CARBON SEQUESTRATION OF TEN YEAR OLD DIFFERENT TREE SPECIES PLANTED IN SHELTER BELT OF NORTHERN TRANSITIONAL ZONE OF KARNATAKA

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By

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CERTIFICATE

This is to certify that the thesis entitled "CARBON SEQUESTRATION OF TEN YEAR OLD DIFFERENT TREE SPECIES PLANTED IN SHELTERBELT OF NORTHERN TRANSITIONAL ZONE OF KARNATAKA" submitted by Mr. ARUNKUMAR ASHTAGI B bearing I. D. Number PGS13FOR6266 for the degree of MASTER OF SCIENCE (FORESTRY) in FOREST GENETIC RESOURCES to the University of Agricultural Sciences, Dharwad is a record of research work carried out by him during the period of his study in this University, under my guidance and supervision, and the thesis has not previously formed the basis of the award of any degree, diploma, associateship, fellowship or other similar titles.

(H. Shivanna)

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(Raju Chavan)

Affectionately dedicated to my Parents, Brothers, Sisters and Loving friends

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1. INTRODUCTION

Carbon is fundamental building block of life, carbon dioxide is essential for photosynthesis in green plants and other photo-auto tropes for producing plant products including food and it is also a prominent green house gas. It is one of strongest causal factor for global warming. The carbon dioxide concentration in atmosphere has increased from 280 ppm at the beginning of the industrial revolution to 403.93 ppm at May 2015 (www.esrl.noaa.gov/gmd/ccgg/trends) and in the present situation India ranked 3rd in carbon emission (596 m ton) from consumption and flaring of fossil fuels after the developed countries like China and USA (www.en.wikipedia.org).

A major problem being faced by human society is the global warming is believed to be rising due to human activities. The major cause thought to be fossil fuel (coal, oil, petroleum, and natural gas) burning and it is a major contributor of carbon dioxide concentration in the atmosphere. In order to reduce CO_2 concentration in atmosphere the concept of carbon sequestration comes in to picture during 1980s. Carbon sequestration is a nature balancing process of removing of the carbon from the atmosphere (Source) by storing it in the biosphere (Chavan and Rasal, 2012) i.e. green plants (Sink). Due to drastic climate change in the globe over several decades, carbon sequestration has resulted to play a prominent role in the control of green house effect, green house gases (GHG) and to reduce carbon dioxide emission to the atmosphere or to offset emissions by strong additional carbon in forest (Anon,1990).

Terrestrial carbon is stored in foliage, stem and root systems and most important is the woody tissue in the main stem of tree. The tree acts as carbon sink which absorbs the carbon from atmosphere and stored the same in the form of wood. Hardwood contains about 48% of carbon in the form of cellulose in the wood. Thus trees absorbing carbon from the air and locking it in the biomass is one of the potential ways of removing carbon from the atmosphere

Forests and Agriculture lands acts as the potential sources of carbon sequestration. Agro ecosystems absorb more carbon compare to forest ecosystems but carbon storage will be for short period. In the forest ecosystem the carbon absorption is more as well as storage will be for longer period. Carbon storage in the agriculture land can be enhanced by having different agroforestry systems viz., shelter belt, windbreak and bund plantations. This helps to reducing the carbon dioxide concentration in the atmosphere and reduces the consequces of global warming

Agroforestry systems were found to be better climate change mitigation option than the ocean and other terrestrial because of the secondary socioeconomic and also environmental benefits such as food security and secured land tenure, farm income enhancing, restoring and maintaining above ground and below ground biodiversity, maintaining watershed hydrology, soil conservation and improvement of microclimatic. By including trees in Agroforestry systems like shelterbelt, wind break and bund planting will enhance the carbon storage in agricultural land.

Northern transitional zone of Karnataka is a plain and dry region, where multipurpose trees are grown in the farm land by the farmers as bund planting, boundary planting, windbreaks and shelter belts. Shelter belt is wide belt of trees, shrubs and herbs planted in rows at prevailing wind direction. Shelter belt deflects the air current and thus by reduces the wind velocity and erosion. It provides protection to leeward areas against the wind erosion and decreases the desiccation effects on plants. Shelterbelts have a typical pyramidal shape and it is achieved by raising the tall trees in center and medium sized trees in adjacent to both sides. Multipurpose trees species planted under shelterbelt helps former directly and indirectly not only provide fodder to cattle’s, fuel wood, small timbers, wood for construction purpose. In these woods absorb carbon and it will be stored in wood biomass and reduce carbon concentration in the atmosphere. However different trees in shelter belt and bund plantation sequester the carbon in different level it various with growth rate, species, age of the tree and site condition.

In order to study the potentiality of the carbon sequestration of different tree species (*Pongamia pinnata Dalbergia sissoo, Acacia auriculiformis, Azadirachta indica* and *Tectona grandis)* the study was under taken with the following objectives.

Objectives

1. To assess the performance of different tree species for growth attributes.

2. To know the carbon sequestration of different tree species planted in the shelter belt.

3. To estimate the form factor of different tree species of Northern transitional zone of Karnataka.

2. REVIEW OF LITERATURE

The trees in agro-forestry system produce the biomass as equal to that of natural vegetation. Shelterbelt is a wide belt of trees, shrubs, etc, helps for the protection of crops against prevailing wind. A multipurpose tree in shelterbelt offers drought resistant, alternative to agricultural crops for fodder, fuel wood. A major problem being faced by human society is the global warming and is believed to be rising due to human activities. The major cause thought to be fossil fuel (coal, oil, petroleum, and natural gas) burning and it is major contributor of carbon dioxide. This Carbon dioxide is the largest contributor for global warming. As a result of increased levels of CO_2 and other green house gases, many trees are planted in the agro forestry systems which serves as productive as well as protective functions and also it stores organic carbon for long term. An effort has been made to review the existing literature relating to growth performance and potentials carbon sequestration of different multipurpose trees species planted in shelterbelt under following headings.

2.1 Performance of different tree species for growth attributes.

2.1.1 Growth performance.

Pathak and Patil (1980) reported that 12 to 15 cm diameter at breast height (dbh) at the age of four years old subabul (var. cunningham). Ponnuswamy (1982) the rate of growth of different Pine species at mid (1050-1250 m) and high altitudes (3050-3250 m) in Permulai of Kodaikanal at the age of 5 years with a spacing of 2.5 x 2.5 m. The species such as *Pinus patula, P. carriabaea, P. brutea, P. elliottii, P. pseudostrbus and P. roxburghii* exhibited a height of 6.78 m, 4.50 m, 3.60 m, and 2.60 m, 2.40 m and 2.10 m and a diameter growth of 8.50 cm, 7.10 cm, 6.40 cm, 5.50 cm, 6.60 cm, 4.50 cm and 2.70 cm respectively at higher altitudes. Akinsanni (1985) stated that volume growth in teak was varying degrees of reliability. The best growth and productivity of *Tectona grandis* was observed in the region where the number of rainy days was 55-100 per year.

Kushalappa (1993) conducted the study on the productivity assessment in *Eucalyptus tereticornis* at Jodigenahally (Bangalore District) where the average numbers of rainy days were 25 in a year. The results revealed that *Eucalyptus tereticornis* with the spacing of 2 x 2 m produced the height and dbh growth of 4.44 m and 4.23 cm respectively at the age of 5 years, 6.35 m and 5.21 cm respectively at 6 years, 7.31 m and 6.51 cm respectively at the age of 7 years and 9.76 m and 8.68 cm respectively at the age of 11 years.

Geeta *et al.,* (1994) reported that growth performance of some tree species at the age of 4 years, *Artocarpous heterophyllus*, *Delonix regia, Mangifera indica* and *Terminalia paniculata* produced the height of 2.55 m, 2.68 m, 2.60 m, 2.26 m and the girth of 22.2 cm, 24.2 cm, 26 cm and 22.2 cm respectively.

Growth performance of some multipurpose trees and shrubs were studied for 5 years at two locations in semiarid areas of Southern Ethiopia. The best performance in terms of rate of survival and growth was attained by *Acacia nilotica*, *A. cyanophylla*, *A. Senegal*, *Cassia siamia* and *Prosopis juliflora* given the ecological limitation of semiarid areas. Growth rate of these species was promosing and indicated that sustainable production system can be realized using proper agro forestry technologies in the semiarid areas of Southern Ethiopia and similar areas elsewhere (Thesfaye Abebe, 1994)

Effendi *et al.,* (1996) Seedlings of Sandal wood grown at lower altitude exhibited that better growth than those at higher altitude. Impact of altitude was studied on moist temperate forest of *Quercus semecarpifolia* in Garahwal Himalaya region and Uttar Pradesh. The data recorded from four study locations such as 2800 m altitude, 2675 m, 2600 m and 2650 m altitudes, the results showed the total basal area cover was highest (5733.48cm^2/ 100m^2) at 2800 m altitude.

Devaranavadgi *et al*., (1999) reported the performance of tree species on eroded soils at Regional Research station Bijapur (Northern dry zone Karnataka). They observed that *Leucaena leucocephala* (plant height 3.86 m; dbh 2.73 cm), *Albizia lebbek* (plant height 3.8 m, dbh 4.9 cm) and *Acacia* *auriculiformis* (plant height 3.41 m, dbh 3.65 cm) were fairly better establishing species where as other tree species like *Casuarina equisetifolia* (plant height 2.04 m, dbh 1.75 cm) and *Beutea monosperma* (plant height 1.05 m, dbh 1.78 cm) did not perform well in denuded vertisols of Northern Karnataka.

Experiment was initiated during 1990 to test the performance of 12 multipurpose tree species under shallow black soils, with typical dry land situation of semiarid track. The data on growth parameters after 8 years of planting revealed that *Leucaena leucocephala* had the highest plant height (8.15 m), dbh (7.055 cm) and crown spread North-South (2.16 m) and East-West (2.28 m), followed by *Acacia auriculiformis*, *Hardwikia binata,* and *Albizia lebbek*. The least growth among MPTS was found in case of *Pongamia pinnata* (plant height 2.96 m, dbh 3.87 cm, crown spread NS 2.69 m and EW 2.24 m). However considering the economic importance of multiple products, *L. leucocephala* and *Azadirachta indica*, could be suitable MPTS for dry land conditions (Devaranavadgi and Murthy, 1999).

Gubhane *et al.,* (1999) studied the relative performance in terms of growth at 8 years old 12 multipurpose tree species in a trial on moderately deep black soils in the semi arid region of Nagpur in Maharashtra, India. Trees were planted at various spacing's (2x2m, 3x3m, and 4x4 m) depending on the species. *Madhuca latifolia* and *Syzigium cumini* failed to survive under the rain fed and partially waterlogged conditions. *Acacia nilotica* was significantly superior in performance followed by *Leucaena leucocephala, Dalbergia sissoo* and *Albizia lebbek*. The performance of remaining species (*Eucalyptus tereticornis, Tectona grandis, Hardwikia binata, Acacia catechu, Azadirachta indica* and *Dendrocalamous strictus*) were poor.

The studies conducted on the growth performance of *Tectona grandis* in different rainfall zones viz., 1250-1500 mm (1), 1500- 2000 mm (II) and 2000- 5000 mm (III) at the age of 19 years in the Uttara Kannada District of Karnataka indicated that the species produced the dbh of 10.2 cm, 12.2 cm and 11.0 cm, mean total height of 9.5 m, 11.5 m and 7.75 m, basal area of 0.0145 m^2, 0.013 m^2 and 0.011 m^2, bole height of 2.60 m, 4.0 m, 2.25 m, total height of 9.0 m, 11.0 m and 7.0 m, bole volume of 0.085 m^3 and crown diameter of 1.78 m, 2.15 m and 2.12 m at three different rainfall zones respectively (Aparanji, 2000).

The experiment conducted on the growth performance of some tree species at the age of 9 and 12 years with the 2 m x 2 m and 4 m x 4 m spacing respectively revealed that *Leucaena leucocephala, Eucalyptus camaldulensis, Acacia albida and Acacia auriculiformis* exhibited the height of 29.3 m, 26.2 m, 21.3 m and 18.4 m and the dbh of 24.1 cm, 24.1 cm, 27.4 cm and 20.9 cm respectively at the age of 9 years. *Albizia lebbeck* (4 m x 4 m), *Azadirachta indica* (4 m x 4 m), *Acacia nilotica* (3 m x 3m) and *Tamarindus indica* (4 m x 4 m) exhibited the height growth of 12.2 m, 11.4 m, 10.5 m and 11.2 m and the dbh of 18.2 cm, 13.7 cm, 15.2 cm and 12.7 cm respectively at the age of 12 years (Giri rao *et al.,* 2000).

Naugraiya and Puri (2001) studied the growth of seven multipurpose tree species such as *Albizia procera, Azadirachta indica, Dalbergia sissoo, Eucalyptus tereticornis, Leucaena leucocephala* and *Terminalia arjuna* under silvi-pastoral and energy plantation systems in Chhattisgarh, India. They noticed the maximum height in *Leucaena leucocephala* (9.3 m) followed by *Eucalyptus tereticornis* (8.4 m). The lowest was recorded in *Terminalia arjuna* (2.7 m) and dbh were maximum in *E. tereticornis* with 12.4 and 9.8 cm respectively.

Saravanan *et al.,* (2005) studied the growth performance of *Tectona grandis* in farm lands under different agro climatic zones of Tamil Nadu. The maximum girth was observed in the upper bund at 95 % critical interval was 38.95 cm at 9 years old plantation. Hence the maximum possible growth, which could be attained at the age of 10 years, will be 50 cm, if the same growth is extrapolated up to 20 years.

Singh (2005) reported relative growth and biomass production of some multipurpose trees (MPTS) under silvi-pastoral system on a stony Rangeland of Arid zone. Growth data in respect of plant height, diameter at breast height, and collar and canopy diameter of MPTS recorded at 13 years of establishment. In this study maximum plant height was recorded in *Acacia tortilis* (3.80 m) followed by *A. senegal* (3.01 m) and minimum in *P. juliflora* (2.41 m), significantly lower than other MPTS. Wide variation in plant height due to the adaptability of these tree species to environmental condition on stony rangeland. Mean diameter at breast height was 6.71 cm with a range of 5 to 11 cm in *Acacia senegal* followed by *Acacia tortilis* (5.84 cm).

Gourav and Roy (2006) conducted a study on the growth patterns and above ground biomass production of 12 years old trees of *Acacia tortilis* in association with pasture under the Silvi-pastoral systems which showed the mean annual increment in height, diameter at breast height at the 14^{th} year to be 0.43 m, 1.10 cm respectively.

Study on management of *Cedrous deodara* under shelter wood system is aimed at drawing attention for long sustenance of management like diameter, height, bole height and crown width increased with the increase in diameter of trees, however number of individuals show decreasing trend with diameter. The variation in crop height was comparatively low (with 17.71 m minimum in PB III and maximum of 22.92 m in PB I) in different Periodic blocks. The higher crop height in PB IV in comparison to PB III was due to the presence of higher sized trees in PB IV. The maximum basal area and standing biomass was recorded in PB I. The correlation between different tree parameters of Deodar was positive and significant (Ashok Singh and Gupta, 2008).

Karki *et al*., (2009) reported that growth performance of nine year old *Diospyros ebenum.* Average height was 5.3 m. Dbh 5.41cm, clear bole height 2.06 m, crown width 1.76 m, basal area of standing tree was 7.72 m^2/ha and volume of stand after 9 year of planting was 14.5m^3/ha respectively.

Chavvan (2009) conducted experiment on growth performance of different trees of shelter belt of northern transitional zone of Karnataka. The result reveals that maximum girth at breast height (gbh) was observed in *Azadirachta indica* (29.93 cm) followed by *Acacia auriculiformis* (28.55cm) and *Dalbergia sissoo* (28.18cm). The lowest was recorded in *Casurina equisetifolia* (14.83cm). Maximum height was observed in case of *Acacia auriculiformis* (7.00 m) followed by *Dalbergia sissoo* (6.5 m) and lowest was recorded in *Pongamia pinnata* (4.16 m). Maximum tree volume was noticed in *Acacia auriculiformis* (0.03 m^3/tree) fallowed by *Azadirachta indica* (0.026 m^3/tree) and lowest in *Casuarina equisetifolia* (0.005 m^3/tree).

2.1.2 Volume accumulation in trees

Jayaraman and Rajan (1991) studied the yield of *Acacia auriculiformis* plantations in Kerala at different age in areas receiving an average annual rainfall of 3000 mm. The results revealed that the species with an average density of 2000 and 3000 trees per hectare, produced a volume of 60.92 m^3/ha and 92.36 m^3/ha respectively at the age of 4 years, 123.81 m^3/ha and 166.984 m^3/ha respectively at 6 years, 210.046 m^3/ha and 290.595 m^3/ha respectively at 8 years and 250.88 m^3/ha and 351.835 m^3/ha respectively at the age of 10 years.

The studies conducted on wood volume of fast growing indigenous species in Dehradun at different age revealed that *Shorea robusta* (30 years), *Toona ciliata* (10 years), *Trewia nudiflora* (20 years), *Melina arborea* (10 years) and *Bischofia javanica* (15 years) produced the volume of 329.7 m^3/ha, 139.2 m^3/ha, 175.1 m^3/ha 122.45 m^3/ha and 141.45 m3/ha respectively (Dwivedi, 1993).

