a vertical object of known height. If vast difference is found in measurement, the instrument is rejected and the new instrument is used for height measurement. It is also practiced to check the known height employing the instrument before actual measurements of trees is taken. The height of tree species was measured from ground level to the tip of the stem with the help of Ravi Altimeter. The height of three plants per species per replication was recorded and its average was worked out.

3.3.1.2 Clear bole height (m)

The Clear bole height of tree species was measured from ground level to the starting the first branch on the trunk with the help of Ravi Altimeter. The bole height of three plants per species per replication was recorded and its average was worked out.

3.3.1.3 Diameter at breast height (DBH) (cm)

The DBH was measured at breast height (1.37 m) of tree species with the help of caliper. The diameter of three plants per treatment per replication was recorded and its average was worked out.

3.3.1.4 Girth at breast height (GBH) (cm)

The GBH was measured at breast height (1.37 m) of tree species with the help of tape. The girth of three plants per treatment per replication was recorded to the nearest centimeter and its average was worked out.

3.3.1.5 Volume (m^3/tree)

Total volume was calculated in standing position with the help of following formula;

Total volume (m^3/tree) = B.A. X h

Where,

Basal Areal (B. A.) = $\pi D^2/4$

$\pi = 3.14$

D = DBH (m)

h = Height of tree (m)

3.3.2 Above ground carbon sequestration

3.3.2.1 Carbon content of leaf, twigs, bark and main stem

The carbon content of leaf, twigs, bark and main stem was determined by Rapid Titration Method (Walkley and Black's, 1934). The different plant parts were collected from different plants as per treatment. The collected samples were oven dried at 62^0C temperature up to a constant weight and after that they were grind by willy mill having stainless steel blade. The samples so prepared were analysed for carbon content and calculated in percentage. Three replications were selected for taking observation and its average was worked out.

3.3.2.2 Carbon sequestration (kg/tree)

Carbon content in above ground biomass was measured by non-distructive method. Carbon content is calculated by following formula given by Brown *et al.* (1986).

If D < 11", $W = 0.25 \times D^2 \times H$

If D > 11", $W = 0.15 \times D^2 \times H$

Where;

W = carbon content in above ground biomass (pound)

D = Diameter at breast height (inch)

H = Total plant height (ft.)

The above ground biomass in pound will be then converted in to kilogram by formula 1 pound = 0.4535 kg.

So, the total carbon sequestration by plant is taken as half of carbon content in above ground biomass (W) as described by Ravindranath *et al.* (1997).

3.3.3 Soil carbon sequestration

3.3.3.1 Soil Organic Carbon (%)

The soil organic carbon content was analyzed by following standard wet digestion method (Walkley and Black's rapid titration method, 1934). For determining the Soil Organic Carbon, the composite soil samples were collected from 0 – 15 and 15 – 30 cm soil depth per tree per replications and average was worked out.

3.4 Statistical analysis

The experimental data were subjected to the statistical analysis by using variance technique as described by Panse and Sukhatme (1967). The method of analysis of variance for

Randomized Block Design (RBD) was used. The treatment differences were tested by 'F' test of significance based on null hypothesis. The appropriate standard error (S.Em.±) was calculated in each case and critical difference (C.D.) at 5 percent level of probability was worked out to compare the treatment means, where the treatment effects were significant. Suitable graphical presentations based on the data is given at the appropriate places.

IV. EXPERIMENTAL RESULTS

The present experiment was undertaken with a view to determine the **"Carbon sequestration potential of some important trees in South Gujarat"** at Instructional Farm, ASPEE College of Horticulture and Forestry, Navsari Agricultural University, Navsari under South Gujarat conditions.

The observations related to above ground morphology i.e., tree height, clear bole height, diameter at breast height, girth at breast height, volume and carbon content in leaf, twigs, bark and main stem and soil organic carbon were recorded. The data obtained are analyzed using Randomized Block Design and results are discussed under with following sub headings *viz.*,

4.1 Above ground morphology

4.2 Above ground carbon sequestration

4.3 Soil carbon sequestration

4.1 Above ground morphology

4.1.1 Tree Height and Clear Bole Height (m)

The mean data pertaining to variation in tree height and clear bole height among different tree species are furnished in Table-4.1 and graphically depicted in Fig. 4.1. A perusal of data reveals that the tree height and clear bole height of different tree species was significantly different among various trees species.

Significantly higher tree height (18.32 m) and clear bole height (9.68 m) was recorded in T_3: *Terminalia arjuna* which was followed by T_4: *Albizia procera* (15.82 m and 7.35 m, respectively). Whereas two horticultural trees remains at par with each other T_6 : *Mangifera indica* (6.05 m) and T_7 : *Manilkara achras* (5.75 m). The tree height (5.75 m) and clear bole height (2.32 m) was recorded significantly lower in T_7 : *Manilkara achras*.

4.1.2 Diameter and Girth at breast height (cm)

The data on variation in diameter and girth at breast height among different tree species are presented in Table-4.2 and graphically depicted in Fig. 4.2. The results were found significant for diameter and girth at breast height.

From Table – 4.2, it can be revealed that T_6 : *Mangifera indica* reported significantly higher diameter (90.67 cm) and girth (284.69 cm) at breast height which was followed by T_3: *Terminalia arjuna* (53.67 cm and 168.51 cm, respectively). In case of various forestry tree species, T_4 : *Albizia procera* (49.67 cm and 155.95 cm, respectively) performed better with respect to diameter and girth at breast at height. Significantly lower diameter and girth at breast height was recorded in T_7 : *Manilkara achras* (38.33 cm and 120.37 cm, respectively).