Dwivedi (1993) studied the productivity of different tree species and observed that *Michelia champaca* produced a volume of 146 m^3/ha at the age of 8 years, *Casuarina equisetifolia* and *Toona ciliata* produced the volume of 75.3 m^3/ha and 92.6 m^3/ha at the age of 5 years respectively with *Artocarpus chaplasha* produced the volume of 163.9 m^3/ha at 10 years and *Albizia moluecana* and *Gmelina arborea* produced a volume of 137.8 m^3/ha, 209.920

m^3/ha at 6 years respectively. Another study conducted by the author revealed that *Eucalyptus grandis* and *Eucalyptus tereticornis* exhibited a standing volume of 88.55 m^3/ha and 205 m^3/ha at the age of 4 and 10 years respectively in Asarori (Dehradun).

The studies conducted on productivity of different fast growing exotic species at different age (Dwivedi, 1993) revealed that *Eucalyptus globulus* produced the standing volume of 151 m^3/ha and 1107 m^3/ha at the age of 10 and 30 years respectively and that of *Eucalyptus tereticornis* was 205 m^3/ha and 202 m^3/ha at the age of 10 and 15 years respectively at different site conditions while *Cryptomeria japonica* produced the standing volume of 339.72 m^3/ha and 601.17 m^3/ha at the age of 20 and 30 years respectively. *Ailanthus grandis* and *Lagerstroemia floxreginae* at 30 years produced the volume of 520 m^3/ha.

Buvaneswaran *et al.,* (2005) revealed that *Acacia mangium* grows at a faster rate by registering mean annual increment ranging from 12 to 13 cm in girth at breast height (gbh) and 2 to 3 m total height in red soils at locations where climate is humid. The productivity ranged from 35-45 m^3/ha/yr. particularly in the southern zone of Kerala. On the other hand in red loamy soils with sub-humid climatic conditions the productivity ranged from 20-25 m^3/ha/yr. Stem wood volume produced in homesteads amounted to 21.1 cft/tree at 8 years age (Harvest age) which is more than that of in block plantation (15.6 cft/tree).

Swamy (2010) conducted a experiment in Northern transition zone of Karnataka in different shelterbelt trees, Maximum girth at breast height (GBH) was recorded in *Azadirachta indica* (32.66 cm) and followed by *Tectona grandis* (28.86 cm) and lowest was found in *Casuarina equisetifolia* (14.83 cm) and maximum height in *Acacia auriculiformis* (7.80 m) fallowed by *Tectona grandis* (6.62 m) and lowest was in *Pongamia pinnata* (3.4 m), maximum volume was observed in *Acacia auriculiformis* (0.033 m^3) and followed by *Tectona grandis* (0.020 m^3).

2.2 Carbon sequestration of different tree species planted in shelterbelt.

2.2.1 Biomass production.

Under semiarid conditions of Jhansi, it was observed that Subabul planted in a single row along boundaries or roadside after three years reached plant height of 5.73 m and dbh of 6.55 cm and produced 3.2 t/ha of wood (Anon., 1980).

A species trial conducted by Swaminathan and Ravindran (1989) to find out suitable tree species for silvi-pastoral system in dry zone of Karnataka indicated that among the four species tried (*Albizia lebbek, Hardwikia binata, Dalbergia sissoo, and Leucaena leucocephala*), *L. leucocephala* and *Dalbergia sissoo* produced significantly higher biomass.

Eight year old *Hardwikia binata* trees spaced at 5x2 m had a standing biomass of 9.9 kg per tree (dry weight) in which the stem constituted 75% and tree recorded a height of 4.5 m (Korwar, 1994).

In an eight year old *Leucaena leucocephala* based silvi-pastoral system at Jhansi, the trees had a total biomass production of 40.89 t per tree. Variability in tree growth and production was ascribed to highly variable edaphic condition at the site (Roy *et al.,* 1997).

Roy *et al*., (1998) noticed that in eight years old silvi-pastoral systems with *Acacia tortilis, Albizia amara,* and *Hardwikia binata*, Peak biomass production from tree component was in *A. amara* (58.9 t/ha) followed by *A. tortilis* (52.1 t/ha) and *H. binata* (15.21 t/ha).

The performance in terms of above and below ground biomass production and net production in three early successional species (*Azadirachta indica, Dalbergia sissoo, and Pongamia pinnata*) and one late successional species (*Shorea robusta*), planted in 1991 at 2x2 m spacing on 4 year old coal mine spoil at Jayant in Singrauli region, Madhya Pradesh, India. After 5 years the biomass production was highest in *P. pinnata*, atleast in *S. robusta* Root production was 27 to 34 % of total biomass production (Singh and Singh, 1998).

Rai (1999) reported that in semi arid region total above ground biomass production of 48.4 kg/tree in 8 years old *Acacia tortilis* plantation spaced at 8 m x 4 m with dry biomass production of 28.2, 18.9, and 1.3 kg/tree for main stem, braches and leaves respectively.

Rai *et al.,* (2000) carried out an experiment at National Research Centre for Agro-forestry, Jhansi, Uttar Pradesh, India to identify suitable MPTS for introduction in Natural grasslands. They observed maximum total biomass production in *Dalbergia sissoo.*

Dalbergia sissoo recorded maximum biomass (214.6 t/ha) followed by *Leucaena leucocephala* (187.8 t/ha). The higher biomass was attributed to more height and dbh in these species (Giri Rao *et al*., 2000).

Naugraiya and Puri (2001) noticed highest above ground biomass in *Leucaena leucocephala* (38.0 kg per tree) followed by *Eucalyptus tereticornis* (26.1 kg/tree) and *Albizia procera* (24.8 kg per tree).

Four Populus clones were grown for two years at 1x1m spacing for study of total biomass production and carbon sequestration capacity on flood plains sites previously in forage grasses under climatic condition of lower Midwest, USA Total biomass (above and below ground) of the first year ranged from 3.9 Mg per ha in *Populus deltoides* x *P. nigra* clone (I45/51) to 1.9 Mg per ha for local source *Populus deltoides* clone (2059). Second year total biomass production was substantially higher, ranging from 13.9 Mg per ha in (I45/51) to 7.4 Mg per ha in *P. deltoides* clone 26C6R51 (Stephen *et al*., 2003).

Subedi, M (2004) conducted above ground biomass studies of *Quercus semecarpifolia* in temperate forests of Nepal. Above ground tree layer biomass was found to be 479.17, 357.53, 462.60, 358.02, 272.15 and 304.21 t/ha from east to west directions in temperate forest respectively.

Rawat and Negi (2004) revealed that *Eucalyptus tereticornis* biomass varied from 11.9 t/ha in 3 year old plantation to 146 t/ha in 9 year old plantation in moist regions. In dry tropical region it varied from 5.65 t/ha in 5 year plantation to 135.5 t/ha in 9 year old plantation. In dry tropical region biomass accumulation was more in cooler areas as compared to warmer areas. Where water is not the limiting factor comparatively higher mean annual temperature of around 25^0C seems to produce higher biomass.

Data on biomass production (kg/tree) for stem, branches, leaves and total yield revealed that maximum stem yield was in *A. tortilis* (17.30 kg/tree) followed by *A. senegal* (8.5 kg/tree) and minimum in *P. juliflora* (5.63 kg/tree). (Singh, 2005)

Gourav and Roy (2006) studied on above ground biomass production of 12 years old trees of *Acacia tortilis* in association with pasture under Silvi-pastoral system showed the mean woody biomass production and total aerial biomass production. The mean woody biomass production was 4.79 t/ha/year and the total aerial biomass production varied between 4.22 and 5.69 t/ha/year. Thus giving average production of 4.95 t/ha/year. All the four growth parameters influence the biomass production.

Representative eight year old trees of *Melia azadirach* planted in single line (2 m apart) on farm boundary were felled for estimation of aerial biomass production. The trees were grouped into three diameter classes. Maximum number of trees were recorded in the diameter range of >22 cm. The trees contributed a total biomass production of 21.1 t/ha of which 66, 24 and 10% were contributed by minor timber, firewood, and fodder respectively (Roy *et al.*, 2006)

A study of an Agri-silvicultural system comprising *Acacia lenticularis* and Turmeric (*Curcuma domestica*) local cv. Rajendra Sonia was conducted. Above and below ground biomass production and distribution of coarse and fine roots were studied in 4 year old *A. lenticularis* planted at a spacing of 2x2 m, 2x3 m, 2x4 m and 2x5 m. results showed that dry biomass of 4 year old *A.*

lenticularis tree varied tree density (1000 tree/ha) plantations showed higher total above ground biomass (12.16 to 20.30 kg/tree) compared to the higher density classes viz. 1250 (19.32 kg/tree), 1660 (15.48 kg/tree) and 2500 (12.16 kg/tree) (Chaturvedi *et al*., 2008).

The biomass and nutrient distribution in *Acacia catechu* wild. Plantations of Punjab have been studied at six sites of different ages (20, 22, 23, 24, 28, 32 years). The biomass ranged from 39.4 kg/tree to 738.98 kg/tree and from 77.29 to 223 t/ha in all these sites. The contribution of individual tree components to total biomass varied as leaf 1.41 to 4.29 %, twig 2.92 to 6.31 %, branch 10.95 to 19.98 %, bark 6.65 to 10.69 %, root 15.29 to 20.69 %, and bole 42.86 to 56.33 %. The per cent contribution of all tree components in all the sites were fall in the order of bole > root > branch > bark > twig > leaf (Laxmi Rawat *et al*., 2008).

Swamy *et al*., (2008), reported the variation in tree growth, above and below ground biomass and nutrient storage in *Gmelina arborea* planted at three densities (4x4 m, 4x6 m, and 4x8 m) under agri-silvicultural systems of Raipur. After 5 years, total biomass ranged from 6.96 to 13.75 Mg/ha. It was highest in trees planted under 4x4 m, spacing and lowest in 4x8 m spacing.

Saravanan *et al*., (2009) reported the biomass production under 4 year *Casuarina* based black gram agroforestry system. The dry matter production accounted to 8314 kg/ha of which 50% was contributed by stem, 27% by leaf and 23% by branch respectively

Chavvan (2009) reported that biomass accumulation in 4 year old different tree species planted under shelterbelt of Northern transitional zone of Karnataka results reveals that maximum biomass was observed in case of *Acacia auriculiformis* (42.62 t/ha) followed by *Azadirachta indica* (35.25 t/ha) and lowest was recorded in *Pongamia pinnata* (13.00 t/ha).

Sunilkumar (2009) reported that plantation of 10 year old *Acacia auriculiformis* is superior in girth (59.15 cm), height (21.13 m) and in volume (0.359 m^3) over the 8 year, 6 year, 4 year old respectively in girth, height and volume.

Swamy (2010) reported that standing biomass and carbon sequestration was highest in *Acacia auriculiformis* followed by *Azadirachta indica*. Maximum above ground biomass was observed in *Acacia auriculiformis* (57.65 t/ha) followed by *Tectona grandis* (55.57 t/ha) while below ground biomass was highest in *Tectona grandis* (20.25 t/ha) followed by *Acacia auriculiformis.* Above ground carbon sequestration was highest in *Acacia auriculiformis* (13.30 t/ha) followed by *Tectona grandis* and maximum below ground carbon sequestration was in *Tectona grandis* followed by *Acacia auriculiformis* in transition zone of Karnataka.

Sheikh *et al.*, (2011) Total estimated carbon stock in Indian Forest biomass varied from 3325Mt to 3161Mt during the years 2003 to 2007 respectively. The data of growing stock, biomass, forest floor and carbon stock were collected in 14 physiographic zones of India. The forests AGB in this study were estimated by multiplying the growing stock to mean density and biomass expansion factors. The below ground biomass (BGB) was evaluated by multiplying the above ground biomass (AGB) to root: shoot ratio. Total biomasses were calculated from summation of AGB and BGB. To estimate the total amount of carbon stock in Indian forests dry weight of biomass was converted into carbon by multiplying by a factor 0.45. Out of 14 Physiographic zones of India, Western Himalaya Zone has reserved maximum carbon stock in their ecosystem than remaining 13 Zones.

Hangarge *et al.*, (2012) reported that 31 tree species having 4000 individuals were recorded in 25 x 25 sq. meter in 80 quadrates at Somjaichi Rai (Sacred grove) of Pune district. Carbon sequestration in trees was estimated by non-destructive method. Above ground biomass (AGB) of species were calculated by multiplying the tree volume with wood density

(Kg/m3). While below ground biomass (BGB) was measured by multiplying the AGB to factor 0.26 (root: shoot ratio). *Terminalia bellarica* species were found to be dominant having 180 trees and sequestrated 327.78 tonnes of carbon followed by *Ficus amplissima* (221 tonnes).

2.2.2 Carbon sequestration.

Terrestrial ecosystem and change in land use system play a major role in global carbon cycle carbon sequestration is a technique that play a major role in bringing down the global warming. Brown *et al.,* (2000) reported that 120 billion tonnes of carbon was exchanged annually between vegetation, soil and the atmosphere in which forest account for 80 per cent of exchange. Since plants absorb carbon dioxide from atmosphere by the process of photosynthesis some part of the absorbed carbon dioxide stored in the form of biomass in this process of carbon assimilation, all autographs convert atmospheric carbon dioxide into biomass. So trees in general are considered as a major sinks of carbon dioxide as they retain carbon for longer duration in their biomass. Carbon sequestration is basically holding with carbon in some safe from other than gaseous form for long period of time after absorbing it from the atmosphere after converting volume of wood into biomass, the next step would be to find out the carbon content in biomass. The carbon content of the different parts of the plant has been found to vary to a certain extent. But in general 50% of the biomass is taken as carbon content for all the carbon estimation (Mac Dicken, 1997).

Indian forest phytomass carbon densities was in the range of 2.5- 4.1 Pg ‘C’ (Ravindranath *et al.,* 1997) using field inventory of growing stock, volume and biomass expansion factors relating wood volume to biomass, forest phytomass carbon pool was estimated at 1.9-4.0 Pg ‘C’ (Dadhwal and Nayak, 1993; Dadhwal and Shah, 1997) of the two commonly followed approaches the growing stock volume based approach gives more reliable carbon pool estimates as they are based on large field surveys.

Globally the carbon sequestration by harvested wood is also important. Currently the amount of carbon sequestered through wood products could neutralize about 2 per cent of the carbon dioxide emitted from fossil fuel production globally (Anon, 1998).

A carbon stock estimate was conducted in Forest of France. The results revealed that the forest area has increased from 13.82 to 14.55 m/ha. At an average rate of 59,000 ha per year between the year 1979 to 1991 and biomass carbon stock has increased from 732 to 857 m/ha (Pignard *et al.*, 2000).

Vivek dhand *et al.*, (2003) estimation of carbon content in some important forest tree species of *Pinus roxburghii* stored maximum carbon in 61.11% wood and 60.72% leaf, followed by *Pterospermum acerifolium* 56.91% wood and 41.72% leaf, *Syzygium cumini* 54.63% wood and 47.31% leaf. In *Dendrocalamus strictus* lowest amount of carbon stored in wood 52.25% and leaf 41.72% respectively.

Siva Kumar *et al.,* (2000) focused on the potentials of rubber plantations in carbon sequestration and presented some economic models, which could form the basis for the smart partnership between land owners downstream manufactures and global multinationals for the purpose of sustainable rubber cultivation. Carbon sequestration from one hectare 27 year old stand of rubber tree was 72.36 tones. The major portion was sequestered in the trunk and primary branch comprising of 21.6 and 18.9 tons respectively. The result showed that sequestration capacity among different organs, highest carbon sequestration of 88 per cent was found in the latex vessels, leaves and twigs have carbon content of 53.8 per cent other woody tissue is trunk and branches. Similarly litter content ranged from 45 to 46 per cent.

The global forests cover 3870 million ha according to global forest resource assessment 2000, and contain a total standing volume of 386 billion m^3 of wood. In terms of mass of the woody vegetation the stock is estimated at 422 billion tons dry matter in the above ground biomass including stems, branches, tops and foliage (Anon., 1998). The average standing stock is thus estimated are 10.9 kg per m^2 in terms of dry biomass and 5.45 kg per m^2 in terms of carbon (Kauppi, 2003).

In one of the studies it was found that Brazil contains 58 to 81 X 10^9 Mg of carbon in vegetation: 6 to 9 X 10^9 Mg of carbon in litter and course woody debris and about 72 X 10^9 Mg of carbon in soil. Over 80% of the vegetation pool was contained in the closed tropical moist forests of Brazil (Schroeder, 1995; and Winjum *et al.*, 1998).

Home gardens are a common small holding agro forestry system in Indonesia and throughout the tropics. The species rich tree based system produced non-wood and wood products for both use and market scale. Due to their high biomass these systems offer potential for carbon storage. A field study in Lampung, Indonesia indicates that home gardens with an average age of 13 years store 35.3 Mg 'C' per ha in their above ground biomass which is on par with carbon stocks reported for the similar and secondary forest in the same area (Roshtko *et al.*, 2002).

In the context of the global carbon cycle, agroforestry is an important land use system for two primary reasons (Pandey, 2002); One, the tree component in agroforestry systems fixes carbon from the atmosphere and stores it until they are cut or die. Secondly, it helps in reducing pressure on forest by supplementing some of the products obtained by natural forests. It is also reported in this study that, agroforestry systems can sequester carbon to a tune of 0.2 to 3.1 C t ha^{-1} yr^{-1}, and estimates indicate that agroforestry has the potential to sequester 7 Gt of carbon between 1995 and 2050 globally; however, better country-specific assessments are needed to refine this estimate. According to another study (Dixon, 1995) the carbon storage potential of agroforestry systems ranges from 12 to 228 t C ha^{-1}, with agroforestry in the humid tropics displaying the greatest carbon storage ability. Kursten and Burschel (1993) found that amount of carbon sequestered directly by the aboveground tree component of agroforestry systems ranges between 3 and 25 t C ha^{-1}. Carbon storage in agroforestry systems is highly dependent on the tree species employed, the density of planting, the age of various components and on local conditions including climate, soil type and management practices applied for example pruning or harvesting of timber.