4.1.3 Volume (m^3/tree)

The mean data regarding variations in volume (m^3/tree) among different tree species are presented in Table-4.3 and graphically depicted in Fig. 4.3. The volume of different tree

Table-4.1: Mean variations in plant height (m) of different plant species

Treatment	Plant Height (m)	Clear Bole Height (m)
T_1 : *Tectona grandis*	15.15	6.65
T_2 : *Mytragyna parvifolia*	13.15	6.32
T_3 : *Terminalia arjuna*	18.32	9.68
T_4 : *Albizia procera*	15.82	7.35
T_5 : *Acacia catechu*	12.88	4.22
T_6 : *Mangifera indica*	6.05	2.58
T_7 : *Manilkara achras*	5.75	2.32
S. Em.$\pm$	0.686	0.359
C.D. at 5 %	2.11	1.11
C.V. %	9.55	11.12

Fig.4.1.Variations in tree height and clear bole height (m) of different plant species

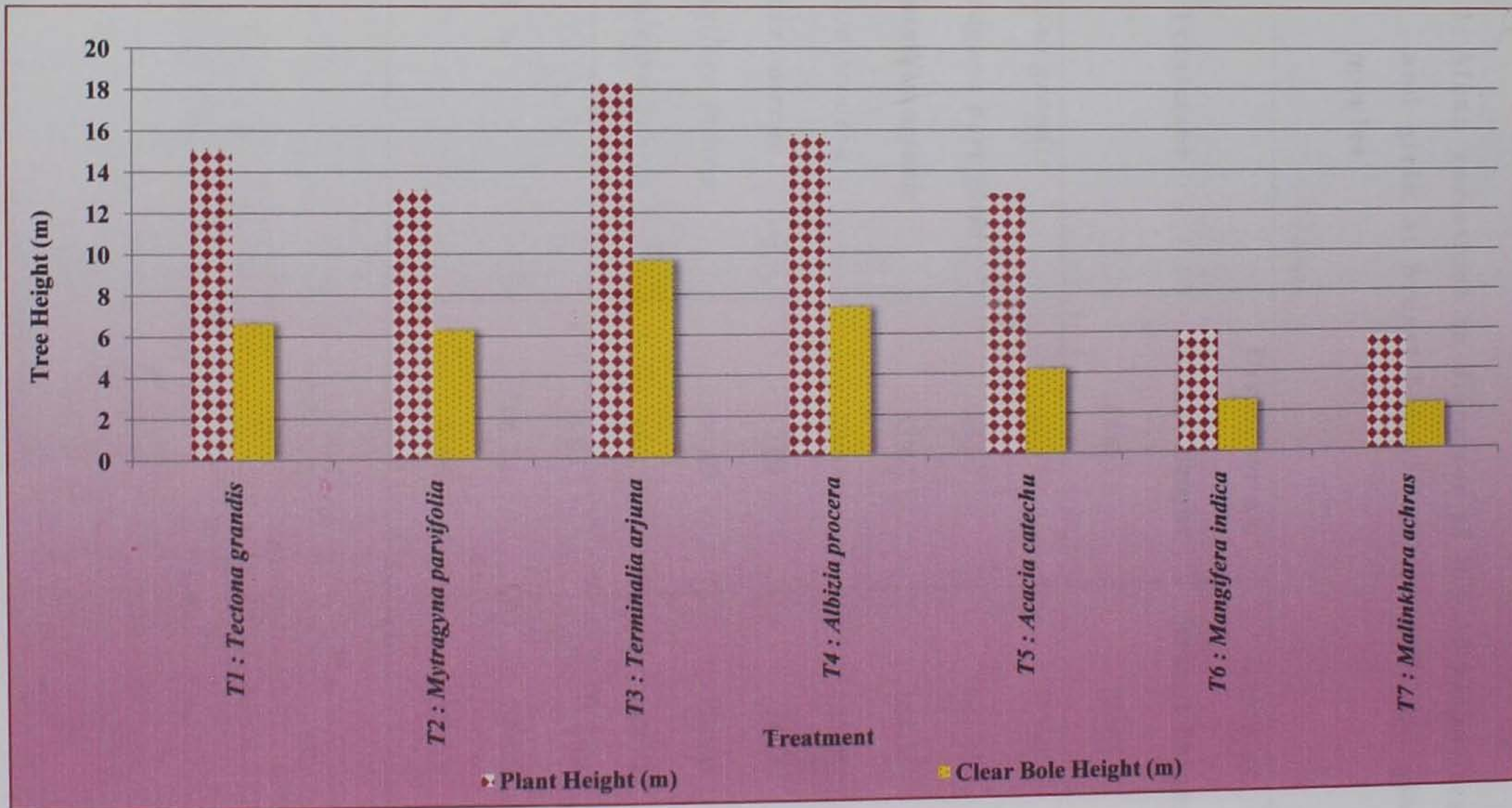
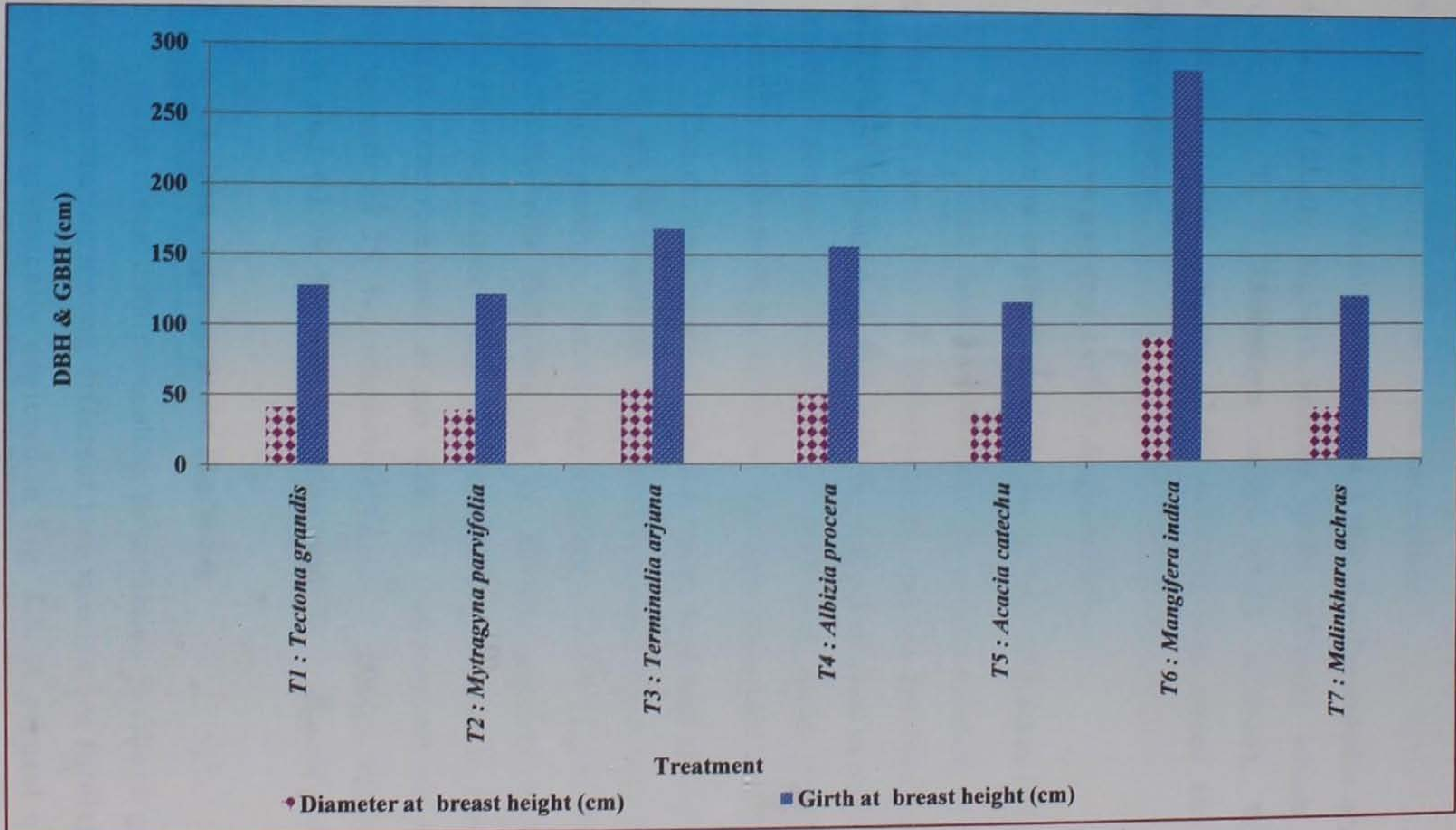


Table-4.2: Mean variations in diameter at breast height (cm) and girth at breast height (cm) of different plant species

Treatment	Diameter at breast height (cm)	Girth at breast height (cm)
T_1 : *Tectona grandis*	40.67	127.69
T_2 : *Mytragyna parvifolia*	38.67	121.41
T_3 : *Terminalia arjuna*	53.67	168.51
T_4 : *Albizia procera*	49.67	155.95
T_5 : *Acacia catechu*	37.00	116.18
T_6 : *Mangifera indica*	90.67	284.69
T_7 : *Manilkara achras*	38.33	120.37
S. Em.±	2.835	9.054
C.D. at 5 %	8.74	27.90
C.V. %	9.86	10.03

Fig.4.2.Variations in diameter at breast height (cm) and girth at breast height (cm) of different plant species



species significantly differed from each other.

It is evident from Table-4.3 that T_3: *Terminalia arjuna* noted significantly highest volume (8.85 m^3/tree) which was followed by T_6 : *Mangifera indica* (6.68 m^3/tree). While, significantly lowest volume (1.08 m^3/tree) was noted in T_7 : *Manilkara achras*.

4.2 Above ground carbon sequestration

4.2.1 Carbon content in bark, twig, leaf and stem (%)

The mean data with respect to carbon content in bark, twig, leaf and stem (%) of different tree species are furnished in Table-4.4 and depicted in Fig. 4.4. A perusal of data reveals that the carbon content in bark, twig, leaf and stem (%) were significantly influenced by different tree species under study.

The carbon content in bark, twig, leaf and stem (58.19 %, 65.40 %, 66.70 % and 68.06 %, respectively) were recorded in T_7 : *Manilkara achras*. The carbon content of bark (52.62 %) and twig (60.79 %) was followed by T_4: *Albizia procera* and T_5 : *Acacia catechu*, respectively. While, carbon content in leaf and main stem were remained at par with T_2 : *Mytragyna parvifolia* (65.59 % and 62.25 %, respectively), T_6 : *Mangifera indica* (64.70 % and 63.79 %, respectively) and T_5 : *Acacia catechu* (62.87 %).