Bhat *et al.,* (2003) Exhibited carbon dynamics for a period of 10 years (1984-1994) in tropical forest of Western Ghats of Uttara Kannada District of Karnataka. The study reveals that carbon stocking has increased in general, with an average growth of 1.008 t/ha/yr. Due to the natural regeneration process.

Haripriya (2003) assessed net carbon balance of Indian forests for the period 1993-1994.The model used in this study took into account the growing stock, additional tree organs, dead biomass, litter layer and soil organic matter, harvesting losses effects of fire, pests etc. Results depicted that, the average biomass carbon of the forest eco system for the year 1994 was 46 Mg/ha of which nearly 76 per cent was above ground biomass and rest was fine coarse root biomass. High average biomass carbon was found in temperate forests dominated by soft wood species. The average mineral soil carbon at the beginning of the year was found to be 80 Mg C ha^{-1}. High soil carbon was found in those eco-climatic provinces that have low mean annual temperature (alpine and temperate zones).

Mohit *et al.,* (2003) estimated the creation of carbon sink and sequestration achieved in community protected forest of Sambalpur forest division. The results have shown that 1.53 to 3.01 tons of carbon is being sequestered per hectare per year with only protection, which can be enhanced through proper implementation of the management prescriptions.

Pande (2003) revealed that the total carbon pool in standing crop was 363.01 million tonnes for dense and 80.30 million tonnes for open forest. The scrub land contributed 2.74 million tonnes of carbon in the pool. As far as bole biomass is concerned dense and open forests contributed 247.40 million tonnes respectively in the total bole carbon in standing crop (304.013 million tonnes).

Species level carbon sequestration of teak was done in Panama. The study revealed that Teak plantations contain 351 tones of 'C'/ha at the end of their rotation period under Panamanian conditions (Margaret *et al.,* 2003).

Singh (2003) studied potential of farm-forestry in carbon sequestration in which land holders divided in to three categories- small, medium and large holdings, the majority of land being with medium landholders. Medium farmers grow more trees on their lands as compared to other categories. Usually Eucalyptus, Poplars, Teak, Kadam are being planted. It is estimated that total biomass production is likely to be 32,800 tones/ year and the stored carbon 16,400 tones/ year. Thus farm forestry holds tremendous potential for sequestering and storing carbon.

Vivek *et al*., (2003) carried out study on estimation of carbon content in some of the important tree species to have an idea about the responses of these species to the changing climate, and result found that *Pinus roxburghii* stored maximum carbon in 60.37 per cent in leaf and 61.11 per cent in wood followed by *Pterospermum acerifolium* 41.72 per cent (leaf) and 56.91 per cent (wood), *Syzigium cumini* 47.31 per cent (leaf) and 54.63 per cent (wood) and *Tectona grandis* 50.85 per cent(leaf) and 52.25 per cent (wood).

To estimate the dry matter from the standing biomass of trees, generally the volume of the wood is multiplied by the density of the specific species of the wood. However density of all the species across the globe may not be available. In order to accumulate such issue IPCC has recommended using 50 per cent of the fresh weight of that biomass (Ajay Kumar. and Singh. 2003).

Chhabra and Dadhwal (2004) reported that growing stock volume approach at state and district levels. Phyto mass carbon stock was in the range of 3.8-4.3 Pg 'C' and mean annual net carbon flux due to land use changes during 1985-1986 was estimated as 9.0 Tg C yr^{-1}.

Jean - Michel Harmand *et al.,*(2004) reported that the amount of 'C' in aerial phytomass (biomass) in full sun coffee systems (10.5 to11 t 'C'ha $^{-1}$), the total 'C' in aerial phytomass in coffee shaded systems by *Eucalyptus deglupta* (110 shade trees ha $^{-1}$) was increased by a factor 2.5 (27.4 and 25.4 t 'C' ha $^{-1}$ respectively) after 7 years of inclusion of the shade trees. The shade trees accounted 82-92 % of 'C' in aerial phytomass. This 'C' accumulation varies for an additional mean annual increment of 2.1-2.3 t 'C/ha $^{-1}yr^{-1}$ in comparison to monoculture.

Fixation of carbon occurs through teak plantation cyclic process. This was studied in age series plantations of 1, 5, 11, 18, 24, 30 years in Tarai forest of Kumaun Himalayan region. Organic carbon concentration in different plant tissues ranged from 49.34 per cent to 56.79 per cent. Standing trees varied after correction of re-translocated amount ranged between 0.94 t/ha/yr and 5.99t/ha/yr (Kaushalendra Kumar Jha, 2005).

Udaya Morabad *et al.,* (2006) quantified the carbon sequestration in harvested wood of Kodagu District in Karnataka for a period of 13 years (1992 to 2004). He found that totally 373.88 x10 $^{9}m^{3}$ (114.9 Gg 'C') of wood was removed from the district, out of which was 58.74 Gg 'C' was fixed in the form of wood products.

Mohit *et al.,* (2006) studied on carbon sequestration potential and cost effectiveness of tree growing operations of farmlands the result show that there is a potential to sequester 821,961 tones of carbon during the period of analysis on farm lands. The annual incremental carbon sequestered per ha of 4.48 tone carbon, because of higher rotation period of 30 to 40 years kept for species like *Tectona grandis*. Agro-forestry options seem to be attractive due to high productivity of the tree plantations of farm lands.

Lasco and Cardinoza (2006) study was conducted to quantify baseline C stocks and sequestration benefits of project components (reforestation with fast-growing species, primarily *Casuarina equisitefolia*, and agro-forestry involving integration of *Paraserianthes falcataria*). Field measurements showed that mature stands (≥30 years) of *P. falcataria* and *C. equisitefolia* contain up to 200 Mg C ha^{-1} in above ground biomass, indicating the vast potential sites to sequester carbon. Baseline C stocks in above ground biomass were very low in both Laclubar (6.2 Mg C ha^{-1} for reforestation sites and 5.2 Mg C ha^{-1} for agro forestry sites and Remexio (3.0 Mg C ha^{-1} for reforestation and 2.5 Mg C ha^{-1} for agro forestry). For the next 25 years, it is projected that 137 671 Mg C and 84 621 Mg C will be sequestered under high- and low C stock scenarios, respectively.

Significant difference was recorded in *Pongamia pinnata* seedlings at different growth intervals of 8, 16, 24^{th} months observations. With respect to height, gbh, crown diameter during 16 and 24 month the mean crown height, girth and crown diameter was recorded as 3.1, 0.19, 1.5 m and 2.89, 0.24, 1.98m respectively and growth parameters like biomass yield, carbon sequestered during 8^{th} 16th and 24^{th} months were 4.23, 2.11, 8.06 and 4.03, 12.40, 6.20 tonnes of 'C'/ha respectively (Shivanna *et al.,* 2006).

Roy *et al.,* (2006) reported that eight year old trees of *Melia azadirach* planted in single line (2m apart) at Indian Grass land and Fodder Research Institute (IGFRI), Jhansi. The trees contributed a total biomass production of 21.11 t/ha of which 66, 24 and 10 per cent were contributed by minor timber, firewood and fodder respectively.

Verma *et al.,* (2006) conducted a study in nine year old energy plantation consisting of *Eucalyptus tereticornis, Melia azadirach* and *Leucaena leucocephala at four planting densities viz.* 5000, 10000, 15000 and 20000 plants/ha. Above ground biomass computed on mean tree and per ha basis differed significantly with the species and density. The contribution of leaf, branch and stem to mean tree biomass irrespective of the species and plant densities varied from 4.11 to 5.21, 16.19 to 25.84 and 69.89 to 79.72 respectively.

Deva Kumar *et al.,* (2006) conducted a study on the comparative assessment of biomass production in three different landscapes. Biomass production was highest in coffee plantations (468 t/ha) and least in the natural forests (94.5 t/ha).

Ramachandran *et al.,* (2007) revealed that the total above and below ground biomass carbon stock in Kolli hills in different forest types of Tamil Nadu. The results reveals that forest types accounts to 2.74 Tg of carbon of which, the semi evergreen forest contributes 22%, Deciduous forest contributes to the maximum of 57 % and the other forest types contribute the rest .The vegetation biomass carbon density is 0.60 Tg ha^{-1} in deciduous forest, 0.35 Tg ha^{-1} in thorn forests and 0.01 Tg ha^{-1} in euphorbia forests.

Shivanna *et al.,* (2007) conducted experiment on potential of *Dalbergia sissoo* in carbon sequestration result revealed that the biomass yield and carbon sequestration during 8^{th},16^{th} and 24^{th} months were 8.10 and 4.05, 14.75 and 7.37, and 24.44 and 12.22 tones/ ha, respectively.

Sanjeev *et al*., (2009) revealed that the total above and below ground biomass and carbon stock in different parts of agroforestry tree species. He was reported the biomass and carbon stocking in different of the tree species (root, stem and leaf). Above ground biomass and carbon stocking is more compare to low in below ground biomass and carbon stocking.

Chavvan (2009) reported that carbon sequestration of 4 year old different tree species of shelterbelt in Northern transition zone of Karnataka, Maximum carbon sequestration was observed in *Azadirachta indica* (22.84 ton/ha) fallowed by *Dalbergia sissoo* (21.78 ton/ha) and lowest was observed in *Casuarina equisetifolia* (5.25 ton/ha).

Yadava, A. K (2010) conducted experiment on biomass production and carbon sequestration in different Agroforestry system. Carbon sequestration to evaluate biomass yield and carbon sequestration capacity of different Agroforestry system. He was reported that above ground biomass and carbon stocking is more compare to low in below ground biomass and carbon stocking

Swamy (2010) conducted a study on carbon sequestration on 5 year old different tree species of shelterbelt in Northern transition zone of Karnataka, he reported that highest carbon sequestration was recorded in *Acacia auriculiformis* (22.55 ton/ha) fallowed by *Azadirachta indica* (21.25 ton/ha) and lowest was observed in *Pongamia pinnata* (4.00 ton/ha).

Reddy *et al*., (2014) conducted a experiment on three agro climatic zones of Karnataka in each zone three age gradation of teak plantations were selected for the study viz 10,15 and 20 year old) Total amount of carbon sequestered per hectare differed significantly due to agro climatic zones and age gradations. It was significantly higher in Northern transition zone (247.47 t/ha) than in Northern dry zone (103.73 t/ha) and Hilly zone (157.60 t/ha). The total amount of carbon sequestered was higher in Northern transition zone to an extent of 138.5 and 57.1 per cent over Northern dry zone and Hilly zone respectively. Subsequently total amount of carbon sequestered was significantly higher in 20-year plantations (330.00 t/ha) than in 15 year (108.53 t/ha) and 10 year plantations (70.27 t/ha). The extent of increase of total tree volume in 20-year plantation was 204.1 and 369.6 per cent over 15 year and 10 year respectively. There was a significant effect shown by The higher amount of carbon sequestrated in Northern transition zone can be attributed to higher total biomass in Northern transition zone (517.22 t/ha) than in Northern dry zone (207.89 t/ha) and Hilly zone (320.67 t/ha) which in turn was due to favorable soil and climatic conditions.

Yashmita Ulman and Avudainayagam (2014) the carbon storage potential of *Eucalyptus tereticornis* plantation of one to four year old was estimated the concentration in different parts of the tree of all aged plantation was found in decreasing order :stem>root>branches>leaf. Total biomass production was maximum in 4 year old plantation (94.76 t/ha) lowest was observed in one year old (14.56 t/ha) plantation. Carbon content percent found to be 38.10 t/ha (one year old plantation) and 115.86 t/ha (four year old plantation).

2.3 Form factor of different tree species of Northern transitional zone of Karnataka

2.3.1 Form factor

Murthy (2003) reported that form factor of *Acacia auriculiformis* ranges from 0.620 and 0.642 among the sites and 0.580 and 0.694 among different age group. There was an inverse relationship between age of the plantation and the form factor. Taper was more in older plantation. As age of the plantation advanced, the height of the plantation increased, thus the form factor decreased. The form factor between 0.68 (coastal zone) and 0.701 (eastern plain) at 4 years, 0.623 (coastal zone) and 0.690 (eastern plain) at six year, 0.560 (eastern plain) and 0.634 (up ghat) at eight year and 0.553 (eastern plain) and 0.590 (up ghat) respectively.

Bonyad, A (2007) reported that form factor of *slash pine*. The results indicate that moderate thinning is significantly improved the farm factor of planted *Slash pine* stands, the production maximum volume and stand quality. The farm factor of *Slash pine* was 0.5 respectively.

Chavvan (2009) reported that form factor of five year old five different tree species it ranges from 0.52 to 0.65 *Dalbergia sissoo* showed 0.54, *Azadirachta indica* 0.65, *Acacia auriculiformis* 0.56, *Pongamia pinnata* 0.56 and *Casuriana equisetifolia* 0.52.

Sunilkumar (2009) reported that there was an inverse relationship between age of the plantation and form factor, Taper was found to more in older plantation when compare to younger plantations. Age of the plantation advanced, the height of the plantation increased thus form factor decreased. The form factor ranges from 0.681 to 0.701(plain zone) at 4 year old plantation. Ghat zone 0.623 to .0690 (plain zone) at 6 years 0.593 (coastal zone) to 0.617 (Ghat zone) at 8 years, 0.533 (plain zone) to 0.636 (ghat zone) at 10 year old *Acacia auriculiformis* plantation.

Swamy (2010) reported form factor ranges from 0.30 to 0.69 among different tree species of 6 year old planted under shelterbelt of Northern transitional zone of Karnataka. Highest form factor was recorded in *Pongamia pinnata* (0.30) followed by *Dalbergia sissoo* (0.44) and least taper were in *Azadirachta indica* (0.69).

3. MATERIAL AND METHODS

The present study entitled "Carbon sequestration of ten year old different tree species planted in shelter belt of Northern transitional zone of Karnataka" was carried out during 2014-2015 at Agricultural College, Hanumanamatti. It comes under Northern transitional zone of Karnataka. The details of the methodology adapted were presented here under.

3.1 Study area

Shelter belt area was selected at AC Hanumanamatti ($14^{0.}$ 40^{1} $.7^{0}.78^{11}$ N Latitude, 75^{0} $.36^{1}$ $.62^{0}.21^{11}$E Longitude) Ranebennur taluk of Haveri District, which falls under the Northern Transition Zone- 8 of Karnataka. The shelterbelt area is located in plain with red sandy loam type of soil.

3.2 Layout of Shelter belt

The shelter belt was oriented in North – South direction. It has five different tree species in three rows, which are planted at spacing of 2×2 meter. Slow growing tree species was planted on either side of the middle row like *Dalbergia sissoo, Azadirachta indica and Pongamia pinnata* and relatively fast growing trees species were planted in middle row trees species like *Acacia auriculiformis* and *Tectona grandis.*

3.3 Climatic (Table 1)

The data on weather parameter such as rainfall (mm), maximum and minimum temperature (^{0}C) and relative humidity was recorded at meteorological observatory at Agricultural Research station, Hanumanamatti of Rannebenur taluk during the 2014-2015. The highest rainfall was received in the month of August (246.75 mm) and July, May and October months received rainfall of 189.0 mm, 149.50 mm and 97.5 mm respectively. The highest minimum temperature was recorded in the month of August of about 21.23 ^{0}C and maximum temperature was recorded during the month of April (39.89 ^{0}C) followed by May 38.50 ^{0}C. Lowest minimum relative humidity was recorded in the month of February and March (7.70%) and maximum was recorded in the month of October (100.00 %). (Table 1).