4.2.2 Carbon sequestration (kg/tree)

The mean data pertaining to variation in above ground carbon sequestration among different tree species are furnished in Table-4.5 and graphically depicted in Fig. 4.5. A perusal of data

Table-4.3: Mean variations in volume (m^3/tree) of different plant species

Treatment	Volume (m^3/tree)
T_1 : *Tectona grandis*	3.43
T_2 : *Mytragyna parvifolia*	3.03
T_3 : *Terminalia arjuna*	8.85
T_4 : *Albizia procera*	5.72
T_5 : *Acacia catechu*	1.86
T_6 : *Mangifera indica*	6.68
T_7 : *Manilkara achras*	1.08
S. Em.±	0.297
C.D. at 5 %	0.91
C.V. %	11.73

Fig.4.3.Variations in volume (m^3/tree) of different plant species

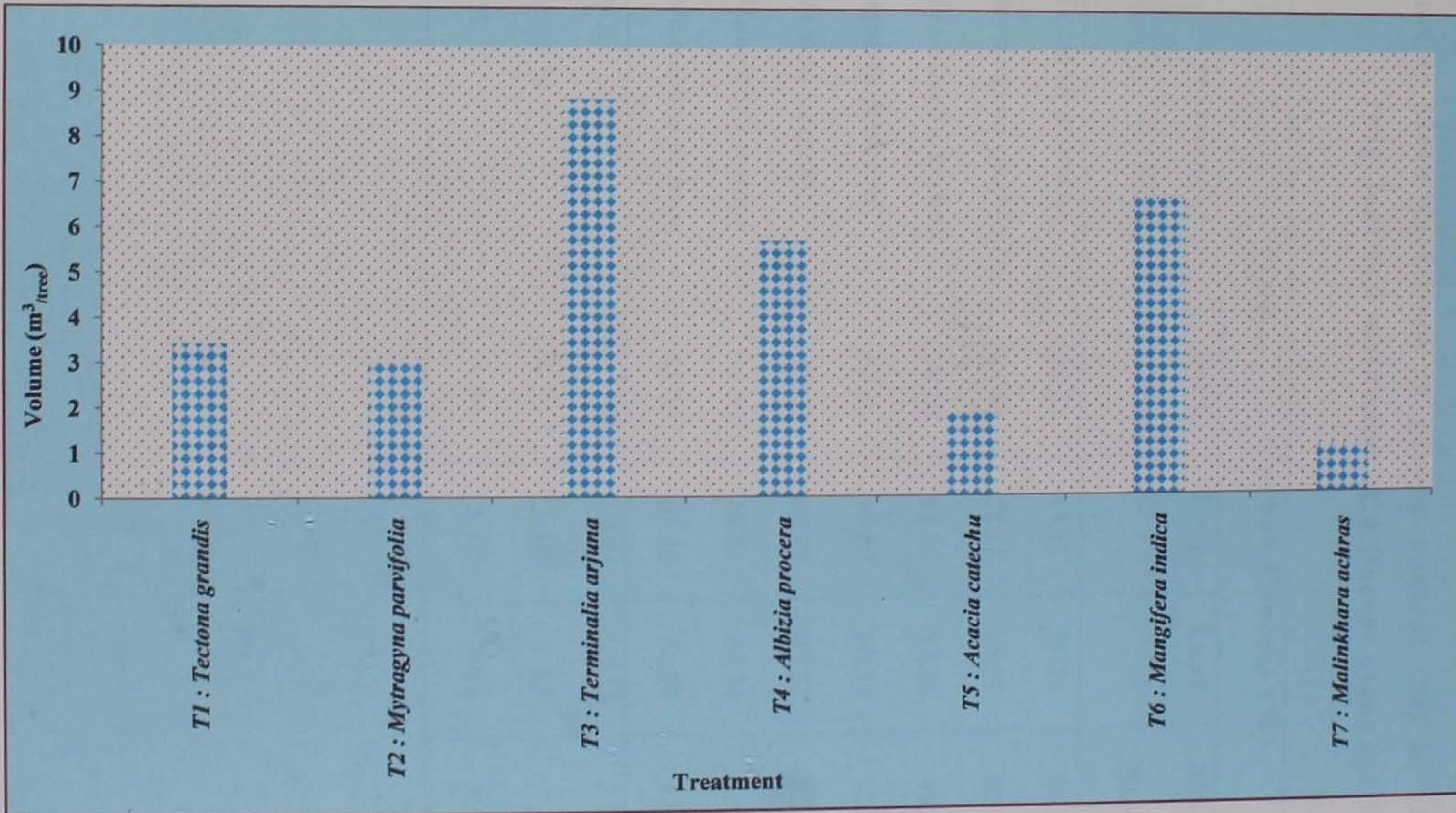
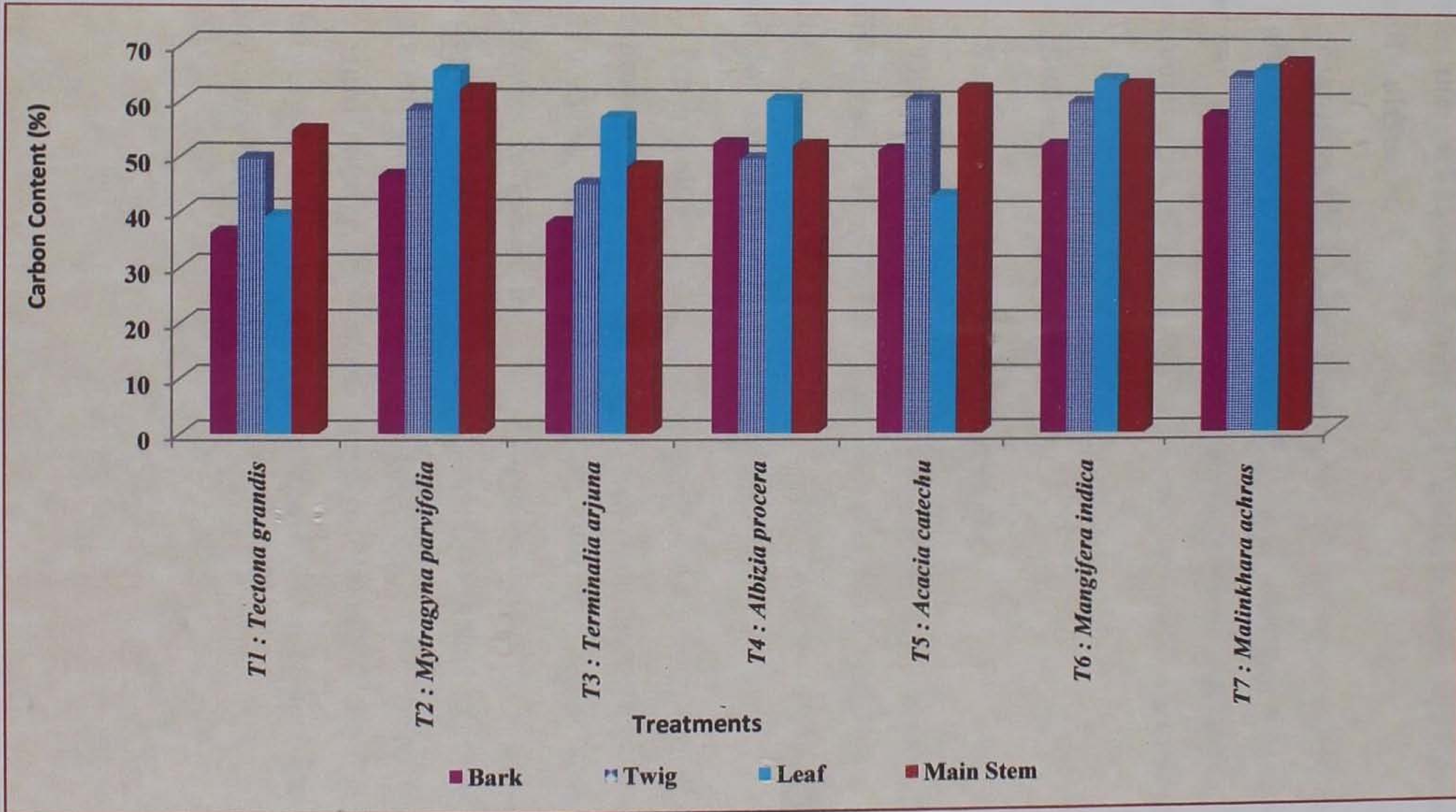


Table-4.4: Mean variations in carbon content (%) in bark, twig, leaf and main stem of different plant species

Treatment	Carbon Content (%)			
	Bark	Twig	Leaf	Main Stem
T_1 : *Tectona grandis*	36.23	49.62	39.25	54.76
T_2 : *Mytragyna parvifolia*	46.60	58.51	65.59	62.25
T_3 : *Terminalia arjuna*	38.20	45.22	57.25	48.36
T_4 : *Albizia procera*	52.62	49.89	60.59	52.36
T_5 : *Acacia catechu*	51.59	60.79	43.37	62.87
T_6 : *Mangifera indica*	52.59	60.51	64.70	63.79
T_7 : *Manilkara achras*	58.19	65.40	66.70	68.06
S. Em.$\pm$	1.398	1.104	1.338	2.281
C.D. at 5 %	4.31	3.40	4.12	7.03
C.V. %	5.04	3.43	4.08	6.70

Fig.4.4. Variations in carbon content (%) in bark, twig, leaf and main stem of different plant species



reveals that the carbon sequestration of different tree species was significantly different.

Significantly higher above ground carbon sequestration (904.83 kg/tree) was recorded in T_3: *Terminalia arjuna* which was on same bar with T_6: *Mangifera indica* (860.82 kg/tree). The carbon sequestration (148.42 kg/tree) was recorded significantly lower in T_7 : *Manilkara achras*.

4.3 Soil carbon sequestration

4.3.1 Soil organic carbon content (%)

The data on variation in soil organic carbon content among different tree species are presented in Table-4.6 and graphically depicted in Fig. 4.6. The results were found significant for soil organic carbon content.

From Table – 4.6, it can be revealed that T_4 : *Albizia procera* reported significantly higher soil organic carbon content (1.80 and 0.95 %, respectively at 0-15 and 15-30 cm depth of soil) which was followed by T_2: *Mytragyna parvifolia* (1.25, at 0-15 cm depth). While, soil organic carbon content of 15-30 cm depth is statistically at par with T_1 (0.82 %), T_2 (0.89 %) and T_6 (0.90 %). Significantly lowest soil organic carbon (0.80 and 0.71 %, respectively at 0-15 and 15-30 cm depth of soil) was found in T_5 : *Acacia catechu*.

Table-4.5 : Mean variations in carbon sequestration (kg/tree) of different plant species

Treatment	Carbon Sequestration (kg/tree)
T_1 : *Tectona grandis*	444.01
T_2 : *Mytragyna parvifolia*	349.18
T_3 : *Terminalia arjuna*	904.83
T_4 : *Albizia procera*	691.36
T_5 : *Acacia catechu*	306.19
T_6 : *Mangifera indica*	860.82
T_7 : *Manilkara achras*	148.42
S. Em.±	33.254
C.D. at 5 %	102.47
C.V. %	10.88