Table 1. Meteorological data of experimental site during study period of January 2014- February 2015

Months	Temp Max. (^0C)	Temp Min. (^0C)	RH Max (%)	RH Min (%)	Rainfall (mm)
January	33.39	13.73	93.80	12.90	00.0
February	34.78	15.62	92.20	7.70	3.00
March	39.12	15.62	90.30	7.70	0.75
April	39.89	20.78	92.20	8.50	17.25
May	38.50	15.62	99.50	19.00	149.50
June	33.62	20.39	97.70	40.00	74.00
July	33.12	20.89	99.40	34.70	189.00
August	28.73	21.23	99.20	63.90	246.75
September	34.28	19.89	99.50	48.40	72.75
October	34.73	16.78	100.0	40.00	97.50
November	32.89	5.00	99.90	21.70	41.75
December	32.84	10.89	99.30	21.30	9.75
January	34.50	14.74	94.80	14.80	0.00
February	35.80	16.74	12.50	7.80	2.00
				Total	904.00

Source: Agricultural Research Station (ARS), Hanumanamatti

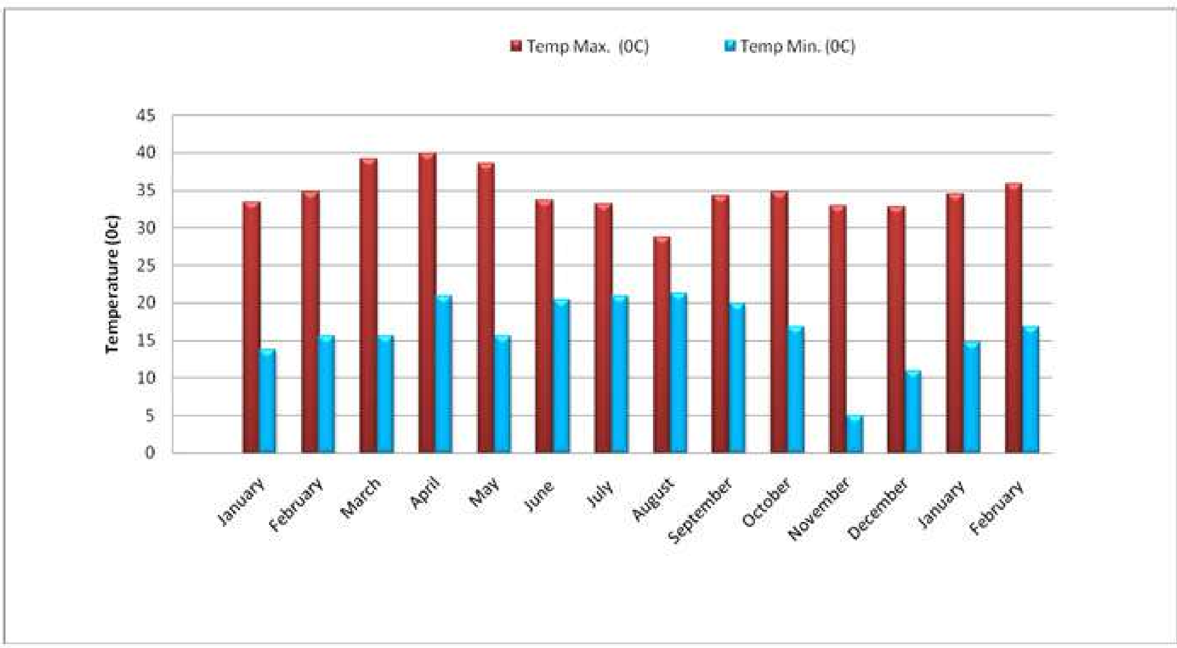

Figure 1. Monthly mean maximum and minimum temperature (°C) at Agriculture Research Station, Hanumanamatti

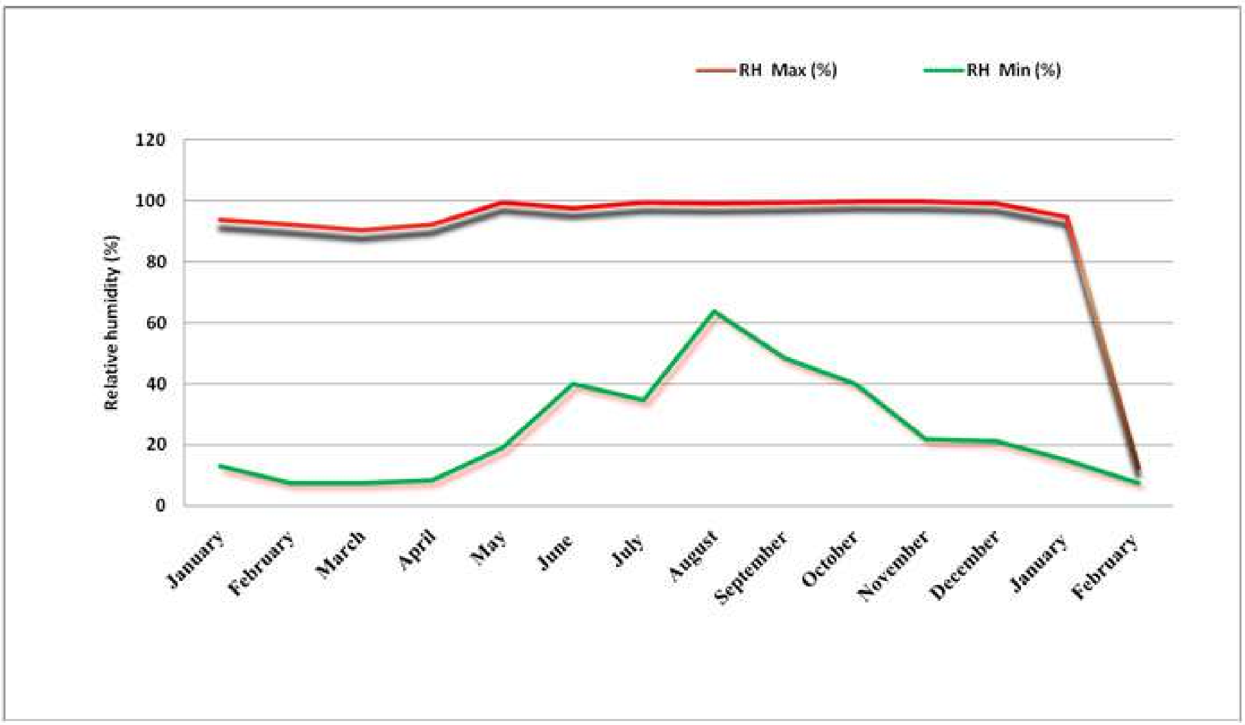

Figure 2. Monthly mean maximum and minimum Relative Humidity (%) at Agriculture Research Station, Hanumanamatti

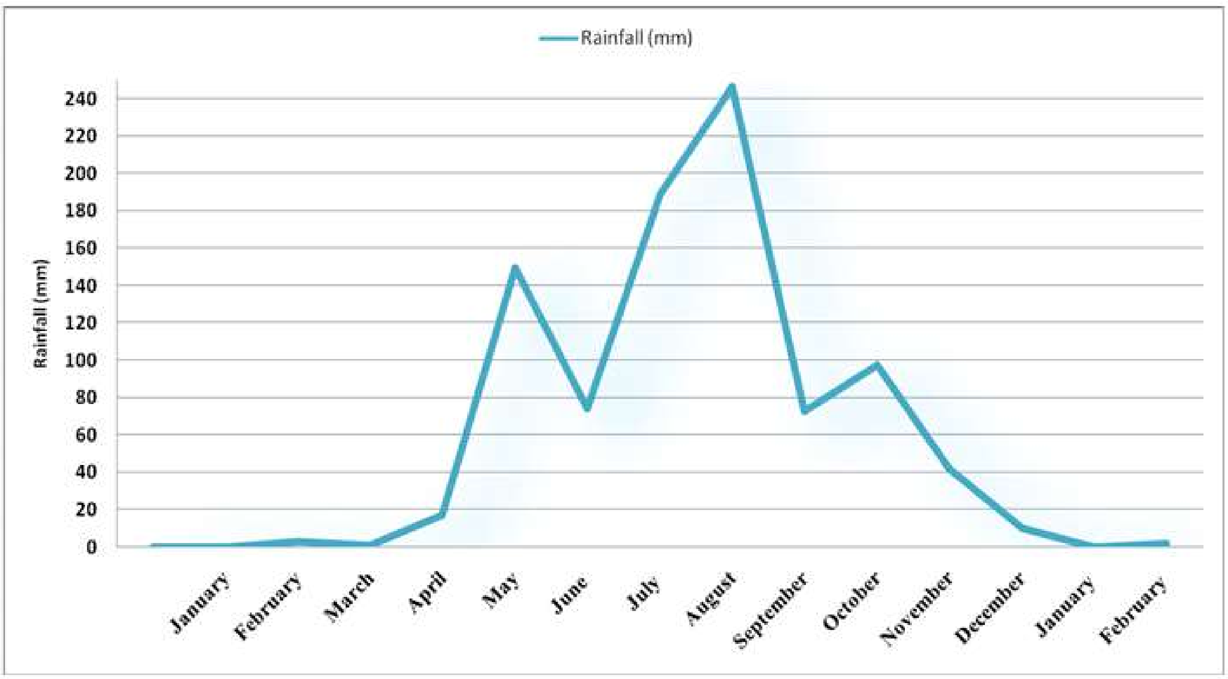

Figure 3. Monthly Rainfall (mm) at Agriculture Research Station, Hanumanamatti

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3.4 Experimental Details

Ten year old existing (120 months after planting) five different trees of shelter belt was selected for study at Agricultural College, Hanumanamatti of Ranebennur Talluk and Haveri district of Karnataka.

Species studied

1. *Azadirachta indica*
2. *Tectona grandis*
3. *Pongamia pinnata*
4. *Dalbergia sissoo*
5. *Acacia auriculiformis*

Here each tree species was considered as a treatment there were five replications in each treatment and five trees were taken for observations in each replications.

Collection of Data

Observations on growth parameters *viz*., height and girth at breast height (gbh) were recorded at three months interval and using standard formulae's volume, biomass, wood density and carbon sequestration is calculated as per procedure followed described as follows.

3.5 To assess the performance of different tree species for growth attributes

3.5.1 Girth at breast height (GBH)

Girth at breast height was recorded with the help of tape at 1.37 m above the ground and expressed in centi-meters (cm).

Plate 1 Over view of windward side of shelterbelt

Plate 2 Over view of lee ward side of shelterbelt

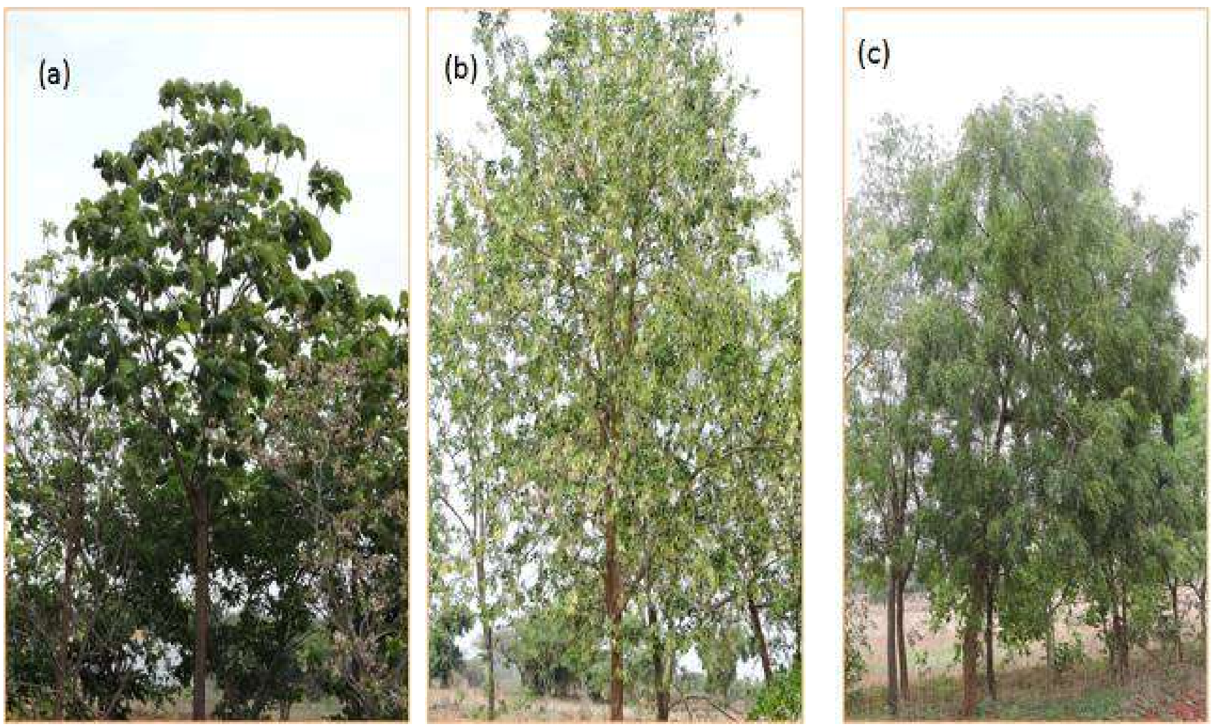

Plate 3a. Tree species selected for experiment (a) Tectona grandis (b) Dalbergia sissoo (c) Azadirachta indica

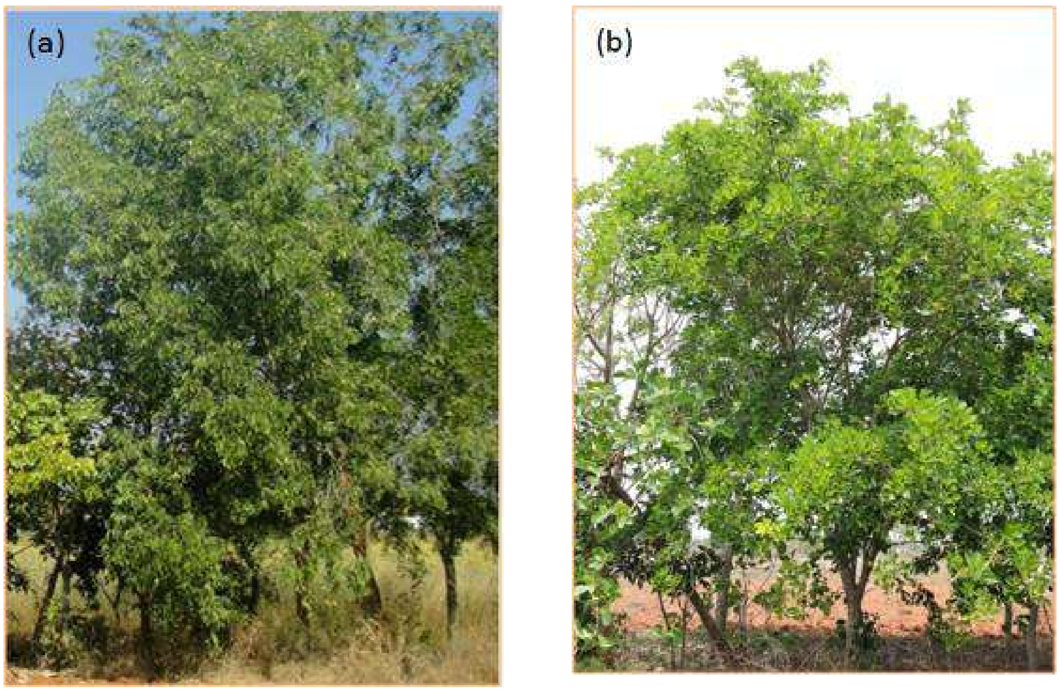

Plate 3b. Tree species selected for the experiment

(a) Acacia auriculiformis (b) Pongamia pinnata

3.5.2 Total height (m)

The total height from base to its tip of the main stem by using Ravi altimeter and expressed in meters (m).

3.5.3 Basal area (m^2/tree)

The basal area was determined by the formula (Chaturvedi and Khanna, 1984).

$$\text{Basal area} = g^2/4\pi \text{ or } \pi d^2/4$$

3.5.4 Total volume (m^3/tree)

Total tree volume was determined by using following formula (Chaturvedi and Khanna, 1984).

Volume = Total height x Basal area x Form factor.

3.5.5 Increment

Increment was calculated for every three month intervals. Increment of girth at breast height (GBH), height and volume are expressed as first interval (Feb-May 2014), Second interval (May-Aug 2014), Third interval (Aug-Nov2014) and Fourth interval (Nov-Feb 2015).

3.6 To know the carbon sequestration of different tree species planted in the shelter belt

3.6 1 Biomass

Biomass both above and below ground biomass was determined separately by using standard formulae's and expressed in tones per hectare.

3.6.1.1 Above ground biomass (AGB)

Above ground biomass was determined by using formula as suggested by Mac Dicken (1997).

Above ground biomass (ton/ha) = Volume of tree x Density of wood

Wood density:

$$\text{Wood density (g/cc)} = \frac{\text{Mass of wood sample}}{\text{Volume of that wood sample}}$$

3.6.1.2 Below ground biomass (BGB)

Below ground biomass includes all biomass of live roots excluding fine roots having <2 mm diameter. The below ground biomass has been calculated by multiplying the above ground biomass (AGB) by 0.26 factor as the root: shoot ratio (Ravindranath *et al.,* 2008).

Below ground biomass (BGB) = Above ground biomass × 0.26

3.6.2 Carbon sequestration (t/ha)

Total biomass (AGB+BGB) of standing trees was estimated to work out the amount of carbon sequestration by reducing the total biomass yield to its 50% (Khajuria and Chauhan, 2003) or converting biomass by multiplying 0.5 (Mac Dicken., 1997) carbon stock is expressed in ton/ha.

Carbon sequestration= Total Biomass (AGB+BGB) × 0.5

3.7 To estimate the form factor of different tree species of Northern transitional zone of Karnataka

3.7.1 Form factor

The form factor is the ratio of volume of a tree or its part to the volume of a cylinder having the same length and cross sectional area. Form is the rate of taper of a log or stem. While taper is the decrease in the diameter of a stem of a tree or of a log from base upwards. The taper varies not only with species, age, site and crop density, but also in different parts of same tree.

For form factor the girth of a stem at regular interval of 1 m from base upwards was measured with the help of tape and ladder was used for climbing the tree. Volume of each unit (1m) was separately calculated and volume of tree was calculated by adding volume of all section of the stem.

The volume of the cylinder with girth equal to gbh and length equal to tree height is calculated. The form factor was calculated by using the formula as suggested by Chaturvedi and Khanna (1984).

$$\text{Form factor} = \frac{\text{Actual volume of the tree}}{\text{Volume of the cylinder}}$$

The mean of Form factor of four trees for each of the different species was taken for standardization of Form factor.

Actual volume of the tree = $(G/4)^2 \times L$ (quarter girth volume)

Volume of the cylinder = $g^2/4 \pi \times L$

3.8 Statistical analysis

After tabulation of all the parameters, data table was prepared. The data was analyzed using the RBD (Randomized block design) design.

4. EXPERIMENTAL RESULTS

Results of the experiments conducted on carbon sequestration of ten year old different trees species planted in shelterbelt of Northern transitional zone of Karnataka are presented under following subheadings.

4.1 To assess the performance of different tree species for growth attributes.

4.1.1 Girth at breast height (GBH)

Girth at breast height was measured at three month intervals and it shows significant difference at initial, 3, 6, 9 and 12 months after initial reading and data is presented in table 2 and figure 4.