Fig.4.5. Variations in carbon sequestration (kg/tree) of different plant species

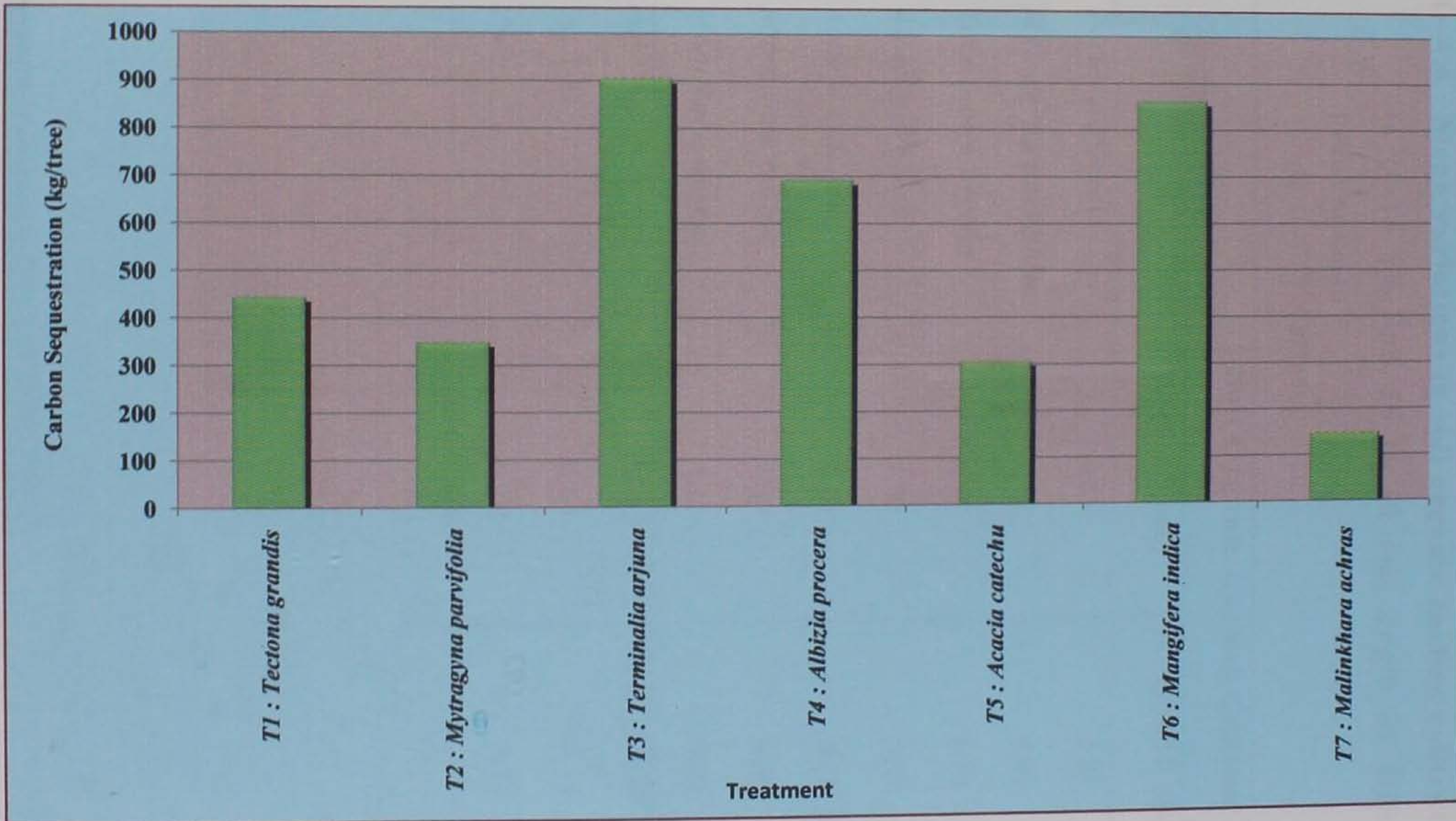
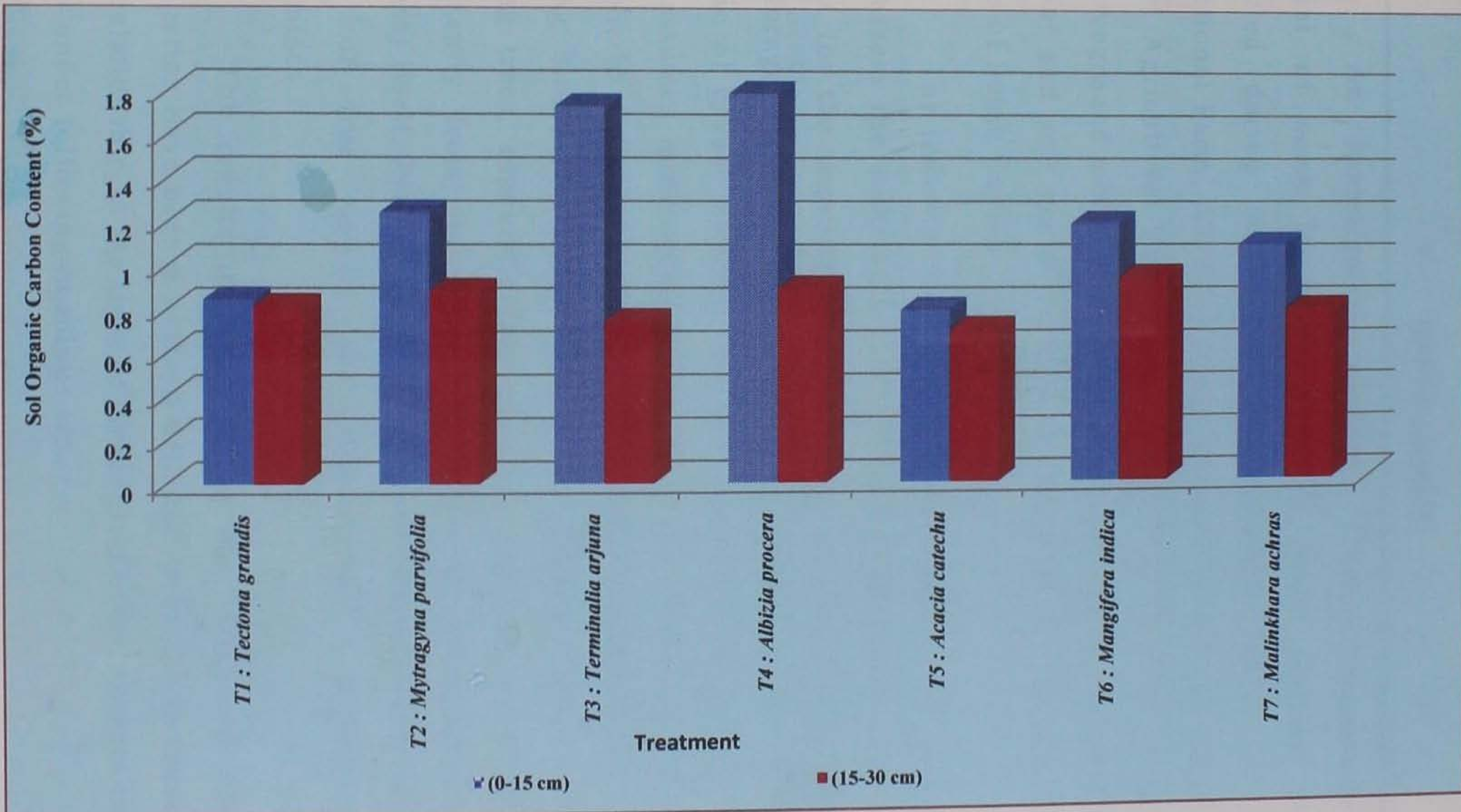