4.1.1.1 Initial reading (120 months after planting)

There was a significant difference in gbh among the tree species planted under the shelterbelt. *Acacia auriculiformis* shows the maximum gbh (39.13 cm) followed by *Azadirachta indica* (39.05 cm) and *Dalbergia sissoo* (34.01 cm). While lowest was recorded in *Pongamia pinnata* (26.50 cm) (Table 2, Fig 4).

4.1.1.2 Three months after initial reading (123 months after planting)

Tree species showed significant difference among them with respect to gbh. The maximum gbh was recorded in *A. auriculiformis* (40.78 cm) followed by *A. indica* (40.30 cm) *D. sissoo* (34.65 cm) and lowest was recorded in *P. pinnata* (27.41 cm) (Table 2, Fig 4).

4.1.1.3 Six months after initial reading (126 months after planting)

There was a significant difference at 126 months after planting among tree species planted under shelter belt. Maximum gbh was recorded in case of *Azadirachta indica* (42.51 cm) followed by *A. auriculiformis* (42.40 cm) and *T. grandis* (37.12 cm). While lowest was recorded in case of *P. pinnata* (30.46 cm) (Table 2, Fig 4).

Table 2. Girth at breast height (cm) of different tree species planted under shelterbelt

Girth at breast height (cm)					
Species	Initial (120 MAP)	3 MAIR (123 MAP)	6 MAIR (126 MAP)	9 MAIR (129 MAP)	12 MAIR (132 MAP)
Acacia auriculiformis	39.13	40.78	42.40	43.73	45.12
Azadirachta indica	39.05	40.30	42.51	44.06	45.21
Tectona grandis	32.44	33.52	37.12	39.24	41.52
Dalbergia sissoo	34.01	34.65	36.97	39.2	40.12
Pongamia pinnata	26.5	27.41	30.46	32.44	33.72
S.Em.±	2.58	2.60	2.45	2.54	2.27
C. D.(0.05)	5.47	5.52	5.20	5.39	4.81
C V	11.91	11.64	10.25	10.12	8.73

(MAIR-months after initial reading, MAP- months after planting)

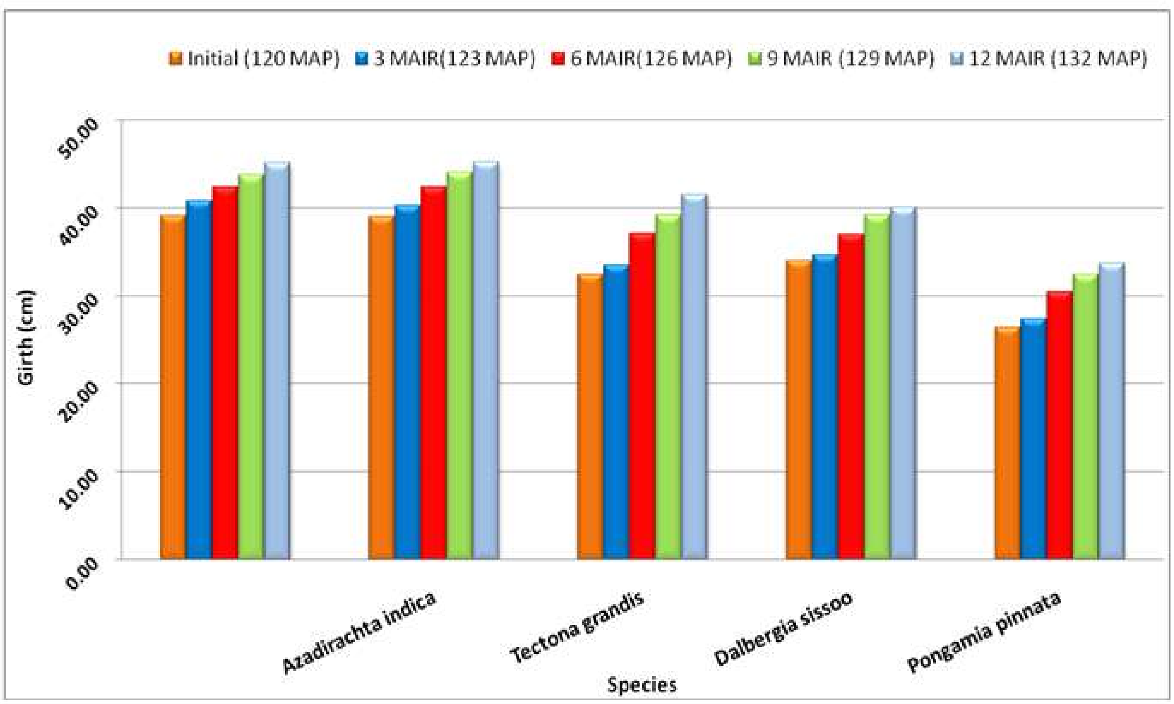

Figure 4 .Girth (cm) of different tree species planted under shelterbelt

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4.1.1.4 Nine months after initial reading (129 months after planting)

At this stage of growth significant difference was recorded with respect to gbh at 129 months after planting. Among these species maximum gbh was recorded in case of *A. indica* (44.06 cm) followed by *A. auriculiformis* (43.73 cm) and *T. grandis* (39.24 cm) and lowest was recorded in *P. pinnata* (32.44 cm) (Table 2, Fig 4).

4.1.1.5 Twelve months after initial reading (132 months after planting)

Gbh showed significant differences across tree species planted under shelter belt at 132 months after planting. Maximum gbh was recorded by *A. indica* (45.21 cm) followed by *A. auriculiformis* (45.12 cm) and *T. grandis* (41.52 cm). The least was recorded in *P. pinnata* (33.72 cm).

4.1.2 Increment in Girth at breast height (GBH)

4.1.2.1 First interval (Feb - May 2014)

The significant difference was observed among different tree species planted under shelter belt with respect to increment in girth. Maximum increment was recorded in *A. indica* (1.44 cm) followed by *A. auriculiformis* (1.38 cm) and *T. grandis* (1.36 cm). Least was recorded in case of *D. sissoo* (0.77cm) (Table 3, Fig 5)

4.1.2.2 Second interval (May - Aug 2014)

There was a significant difference among the tree species with respect to increment in girth. Maximum increment was found in case of *T. grandis* (3.32 cm) followed by *P. pinnata* (2.95 cm) and *D. sissoo* (2.24 cm). *A. auriculiformis* had showed least (1.91 cm) (Table 3, Fig 5).

4.1.2.3 Third interval (Aug - Nov 2014)

Different tree species differed significantly among them with respect to increment in gbh at third interval (Aug 2014-Nov 2014).The maximum increment in girth was recorded in *D. sissoo* (2.23 cm) followed by *T. grandis*

Table 3. Increment in GBH (cm) of different tree species planted under shelterbelt

Increment in girth at breast height (cm)				
Species	First interval (Feb-May2014)	Second interval (May-Aug 2014)	Third interval (Aug - Nov2014)	Fourth interval (Nov -Feb 2015)
Acacia auriculiformis	1.38	1.91	1.33	1.50
Azadirachta indica	1.44	1.96	1.66	1.26
Tectona grandis	1.36	3.32	2.12	1.37
Dalbergia sissoo	0.77	2.27	2.23	1.19
Pongamia pinnata	1.03	2.95	1.98	1.39
S.Em.±	0.17	0.31	0.24	0.18
C.D.(0.05)	0.35	0.65	0.50	N.S.
C.V.	22.49	19.49	20.10	21.57

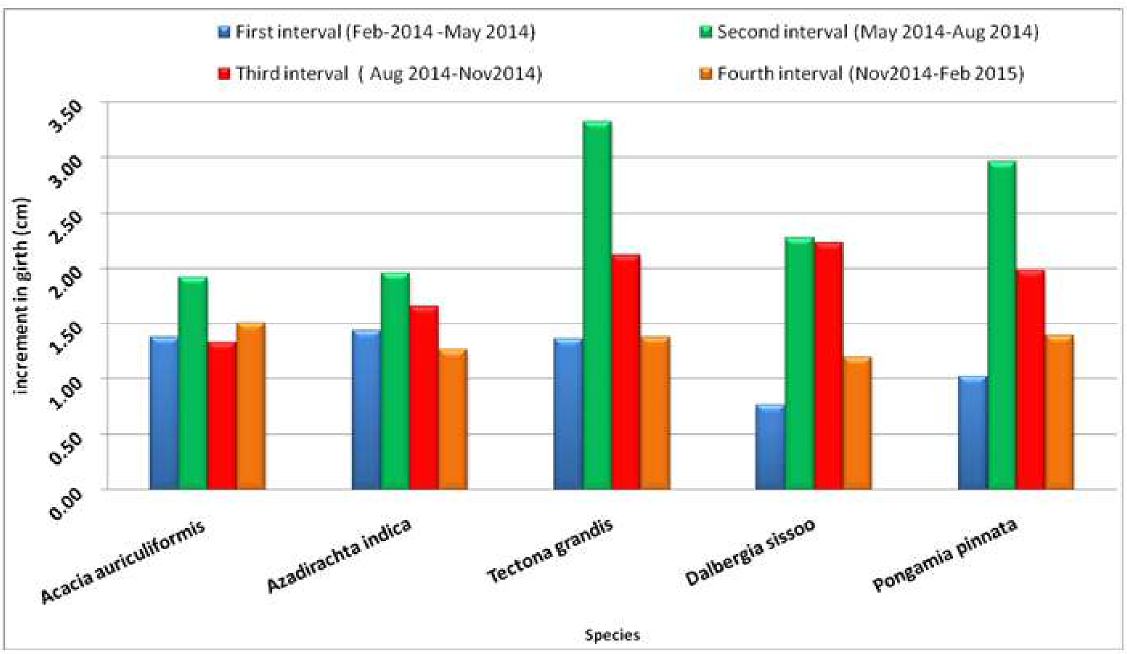

Figure 5. Increment in girth (cm) of different tree species planted under shelterbelt

(2.12 cm) and *P. pinnata* (1.98 cm). While lowest was recorded in *A. auriculiformis* (1.33 cm) (Table 3, Fig 5)

4.1.2.4 Fourth interval (Nov - Feb 2015)

Non significant difference was observed among the different tree species with respect to increment in girth at fourth interval (Nov 2014-Feb 2015). *A. auriculiformis* was recorded the maximum increment in girth (1.50 cm) followed by *P. pinnata* (1.39 cm) and *T. grandis* (1.37 cm). The least was noticed in case of *D. sissoo* (1.19 cm) (Table2, Fig 5).

4.1.3 Height (m)

4.1.3.1 Initial reading (120 month after planting)

Height showed significant difference among the different tree species planted under shelterbelt. Maximum tree height was recorded in case of *A. auriculiformis* (7.06 m) followed by *D. sissoo* (6.21 m) and *T. grandis* (5.47 m) (Table 4, Fig 6). The lowest was recorded in *P. pinnata* (3.9 m).

4.1.3.2 Three months after initial reading (123 months after planting)

There was a significant difference among the different tree species planted under shelterbelt with respect to height at three months after initial reading (123 months after initial reading) *A. auriculiformis* recorded maximum height of 7.13 m followed by *D. sissoo* (6.38 m) and *T. grandis* (5.65 m) least was noticed in *P. pinnata* (4.04 m) (Table 4, Fig 6).

4.1.3.3 Six months after initial reading (126 months after planting)

Height showed significant difference among the five tree species. Maximum height growth was recorded in case of *A. auriculiformis* (7.40 m) followed by *D. sissoo* (6.62 m) and *T. grandis* (5.99 m). The least height growth was recorded in *P. pinnata* (4.29 m) (Table 4, Fig 6).

Table 4. Height (m) of different tree species planted under shelterbelt

Height (m)					
Species	Initial (120 MAP)	3 MAIR (123 MAP)	6 MAIR (126 MAP)	9 MAIR (129 MAP)	12 MAIR (132 MAP)
Acacia auriculiformis	7.06	7.13	7.40	7.52	7.60
Azadirachta indica	5.35	5.56	5.71	5.87	5.92
Tectona grandis	5.47	5.65	5.99	6.11	6.18
Dalbergia sissoo	6.21	6.38	6.62	6.84	6.94
Pongamia pinnata	3.9	4.04	4.29	4.48	4.50
S.Em.±	0.274	0.282	0.283	0.287	0.276
C.D.(0.05)	0.581	0.598	0.60	0.608	0.585
C.V	7.77	7.76	7.47	7.36	6.92

(MAIR-months after initial reading, MAP- months after planting)

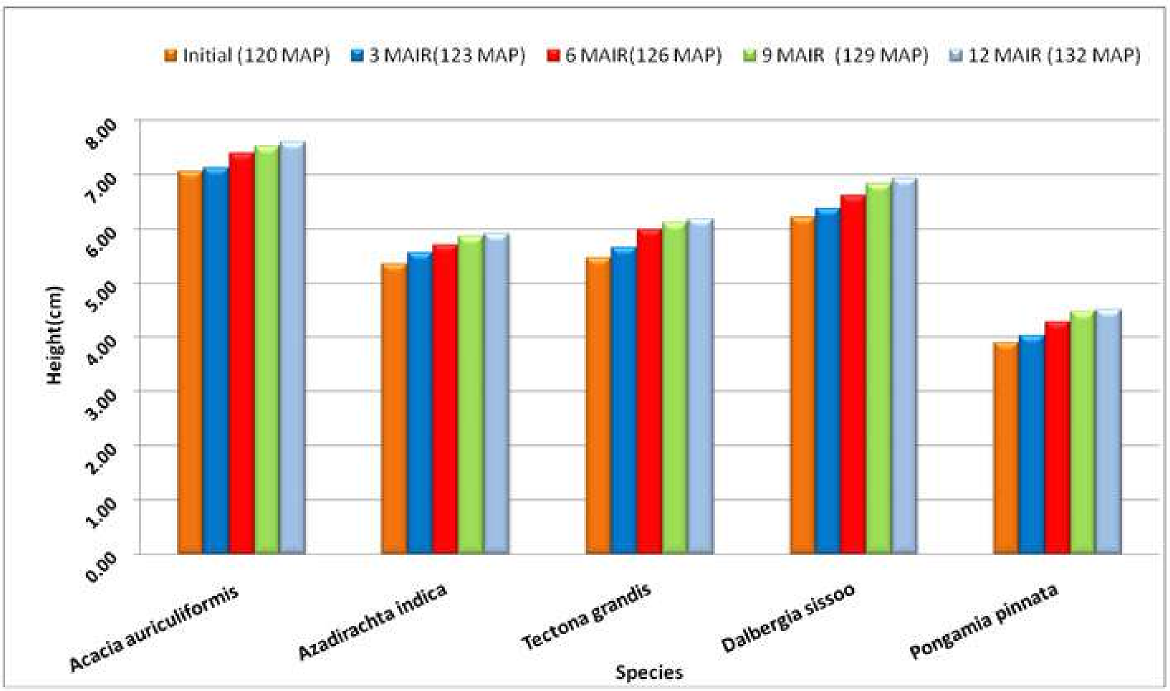

Figure 6. Height (m) of different tree species planted under shelterbelt

4.1.3.4 Nine months after initial reading (129 months after planting)

Significant difference was observed among the tree species with respect to height at 129 months after planting. Among the five species maximum height was recorded in case of *A. auriculiformis* (7.52 m) followed by *D. sissoo* (6.84 m) and *T. grandis* (6.11 m) least was noticed in *P. pinnata* (4.48 m) (Table 4, Fig 6).

4.1.3.5 Twelve months after initial reading (132 months after planting)

Twelve months after initial reading height shows significant difference among the different tree species at 132 months after planting. Maximum height was recorded in *A. auriculiformis* (7.60 m) followed by *D. sissoo* (6.94 m) and *T. grandis* (6.18 m) and least was recorded in *P. pinnata* (4.50 m) (Table 4, Fig 6).

4.1.4 Increment in height (m)

4.1.4.1 First interval (Feb - May 2014)

There was non significant difference was observed among different tree species planted under shelter belt with respect to increment in height. *A. indica* recorded maximum increment in height (0.210 m) followed by *A. auriculiformis* (0.185 m) and *T. grandis* (0.180 m). While least was recorded in case of *P. pinnata* (0.144 m). (Table. 5, Fig 7)

4.1.4.2 Second interval (May - Aug 2014)

There was a significant difference observed among the different tree species with respect to increment in height. Maximum increment was found in case of *T. grandis* (0.338 m) followed by *A. auriculiformis* (0.269 m) (Table 5, Fig 7) and lowest was recorded in *A. indica.*

4.1.4.3 Third interval (Aug - Nov 2014)

Species differed significantly among them with respect to increment in height. The maximum increment in height was recorded by *D. sissoo*

Table 5. Increment in height (m) of different tree species planted under shelterbelt

Increment in height (m)				
Species	First interval (Feb-May 2014)	Second interval (May-Aug 2014)	Third interval (Aug-Nov 2014)	Fourth interval (Nov-Feb 2015)
Acacia auriculiformis	0.185	0.269	0.121	0.139
Azadirachta indica	0.210	0.154	0.162	0.151
Tectona grandis	0.180	0.338	0.124	0.150
Dalbergia sissoo	0.170	0.244	0.216	0.148
Pongamia pinnata	0.144	0.246	0.198	0.147
S.Em.±	0.023	0.036	0.024	0.025
C.D.(0.05)	N.S.	0.076	0.051	N.S.
C.V.	19.890	22.460	23.480	26.800

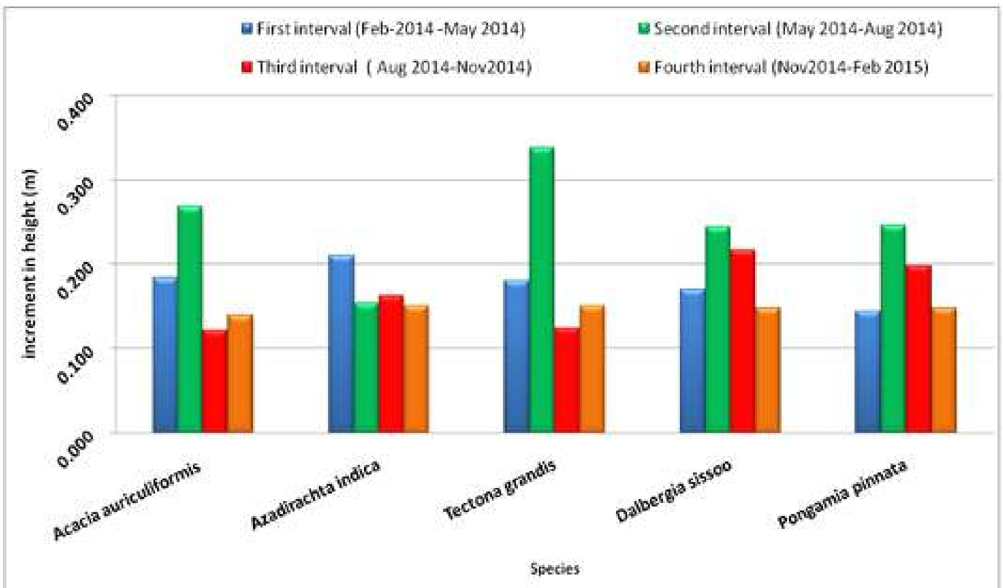

Figure 7 .Increment in height (m) of different tree species planted under shelter belt

(0.216m) followed by *P. pinnata* (0.198 m) and *A. indica* (0.162m). While lowest was noticed in *A. auriculiformis* (0.121m) (Table 5, Fig 7).