Table-4.6 : Mean variations in soil organic carbon content (%) in (0-15 cm and 15 to 30 cm) depth of different plant species

Treatment	Soil Organic Carbon Content (%)	
	(0-15 cm)	(15-30 cm)
T_1 : *Tectona grandis*	0.85	0.82
T_2 : *Mytragyna parvifolia*	1.25	0.89
T_3 : *Terminalia arjuna*	1.74	0.75
T_4 : *Albizia procera*	1.80	0.95
T_5 : *Acacia catechu*	0.80	0.71
T_6 : *Mangifera indica*	1.20	0.90
T_7 : *Manilkara achras*	1.10	0.80
S. Em.±	0.063	0.047
C.D. at 5 %	0.19	0.14
C.V. %	8.70	9.71

Fig.4.6.Variations in soil organic carbon content (%) in (0-15 cm and 15 to 30 cm) depth of different plant species



V. DISCUSSION

An investigation entitled "Carbon sequestration potential of some important trees in South Gujarat" was conducted during July- 2011 to December -2011, at the Instructional Farm, ASPEE College of Horticulture and Forestry, Navsari Agricultural University, Navsari was taken up to study the aboveground morphology and to estimate carbon sequestration potential and soil organic carbon as affected by important tree species of South Gujarat.

The information gathered from present study will help us to assess the contribution of different tree species of South Gujarat for the important ecosystem service of carbon fixation and storage (Winjum and Schroeder, 1997). 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. CO_2, since roughly 50.00 % of their standing biomass is carbon itself (Ravindranath *et al.* 1997). Planting trees, especially fast growing help to remove carbon significantly from the cycle and sequester within the wood (biomass) itself. Present study may also help in location specific choice of tree species for afforestation / reforestation programmes.

The results obtained during the course of present investigation have been discussed with aim to establish cause and effect relationship in the light of findings of other workers in this chapter under following headings *viz.*,

5.1 Above ground morphology

In the present study the variation in above ground morphological characters among different tree species differed considerably with respect to tree height, clear bole height, diameter at breast height (DBH), girth at breast height (GBH) and volume.

It is evident from the data presented in respective tables that among different trees significantly higher tree height, clear bole height and volume were recorded in T_3: *Terminalia arjuna*. While, diameter and girth at breast height was noted significantly maximum in T_6 : *Mangifera indica*.

Variation in tree morphology might be due to the genetical constituent and different growth habit of trees. Secondly, it might be due to agro-climatic condition that is suitable for the silvicultural requirements of the species. Similar variations were earlier reported by Kakkar and Nagaraja (2011), Safavi (2011) in *Populus deltoides*, Dhillon and Sidhu (2010) in *Populus deltoides*, Kumar *et al.* (2006) in *Jatropha curcas* and Mwihomeke *et al.* (2001) in *Casurina junghuhniana*.

5.2 Above ground carbon sequestration

The mean data with respect to carbon content in bark, twig, leaf and stem (%) as well as above ground carbon sequestration of different tree species are furnished in Table - 4.4

and Table – 4.5. The carbon content in bark, twig, leaf and stem were recorded in T_7 : *Manilkara achras* whereas carbon sequestration was recorded in T_3: *Terminalia arjuna*.

Wide variation of carbon content in bark, twig, leaf and stem of different tree species might be due to different genetic makeup and growth habit of different tree species. These results are in conformity with the earlier findings of Kakkar and Nagaraja (2011), Rizvi *et al.* (2011) in *Populus deltoides*, Prasad *et al.* (2010) in *Acacia pendula*.

5.3 Soil carbon sequestration

The data with respect to soil organic carbon content among different tree species are presented in Table-4.6. Significantly higher soil organic carbon content was recorded in T_4 : *Albizia procera*.