4.1.4.4 Fourth interval (Nov - Feb 2015)

Non significant difference was exhibited among the tree species with respect to increment in height. *A. indica* has recorded the maximum increment in height (0.151 m) (Table 5, Fig 7) followed by *T. grandis* (0.150 m) & least was found in case of *A. auriculiformis* (0.139 m).

4.1.5 Basal area (m^2/tree)

4.1.5.1 Initial reading (120 month after planting)

There was significant difference among the tree species with respect to basal area. Among the five tree species maximum basal area was recorded in case of *A. auriculiformis* (0.0129 m^2/tree) followed by *A. indica* (0.0126 m^2/tree) and *D. sissoo* (0.0098 m^2/tree). The lowest was recorded in *P. pinnata* (0.0058 m^2/tree) (Table 6, Fig 8).

4.1.5.2 Three months after initial reading (123 months after planting)

There was a significant difference among the tree species with respect to basal area at three months after initial reading. Maximum basal area was recorded in *A. auriculiformis* (0.0138 m^2/tree) followed by *A. indica* (0.135 m^2/tree) and *D. sissoo* (0.0101 m^2/tree). The lowest was recorded in *P. pinnata* (0.0062 m^2/tree) (Table 6, Fig 8).

4.1.5.3 Six months after initial reading (126 months after planting)

Basal area showed significant difference among the different tree species planted in shelterbelt. Maximum basal area was recorded in case of *A. auriculiformis* (0.0150 m^2/tree) followed by *A. indica* (0.0148 m^2/tree) and *D. sissoo* (0.0098 m^2/tree). The lowest was recorded in *P. pinnata* (0.0058 m^2/tree) (Table 6, Fig 8)

Table 6. Basal area (m^2/tree) of different tree species planted under shelterbelt

Basal area (m^2/tree)					
Species	Initial (120 MAP)	3 MAIR (123 MAP)	6 MAIR (126 MAP)	9 MAIR (129 MAP)	12 MAIR (132 MAP)
Acacia auriculiformis	0.0129	0.0138	0.0150	0.0154	0.0164
Azadirachta indica	0.0126	0.0135	0.0148	0.0164	0.0172
Tectona grandis	0.0085	0.0093	0.0110	0.0127	0.0141
Dalbergia sissoo	0.0098	0.0101	0.0115	0.0129	0.0135
Pongamia pinnata	0.0058	0.0062	0.0077	0.0087	0.0094
S.Em.±	0.001	0.001	0.001	0.002	0.002
C.D.(0.05)	0.002	0.002	0.002	0.004	0.004
C.V.	21.87	22.77	22.37	26.83	25.5

(MAIR-months after initial reading, MAP- months after planting)

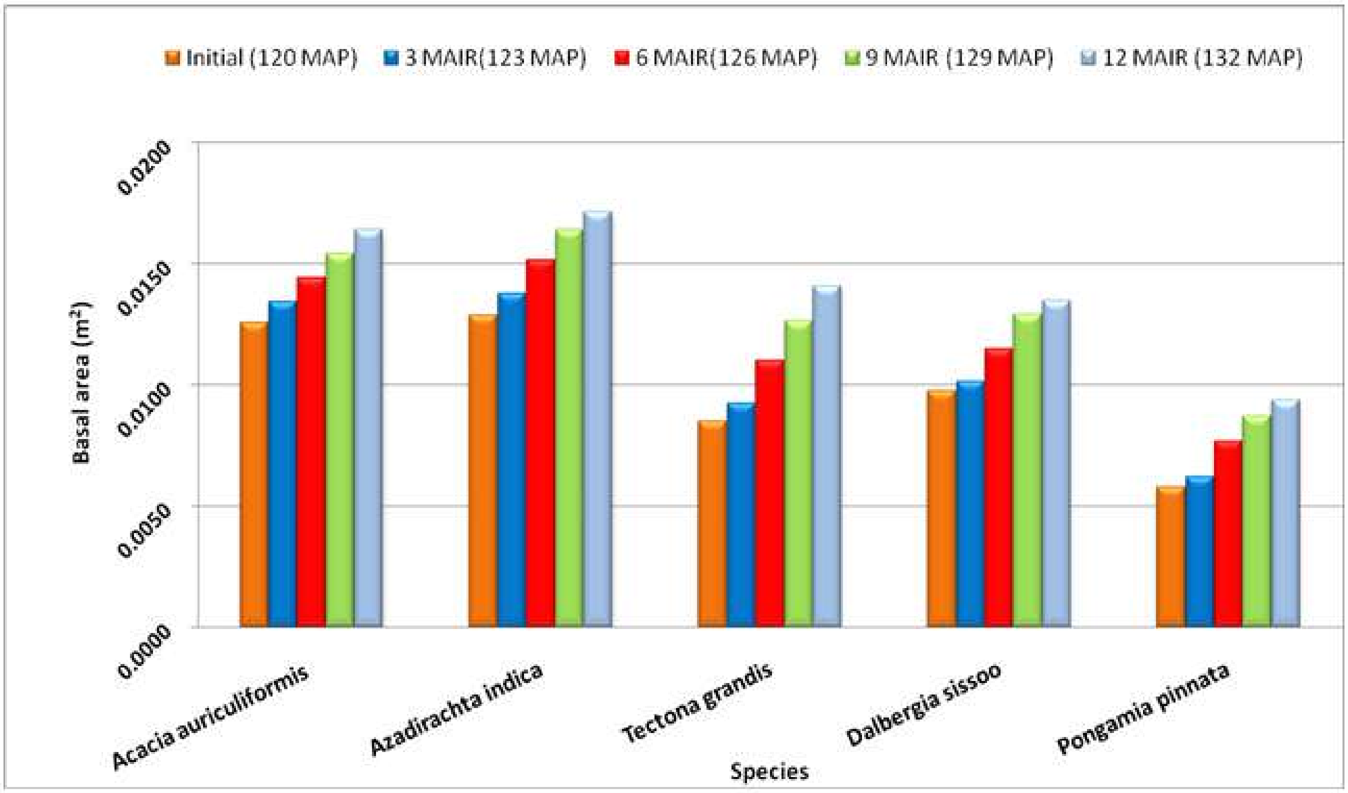

Figure 8. Basal area (m^2/tree) of five different tree species planted under shelterbelt

4.1.5.4 Nine months after initial reading (129 months after planting)

Significant difference was observed among the tree species with respect to basal area at 129 months after initial reading. Among these species maximum basal area was recorded in case of *A.* (0.0164 m^2/tree) followed by *A. auriculiformis* (0.0154 m^2/tree) and *D. sissoo* (0.0129 m^2/tree). The lowest was recorded in *P. pinnata* (0.0058 m^2/tree) (Table 6, Fig 8).

4.1.5.5 Twelve months after initial reading (132 months after planting)

Basal area showed significant difference after twelve months after initial reading. Among the different tree species maximum basal area was recorded in *A. indica* (0.0172 m^2/tree) followed by *A. auriculiformis* (0.0164 m^2/tree) and *T. grandis* (0.0141 m^2/tree). The lowest was recorded in *P. pinnata* (0.0094 m^2/tree) (Table 6, Fig 8).

4.1.6 Volume (m^3/tree)

4.1.6.1 Initial reading (120 months after planting)

Total volume of different tree species differed significantly at 10 year age, the maximum volume was recorded in *A. auriculiformis* (0.046 m^3/tree) followed by *A. indica* (0.039 m^3/tree) and *D. sissoo* (0.033 m^3/tree) The least was recorded in *P. pinnata* (0.013 m^3/tree) (Table7, Fig 9).

4.1.6.1 Three months after initial reading (123 months after planting)

There was a significant difference among tree species planted under shelter belt with respect to total volume (Table 7). Maximum volume was recorded *A. auriculiformis* (0.051 m^3/tree) followed by *A. indica* (0.043 m^3/tree) and *D. sissoo* (0.036 m^3/tree). The least was recorded in *P. pinnata* (0.015 m^3/tree) (Fig.9).

4.1.6.3 Six months after initial reading (126 months after planting)

There was a significant difference among thet tree species with respect to volume. Maximum volume was recorded in case of *A. auriculiformis* (0.056

Table 7. Total volume (m^3/tree) accumulated in different trees species planted under shelterbelt

Volume (m^3/tree)					
Species	Initial (120 MAP)	3 MAIR (123 MAP)	6 MAIR (126 MAP)	9 MAIR (129 MAP)	12 MAIR (132 MAP)
Acacia auriculiformis	0.046	0.051	0.056	0.060	0.065
Azadirachta indica	0.039	0.043	0.049	0.055	0.057
Tectona grandis	0.024	0.027	0.035	0.041	0.047
Dalbergia sissoo	0.033	0.036	0.042	0.048	0.051
Pongamia pinnata	0.013	0.015	0.020	0.024	0.031
S.Em.±	0.005	0.006	0.006	0.007	0.007
C.D.(0.05)	0.011	0.013	0.013	0.015	0.015
C.V.	28.44	30.35	23.21	22.01	20.95

(MAIR-months after initial reading, MAP- months after planting)

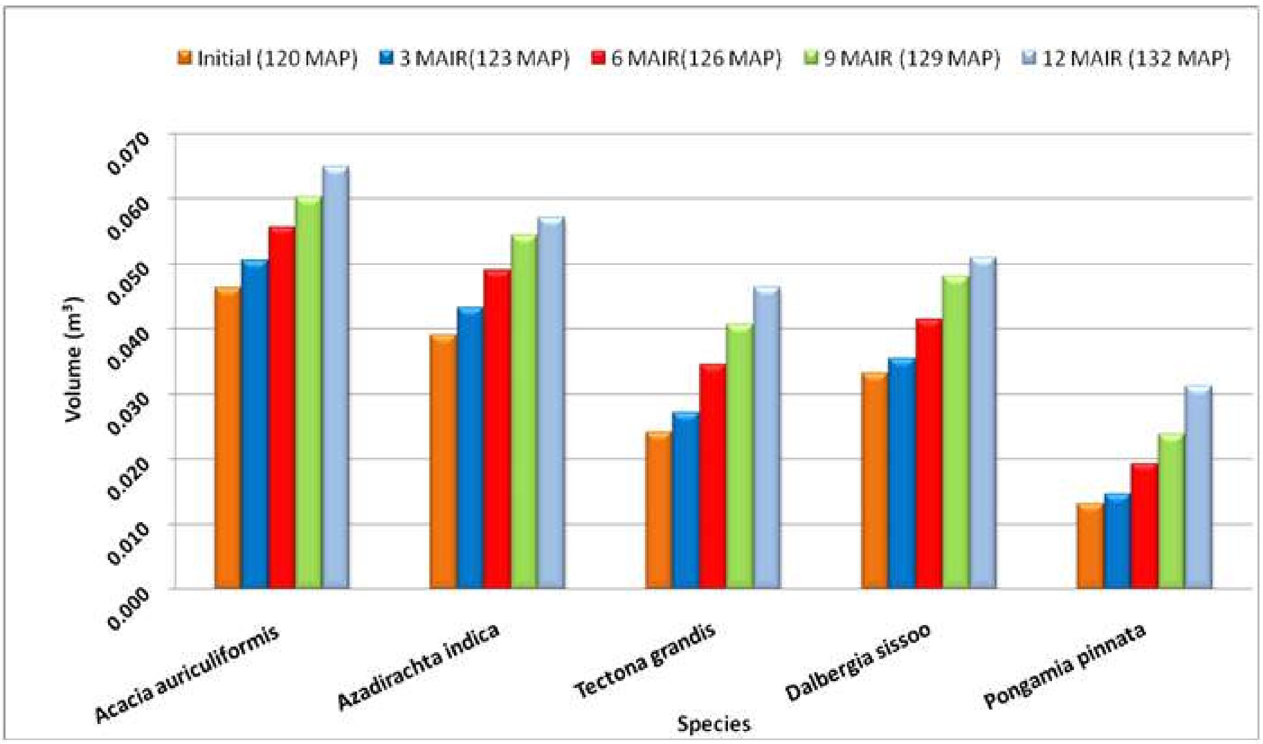

Figure 9. Volume (m^3/tree) of different tree species planted under shelterbelt

m^3/tree) followed by *A. indica* (0.04 m^3/tree) and *D. sissoo* (0.042 m^3/tree). The least was recorded in *P. pinnata* (0.020 m^3/tree) (Table 7, Fig 9).

4.1.6.4 Nine months after initial reading (129 months after planting)

Total volume of different tree species showed significant difference at nine months after initial reading (129 months after planting). The maximum volume was recorded in *A. auriculiformis* (0.060 m^3/tree) followed by *A. indica* (0.055 m^3) and *D. sissoo* (0.48 m^3/tree). Lowest was recorded in *P. pinnata* (0.024 m^3/tree) (Table 7, Fig.9).

4.1.6.5 Twelve months after initial reading (132 months after planting)

Significant difference was observed among the different tree species with respect to volume. Maximum volume was recorded in case of *A. auriculiformis* (0.065 m^3/tree) followed by *A. indica* (0.057 m^3/tree) and *D. sissoo* (0.051 m^3/tree). Lowest was recorded in *P. pinnata* (0.031 m^3/tree) (Table 7, Fig 9).

4.1.7 Increment in volume (m^3/tree)

4.1.7.1 First interval (Feb -May 2014)

There was a significant difference observed among tree species planted under shelterbelt with respect to volume increment. Maximum was recorded in *A. indica* (0.043 m^3/tree) followed by *A. auriculiformis* (0.0042 m^3/tree) and *T. grandis* (0.0029 m^3/tree). Lowest was recorded in case of *P. pinnata* (0.0015 m^3/tree) (Table 8, Fig 10)

4.1.7.2 Second interval (May -Aug 2014)

Non significant difference was observed among the different tree species at second interval with respect to increment of volume. Maximum increment was found in case of *T. grandis* (0.0074 m^3/tree) followed by *D. sissoo* (0.0061m^3/tree) and *A. indica* (0.0057 m^3/tree). Lowest was recorded in *P. pinnata* (0.0047 m^3/tree) (Table 8, Fig 10).

Table 8. Volume increment (m^3/tree) of different trees species planted under shelterbelt

Volume increment (m^3/tree)				
Species	First interval (Feb-May 2014)	Second interval (May-Aug 2014)	Third interval (Aug-Nov 2014)	Fourth interval (Nov-Feb 2015)
Acacia auriculiformis	0.0042	0.0051	0.0046	0.0011
Azadirachta indica	0.0043	0.0057	0.0054	0.0007
Tectona grandis	0.0029	0.0074	0.0062	0.0008
Dalbergia sissoo	0.0021	0.0061	0.0066	0.0006
Pongamia pinnata	0.0015	0.0047	0.0044	0.0007
S.Em.±	0.0004	0.0010	0.0020	0.0001
C.D.(0.05)	0.0011	N.S.	N.S.	0.0002
C.V.	28.00	20.23	28.28	20.00

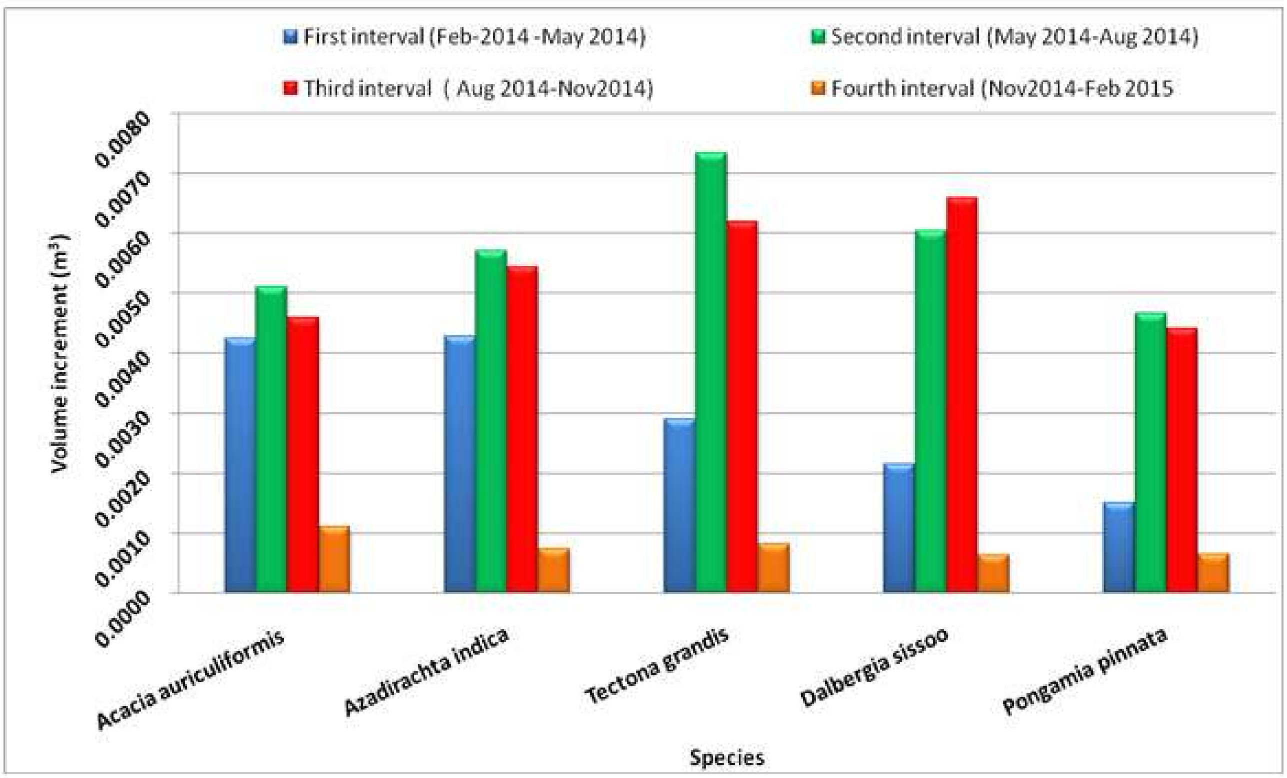

Figure 10. Volume increment of tree (m^3/tree) of different tree species planted under shelterbelt

4.1.7.3 Third interval (Aug -Nov 2014)

Volume increment showed non significant difference among the different tree species. Maximum increment in volume was recorded in *D. sissoo* (0.0066 m^3/tree) followed by *T. grandis* (0.0062 m^3/tree) and *A. indica* (0.0054 m^3/tree) lowest was recorded in *P. pinnata* (0.0044 m^3/tree) (Table 8, Fig 10).

4.1.7.4 Fourth interval (Nov-Feb 2015)

There was a significant difference observed among the tree species with respect to volume increment. *A. auriculiformis* recorded maximum volume increment (0.0011 m^3/tree) followed by *T. grandis* and *P. pinnata* (0.0007 m^3/tree) least was found in case of *D. sissoo* (0.0006 m^3/tree) (Table 8, Fig 10).

4.2 To know the carbon sequestration of different tree species planted in the shelter belt

4.2.1 Biomass (ton /ha).

4.2.1.1 Above ground biomass (ton /ha).

4.2.1.1.1 Initial reading (120 month after planting).

There was a significant difference observed among the tree species with respect to above ground biomass production. Maximum biomass was recorded in *A. auriculiformis* (103.19 ton/ha) followed by *A. indica* (71.38 ton/ha) and *D. sissoo* (68.40 ton/ha). Lowest was recorded in *P. pinnata* (27.05 ton/ha) (Table 9, Fig 11).

4.2.1.1.2 Three month after initial reading (123 month after planting).

Significant difference was recorded among the different tree species with respect to above ground biomass. Maximum biomass was noticed in case of *A. auriculiformis* (112.64 ton/ha) followed by *A. indica* (79.19 ton/ha) and *D. sissoo* (72.81 ton/ha). Lowest was recorded in *P. pinnata* (30.11 ton/ha) (Table 9, Fig 11).

Table 9. Above ground biomass (ton/ha) of different tree species planted in shelterbelt

	Above ground biomass (ton/ha)				
Species	Initial (120 MAP)	3 MAIR (123 MAP)	6 MAIR (126 MAP)	9 MAIR (129 MAP)	12 MAIR (132 MAP)
Acacia auriculiformis	103.19	112.64	124.03	134.27	144.68
Azadirachta indica	71.38	79.19	89.62	99.57	104.41
Tectona grandis	46.25	51.77	65.75	77.52	88.38
Dalbergia sissoo	68.40	72.81	85.23	98.78	104.64
Pongamia pinnata	27.05	30.11	39.56	48.50	51.24
S.Em.±	10.44	11.10	11.41	13.47	12.91
C.D.(0.05)	22.14	23.53	24.18	28.55	27.36
C.V.	26.11	25.32	22.31	23.22	20.94

(MAIR-months after initial reading, MAP- months after planting)

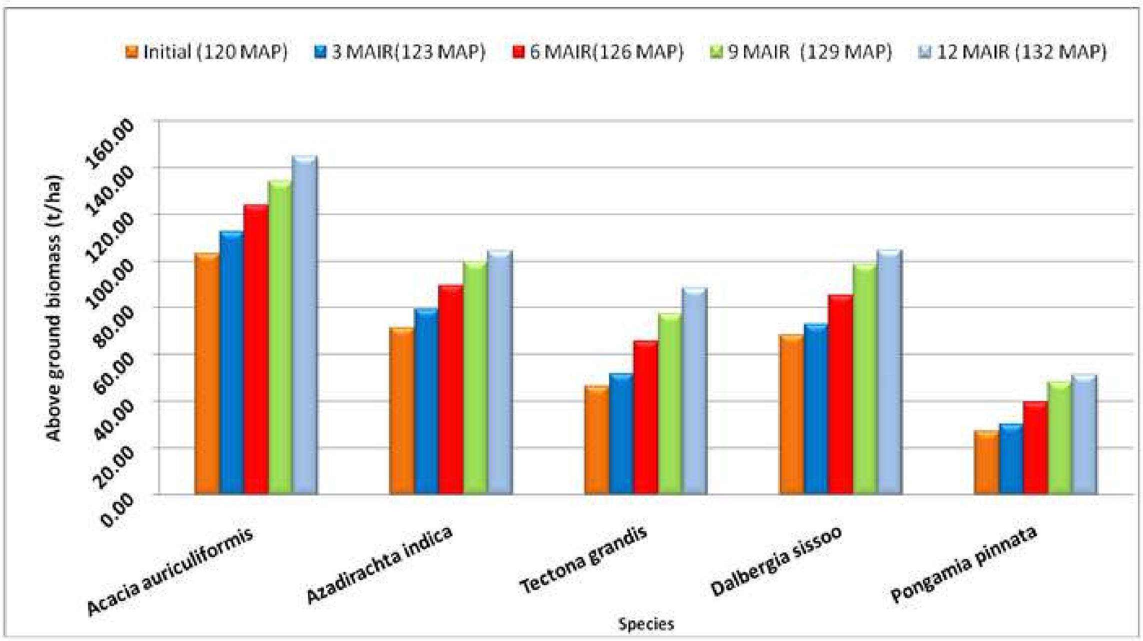

Figure 11. Above ground biomass (ton/ha) production by different tree species planted in shelter belt

4.2.1.1.3 Six month after initial reading (126 month after planting)

Above ground biomass showed significant difference among the tree species. Highest biomass was recorded in *A. auriculiformis* (124.03 ton/ha) followed by *A. indica* (89.62 ton/ha) and *D. sissoo* (85.23 ton/ha) (Table 9, Fig 11). Least was recorded in *P. pinnata* (39.56 ton/ha).

4.2.1.1.4 Nine months after initial reading (129 months after planting)

There was a significant difference among tree species. Maximum biomass was recorded in *A. auriculiformis* (134.27ton/ha) followed by *A. indica* (99.57 ton/ha) and *D. sissoo* (98.78 ton/ha). Lowest was recorded in *P. pinnata* (48.50 ton/ha) (Table 9, Fig 11).

4.2.1.1.5 Twelve months after initial reading (132 months after planting)

There was a significant difference among different tree species with respect to above ground biomass production at 132 months after planting. Maximum biomass was recorded in *A. auriculiformis* (144.68 ton/ha) followed by *D. sissoo* (104.64 ton/ha) and *A. indica* (104.41 ton/ha) and. Lowest was recorded in *P. pinnata* (51.23 ton/ha) (Table 9, Fig 11).

4.2.1.2 Below ground biomass (ton /ha).

4.2.1.2.1 Initial reading (120 month after planting)

There was a significant difference observed among the different tree species with respect to below ground biomass production. Maximum biomass was recorded in *A. auriculiformis* (26.89 ton/ha) followed by *A. indica* (18.56 ton/ha) and *D. sissoo* (17.78 ton/ha). Lowest was recorded in *P. pinnata* (7.03 ton/ha) (Table 10, Fig 12).

4.2.1.2.2 Three month after initial reading (123 month after planting)

Significant difference was recorded among the tree species with respect to below ground biomass. Maximum biomass was noticed in case of *A. auriculiformis* (29.29 ton/ha) at 123 months after planting followed by *A.*

Table 10. Below ground biomass (ton/ha) of different tree species planted under shelterbelt

Below ground biomass (ton/ha)					
Species	Initial (120 MAP)	3 MAIR (123 MAP)	6 MAIR (126 MAP)	9 MAIR (129 MAP)	12 MAIR (132 MAP)
Acacia auriculiformis	26.83	29.29	32.25	34.91	37.62
Azadirachta indica	18.56	20.59	23.30	25.89	27.15
Tectona grandis	12.02	13.46	17.10	20.16	22.98
Dalbergia sissoo	17.78	18.93	22.16	25.68	27.21
Pongamia pinnata	7.03	7.83	10.28	12.61	13.32
S.Em.±	2.71	2.88	2.96	3.50	3.35
C.D.(0.05)	5.75	6.11	6.28	7.42	7.11
C.V.	26.10	25.32	22.31	23.22	20.94

(MAIR-months after initial reading, MAP- months after planting)

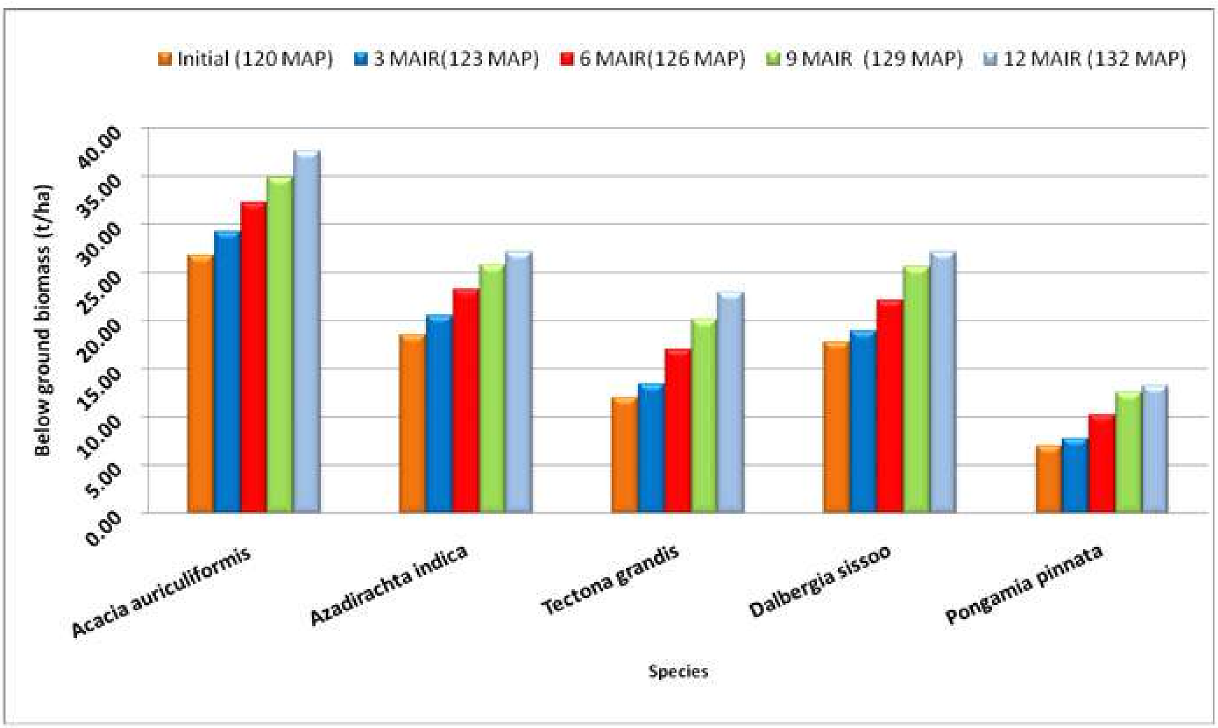

Figure 12. Below ground biomass (ton/ha) production by different tree species planted under shelter belt

indica (20.59 ton/ha) and *D. sissoo* (18.93 ton/ha). Lowest was recorded in *P. pinnata* (7.83 ton/ha) (Table 10, Fig 12).

4.2.1.2.3 Six month after initial reading (126 month after planting)

Biomass showed significant difference among the tree species. Highest below ground biomass was recorded in *A. auriculiformis* (32.25 ton/ha) (Table 10, Fig 12) followed by *A. indica* (23.30 ton/ha) and *D. sissoo* (22.16 ton/ha). Least was recorded in *P. pinnata* (10.28 ton/ha).

4.2.1.2.4 Nine months after initial reading (129 months after planting)

There was a significant difference among different tree species. Maximum below ground biomass was recorded in *A. auriculiformis* (34.91 ton/ha) followed by *A. indica* (25.89 ton/ha) and *D. sissoo* (25.68 t/ha). Lowest was recorded in *P. pinnata* (12.61 ton/ha) (Table 10, fig 12).

4.2.1.2.5 Twelve months after initial reading (132 months after planting)

Significant difference was observed among different tree species at 132 months after initial reading with respect to below ground biomass production (Table 10, Fig12). Maximum below ground biomass was recorded in *A. auriculiformis* (37.62 ton/ha) followed by *D. sissoo* (27.21 ton/ha) and *A. indica* (27.15 ton/ha) and lowest was recorded in *P. pinnata* (13.52 ton/ha).

4.2.2 Carbon sequestration (ton/ha)

4.2.2.1 Initial (120 months after planting)

Carbon sequestration showed significant difference among the different tree species. *A. auriculiformis* showed maximum of 65.01 ton/ha (Table11, Fig 13) followed by *A. indica* (44.97 ton/ha) and *D. sissoo* (43.09 ton/ha). Lowest was recorded in *P. pinnata* (17.04 ton/ha).

Table 11. Carbon sequestration (ton/ha) of different tree species planted in shelterbelt

Carbon sequestration (ton/ha)					
Species	Initial (120 MAP)	3 MAIR (123 MAP)	6 MAIR (126 MAP)	9 MAIR (129 MAP)	12 MAIR (132 MAP)
Acacia auriculiformis	65.01	70.96	78.14	84.59	91.15
Azadirachta indica	44.97	49.89	56.46	62.73	65.78
Tectona grandis	29.14	32.62	41.42	48.84	55.68
Dalbergia sissoo	43.09	45.87	53.70	62.23	65.92
Pongamia pinnata	17.04	18.97	24.92	30.55	32.58
S.Em.±	6.58	6.99	7.18	8.48	8.13
C.D.(0.05)	13.95	14.82	15.24	17.99	17.23
C.V.	26.11	25.32	22.31	23.22	20.93

(MAIR-months after initial reading, MAP- months after planting)

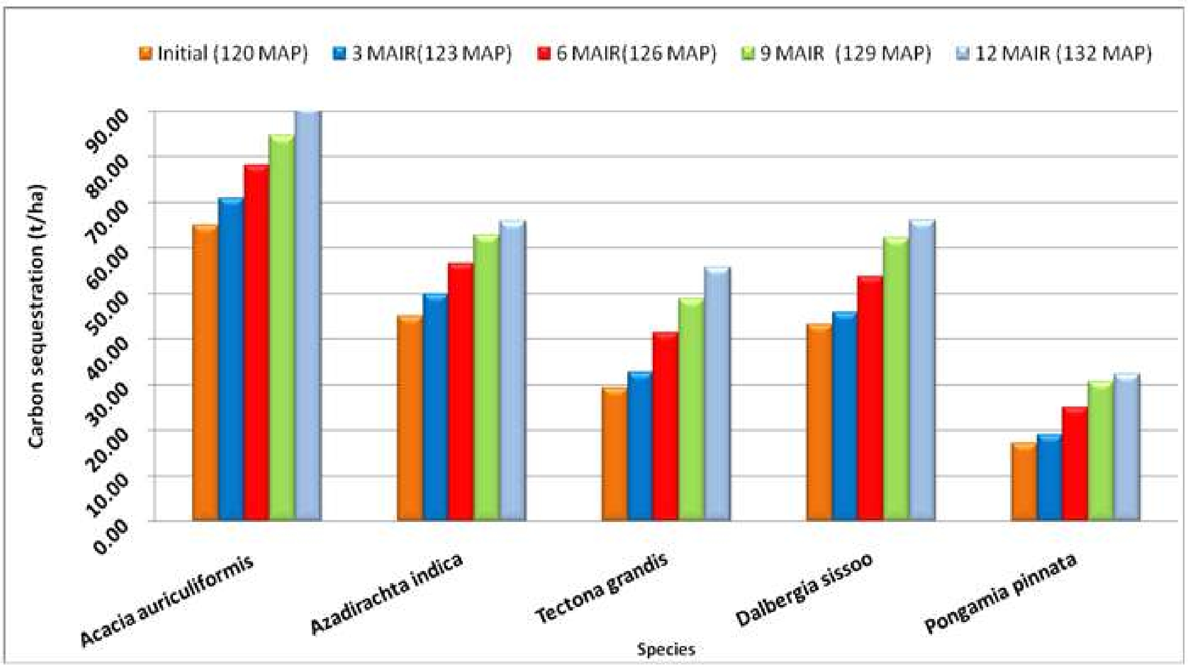

Figure 13. Carbon sequestration (ton/ha) of different tree species planted under shelter belt

4.2.2.2 Three months after initial reading (123 months after planting)

Significant variation was observed among the tree species planted under shelter belt with respect to carbon sequestration at 123 months after planting (Table 11, Fig 13). Maximum sequestration was recorded in *A. auriculiformis* (70.96 ton/ha) followed by *A. indica* (49.89 ton/ha) and *D. sissoo* (45.87 ton/ha) lowest was recorded in *P. pinnata* (18.97 ton/ha).