This might be due to variation in the genetic make-up of the tree species as well as different growth habit of tree species. Secondly, it may also be due to variation in decomposition rate of different species. These results are in line with earlier findings of Dinakaran *et al.* (2011), Madhusudanan *et al.* (2011), Xu *et al.* (2011), Burger *et al.* (2010), Chandran *et al.* (2009), Zhanga *et al.* (2008), Qiu *et al.* (2006) and Singh (2005).

VI. SUMMARY AND CONCLUSION

The present investigation entitled "Carbon sequestration potential of some important trees in South Gujarat" was conducted during July-2011 to December-2011, at the Instructional Farm, ASPEE College of Horticulture and Forestry, Navsari Agricultural University, Navsari.

The study involved assessment of morphology, carbon sequestration potential and soil carbon sequestration in the aboveground components of seven important tree species. They were 23 years old. The *Mytragyna parvifolia* and *Terminalia arjuna* are planted at 10.0 x 2.5 m spacing while other tree species are planted at 5.0 m x 5.0 m spacing.

The various parameters like morphological (tree height, clear bole height, DBH, GBH and volume) and above ground carbon sequestration (carbon content in bark, twig, leaf and stem) and soil organic carbon were studied during the course of investigation. Interpretations of results were made on the basis of statistical analysis. The results presented and discussed in preceding chapter are summarized under with following sub headings viz.,

6.1 Above ground morphology

6.2 Above ground carbon sequestration

6.3 Soil carbon sequestration

6.1 Above ground morphology

The morphology of various tree species differed significantly.

6.1.1 Significantly higher tree height (18.32 m) and clear bole height (9.68 m) were recorded in T_3: *Terminalia arjuna* which was followed by T_4: *Albizia procera* (15.82 m and 7.35 m, respectively). Whereas two horticultural trees remains at par with each other T_6 : *Mangifera indica* (6.05 and 2.58 m, respectively) and T_7 : *Manilkara achras* (5.75 and 2.32 m, respectively).

6.1.2 The tree species T_6: *Mangifera indica* reported significantly higher diameter (90.67 cm) and girth (284.69 cm) at breast height which was followed by T_3: *Terminalia arjuna* (53.67 cm and 168.51 cm, respectively).

6.1.3 The highest volume was noted (8.85 m^3) in T_3: *Terminalia arjuna* which was followed by T_6 : *Mangifera indica* (6.68 m^3).

6.2 Above ground carbon sequestration

6.2.1 The carbon content in bark, twig, leaf and stem (58.19 %, 65.40 %, 66.70 % and 68.06 %, respectively) were recorded in T_7 : *Manilkara achras*. The carbon content of bark (52.62 %) and twig (60.79 %) was followed by T_4: *Albizia procera* and T_5 : *Acacia catechu*, respectively. While, carbon content in leaf and main stem were remained at par with T_2 : *Mytragyna* *parvifolia* (65.59 % and 62.25 %, respectively), T_6 : *Mangifera indica* (64.70 % and 63.79 %, respectively) and T_5 : *Acacia catechu* (62.87 %).

6.2.2 Significantly higher above ground carbon sequestration (904.83 kg) was recorded in T_3: *Terminalia arjuna* which was on same bar with T_6: *Mangifera indica* (860.82 kg).

6.3 Soil carbon sequestration

6.3.1 Soil organic carbon content was reported significantly higher in T_4 : *Albizia procera* (1.80 and 0.95 %, respectively at 0-15 and 15-30 cm depth of soil) which was followed by T_2: *Mytragyna parvifolia* (1.25 %, at 0-15 cm depth). While, soil organic carbon content of 15-30 cm depth was statistically at par with T_1 (0.82 %), T_2 (0.89 %) and T_6 (0.90 %).

Conclusion:

The results of the present study will enhanced our knowledge on tree plantation on basis of above ground morphology, above ground carbon sequestration and soil organic carbon for reforestation and afforestation through the tree plantations in South Gujarat conditions and in other regions with similar ecological features.

Among the five forestry tree species *Terminalia arjuna* performed well with respect to tree height, clear bole height, volume and above ground carbon sequestration. In case of two horticulture tree species *Mangifera indica* recorded significantly higher DBH and GBH whereas carbon content in bark, twig, leaf and stem were recorded higher in *Manilkara achras*. The *Albizia procera* was found to contribute the highest soil organic carbon. Moreover, such information helps as to attain more clarity on the functional role of trees plantations in respect of diverse economic, social and ecological functions that may ultimately help to reduce atmospheric CO_2 accumulation.

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* - Original not seen

Appendix - I: Mean meteorological data during the year July - 2011 to December- 2011

Year - 2011								
Month	Temperature (^{0}C)		RH (%)		Wind Speed (km/hrs)	Sunshine (hr)	Rainfall (cm)	Evaporation (mm/day)
	Max	Min	Max	Min				
July	33.55	28.21	95.32	90.19	5.33	2.22	17.21	5.03
August	32.34	27.99	94.52	98.26	4.67	1.24	25.64	2.60
September	32.48	26.16	94.19	81.95	3.70	4.37	11.56	2.98
October	39.53	26.29	95.49	51.71	1.86	8.13	0.04	4.14
November	37.74	20.03	75.40	35.99	2.19	9.42	0.00	4.78
December	35.84	16.33	88.32	34.41	1.47	9.04	0.00	5.14

CERTIFICATE

This is to certify that I have no objection for supplying to any scientist any copy or any part of this thesis at a time through reprographic process, if necessary for rendering reference services in a library or documentation centre.

Place : Navsari

Date : 31.12.2012

(N. M. Patel)