4.2.2.3 Six months after initial reading (126 months after planting)

There was a significant difference among tree species at 126 months after planting with respect to carbon sequestration (Table 11, Fig 13). Maximum sequestration was observed in case of *A. auriculiformis* (78.14 ton/ha) followed by *A. indica (*56.46 ton/ha) and *D. sissoo* (53.70 ton/ha). Lowest was recorded in *P. pinnata* (24.92 ton/ha).

4.2.2.4 Nine months after initial reading (129 months after initial reading)

The carbon sequestration showed the significant difference among the different tree species planted under shelterbelt. Maximum carbon sequestration was recorded in case of *A. auriculiformis* (84.59 ton/ha) followed by *A. indica* (62.73 ton/ha) and *D. sissoo* (62.63 ton/ha). Least was recorded in *P. pinnata* (30.23 ton/ha) (Table 11, Fig 13).

4.2.2.5 Twelve months after planting (132 months after planting)

There was a significance difference among the different tree species amount of carbon sequestrated at 132 months after planting is maximum in *A. auriculiformis* (91.15 ton/ha) followed by *D. sissoo* (65.92 ton/ha) and *A. indica* (65.78 ton/ha) least was in *P. pinnata* (32.58 ton/ha) (Table 11, Fig 13)

Total carbon sequestration of five different tree species was recorded at 132 months after planting. Maximum was recorded in *A. auriculiformis* (91.15 ton/ha) with a total biomass production (AGB+BGB) of about 182.3 ton/ha followed by *D. sissoo* (65.92 ton/ha) and *A. indica* (65.78 ton/ha). Least carbon sequestrated in *P. pinnata* (32.58 ton/ha) (Table 12)

4.3 To estimate the form factor of different tree species of Northern transitional zone of Karnataka

Farm factor of ten year old tree species was worked out among these species. Maximum form factor was recorded in *A. auriculiformis* and lowest was recorded in P. *pinnata* and highest wood density was found in *A. auriculiformis* and lowest was recorded in case of *A. indica* (Table 13).

Table 12. Total carbon sequestration up to 11 year old trees under shelter belt of Northern transitional zone of Karnataka

Species	Above ground biomass (AGB) (ton/ha)	Below ground biomass (BGB) (ton/ha)	Total biomass (AGB+BGB) (ton/ha)	Carbon sequestration (ton/ha)
Acacia auriculiformis	144.68	37.62	182.3	91.15
Azadirachta indica	104.41	27.15	131.56	65.78
Tectona grandis	88.38	22.98	111.36	55.68
Dalbergia sissoo	104.64	27.21	131.85	65.92
Pongamia pinnata	51.24	11.76	63	32.58
S.Em.±	12.91	3.355	---	8.13
C.D.(0.05)	27.36	7.112	---	17.235
C.V.	20.94	20.94	---	20.93

Table 13. Form factor and wood density of different tree species of shelterbelt in Northern transitional zone of Karnataka

Species	Form factor	Wood density (g/cc)
Acacia auriculiformis	0.55	0.90
Azadirachta indica	0.54	0.74
Tectona grandis	0.52	0.77
Dalbergia sissoo	0.53	0.83
Pongamia pinnata	0.51	0.82

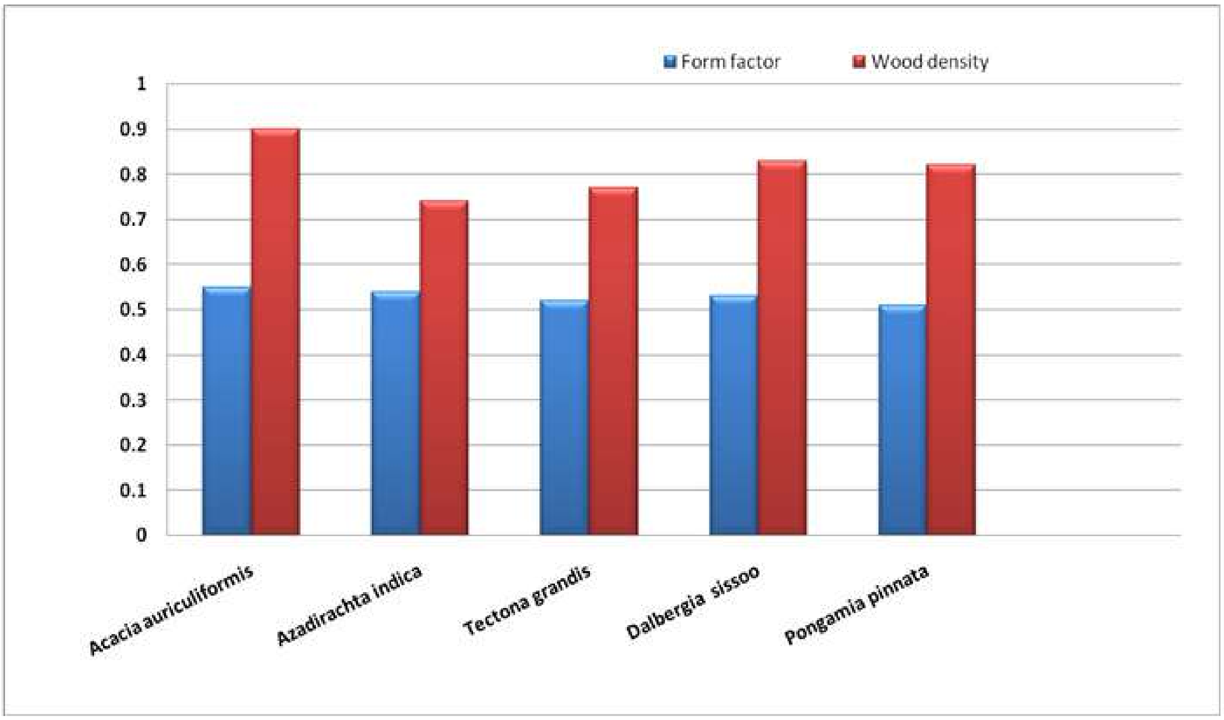

Figure 14. Form factor and wood density of different tree species in shelterbelt of Northern transitional zone of Karnataka

5. DISCUSSION

Results of the experiment conducted on Carbon sequestration of ten year old different tree species planted in shelter belt of Northern transitional zone of Karnataka at Agricultural College Hanumanamatti during 2014-2015 are discussed in this chapter under the following headings

5.1 To assess the performance of different tree species for growth attributes.

5.2 To know the Carbon sequestration of different tree species planted in the shelter belt

5.3 To estimate the form factor of different tree species of Northern transitional zone of Karnataka

5.4 Practical implication of results

5.5 Future line of work

5.1 To assess the performance of different tree species for growth attributes

Several climatic factors like moisture, rainfall, temperature, humidity etc affect the vegetation and productivity of the trees. Among the climatic factors rainfall play a prominent role in each of the site condition (Dwivedi, 1992). Improper soil and water conservation practices and lack of perennial vegetation has led to degradation of land resulting in loss of fertility and productivity. Plant growth is low in drier region due to lack of adequate soil moisture, because of excess evapo-transpiration, often more than the precipitation.

In the present study observation were taken at three months interval showed gradual increase in growth parameters of five trees species *viz*., *Acacia auriculiformis, Dalbergia sissoo, Tectona grandis, Azadirachta indica* and *Pongamia pinnata.*

Girth at breast height (cm)

At the initial reading (120 months after planting) different tree species planted in shelter belt *A. auriculiformis*, *A. indica* and *D. sissoo* were showed significantly superior girth at breast height (Gbh) over the other species. Three months after initial reading *A. auriculiformis* shows maximum girth followed by *A. indica* and *D. sissoo*. Six, nine and twelve month after initial reading maximum girth was recorded in *A. indica* followed by *A. auriculiformis, D. sissoo*, and *T. grandis*. Least was recorded in *P. pinnata* (Table 2). These results are in line with the findings of Chavvan (2009). In different shelter belt trees maximum gbh was recorded in *A. indica*, *A. auriculiformis and D. sissoo.* They performed well with respect to gbh in dry climatic condition similarly Ponnuswamy (1982) found that in Perumalai of Kodikanal at five year age *Pinus petula* attained highest gbh followed by *Pinus carriabaea.*

Increment in girth at breast height (Gbh) at first, second and third intervals showed significant difference but at fourth interval (Nov-Feb) non-significant difference was observed. In first interval maximum increment in gbh was recorded in *A. indica* followed by *A. auriculiformis* and *T. grandis.* In second interval *T. grandis* shows maximum increment followed by *D. sissoo* and *P. pinnata*. In third interval gbh was found in *D. sissoo* followed by *T. grandis* and *P. pinnata* (Aug-Nov) and in last interval maximum gbh was found in *Acacia auriculiformis* (Nov-Feb) followed by *T. grandis*, *A. indica*. Highest increment was recorded in second interval (May-Aug); this may be due to higher rainfall and relative humidity available at this stage of growth compared to other months (Table. 3).

Height (m)

The tree species differed significantly with respect to height at 10 years aged shelter belt trees. *A. auriculiformis, D. sissoo* and *T. grandis* were significantly superior over other species. In three, six and nine months after initial reading maximum height were recorded in *A. auriculiformis* followed by *D. sissoo* and *T. grandis* (table 4). This result is in line with the findings of Chavvan (2009) and Thesfaye Abebe (1994) in *A. nilotica*, *A. cyanophylla*, *A. Senegal*, *Cassia siamia* and *Prosopis juliflora* in semiarid area. Similarly in the present study superior performance in height was observed in *A. auriculiformis* and *D. sissoo* over the other species planted under shelter belts, may be due to its fast growing nature.

Tree planted under shelter belt showed non significant difference with respect to increment in height. Maximum height increment was recorded in *A. auriculiformis* followed by *T. grandis* at first interval (Feb-May). *T. grandis* showed maximum increment at second interval (May-Aug) followed by *A. auriculiformis* and *P. pinnata.* In third interval (Aug-Nov) maximum height increment was observed in *D. sissoo* followed by *P. pinnata, A. indica* and *T. grandis* and in fourth interval maximum increment in height was observed in *A. indica* followed by *T. grandis* and *D. sissoo* (Nov -Feb) (Table 5).

Basal area (m^2/tree)

There was a significant difference among the tree species with respect to basal area at initial stage of reading (120 months after planting) up to 12 months after initial reading. During initial *A. auriculiformis* showed maximum basal area followed by *A. indica* and *D. sissoo* same trend was followed at three, six months after initial reading. *A. indica* showed maximum basal area at nine and twelve months after initial reading followed by *A. auriculiformis, T. grandis* and *P. pinnata* recorded least in all stages (Table 6).

Volume (m^3/tree)

Volume showed significant differences among the tree species planted under shelter belt. Among five tree species *A. auriculiformis, A. indica,* and *D. sissoo* showed significantly superior performance was observed over the other species at initial (120 months after planting), three, six, nine and 12 months after initial reading. Maximum volume was recorded in *A. auriculiformis* followed by *A. indica* and *D. sissoo* (Table 6) similar results have been found by Sunilkumar (2009) in 10 year old *A. auriculiformis* plantation (0.359 m^3). Similarly Chavvan (2009) in different shelter belt trees *A. auriculiformis* recorded maximum volume followed by *A. indica* and *D. sissoo*. Jayaraman and Rajan (1991) reported that 351.83 m^3/ha volume was produced at the age of 10 years. In the present study *A. auriculiformis, A. indica* and *D. sissoo* performed well with respect to total volume is may be due to utilization of available natural resource by the plants for their optimum growth (Table 7).

Tree planted under shelter belt showed significant difference with respect to volume increment at first (Feb-May) and last interval (Nov-Feb). Non significant difference was observed in second and third interval. In first interval maximum increment in volume is recorded in *A. indica* followed by *A. auriculiformis*, *T. grandis.* In second interval maximum volume increment was recorded in *T. grandis* followed by *D. sissoo* and *A. indica* (May-Aug). *D. sissoo* showed maximum increment in third interval and in last interval maximum increment was recorded in *A. auriculiformis* followed by *T. grandis* and *P. pinnata* (Table 8) among the tree species maximum increment was noticed at second interval compare to other intervals is may be due to high rainfall and relative humidity (Table 1) and all the species showed least volume increment in fourth interval (Nov-Feb) is may be due to winter season less growth of all the tree species was observed and it is a period of leaf shedding in transitional zone (Chavvan 2009).

5.2 To know the Carbon sequestration (ton/ha) of different tree species planted in the shelter belt

Biomass (ton/ha)

Biomass was calculated by non destructive method both above ground biomass (AGB) and below ground biomass (BGB) determined separately.

Trees planted under shelter belt showed significant difference among them. Maximum above ground biomass was recorded in *A. auriculiformis* followed by *A. indica* and *D. sissoo* at initial reading (120 months after planting), three, six, nine and 12 months after initial reading (Table 9). *A. auriculiformis, A. indica* and *D. sissoo* superior over the other tree species in above ground biomass production. Maximum above ground biomass production was attributed to maximum volume and wood density of the tree species. These results are in line with the findings of Swamy (2010) reported at 5 year old shelter belt trees maximum biomass was recorded in *A. auriculiformis* followed by *A. indica* and *D. sissoo.*

Maximum below ground biomass was noticed in *A. auriculiformis* followed by *A. indica* and *D. sissoo*. Least was recorded in *P. pinnata* at initial (120 months after planting), three, six, nine and 12 months after initial reading. Maximum below ground biomass was recorded in *A. auriculiformis* followed by *D. sissoo* and *A. indica* (Table 10). Maximum below ground biomass production is attributed by maximum above ground biomass same results are founded by Yashmita ulman and Avudainayagam (2014).

Carbon sequestration (ton/ha)

Carbon sequestration showed significant difference among the tree species planted under shelter belt. Maximum carbon sequestration was recorded in *A. auriculiformis* followed by *A. indica* and *D. sissoo* at initial (120 months after planting), three, six, nine and 12 months after planting and least was recorded in *P. pinnata.* Maximum carbon sequestration was attributed by maximum biomass production this results are line with the findings of Yashmita ulman and Avudainayagam (2014) reported in *Eucalyptus teriticornis* plantation. Similarly Shivanna *et al.,* (2007) reported at different growth intervals of 8, 16 and 24 month observations in *Dalbergia sissoo.* Carbon sequestration was increasing with increase in age of the tree from 120 months after planting to 132 months after plating this results are in line with findings of Jha (2005) were it was found that the carbon stored in vegetation was increased with increase in age of the plantation.

Total carbon sequestration of five different tree species was recorded at 132 months after planting. Maximum carbon sequestration was recorded in *A. auriculiformis* followed by *D. sissoo* and *A. indica* is due to more biomass production by this species leads to more carbon sequestration. These results are in line with the findings of Reddy *et al*., (2014). Among this five different tree species planted under shelter belts of AC Hanumanamatti. *A. auriculiformis*, *A. indica* and *D. sissoo* showed superior performance compare to *P. pinnata* with respect to volume, biomass production and carbon sequestration this species have different growth rates throughout the year and each species is different from each other due to its fast growing ability and capacity to adapt to dry climatic condition.

5.3 To estimate the form factor of different tree species of Northern transitional zone of Karnataka

Generally trees are not exactly equal to true cylindrical shape but for estimation of volume of standing tree girth is measured at breast height (1.37 m) assuming that trees are cylindrical in nature but trees show tapering nature at breast height girth is more and become less as we move towards the tip of the tree. If we used breast height girth for calculation volume of the tree it would be overestimated hence in order to avoid this problem and to estimate the accurate volume of tree form factor value is multiplied with the calculated volume for a given species. Form factor is refers to ratio between the volume of a tree to the product of basal area and height of the tree and this will various with species, age, site and crop density. Form factor usually various form 0-1. If the form factor is nearer to 0, then the tree stem is irregular (not near to cylindrical shape), if the form factor is nearer to 1.0 then tree stem would be more nearer to cylindrical.

In this present study form factor of five trees is determined and is ranges from 0.51 to 0.55 among them highest tapering is showed by *P. pinnata* (0.51) followed by *T. grandis* (0.52) lowest tapering was recorded in *A. auriculiformis* (0.55) (Table 13) trees growing on either side of the shelterbelt have large crowns and so the pressure exerted on them is greatest. These trees allocate most of their growth material towards the base of the tree at expense of height (Chaturvedi and Khanna, 1994). This result is in agreement with findings of Swamy (2010) in shelter belt trees. As a tree height increases form factor will decreases this results are in line with the findings of Murthy (2003) in *A. auriculiformis*.

PRACTICAL IMPLICATIONS OF RESULTS

- From the present study we could say that carbon sequestration potential is very high in *Acacia auriculiformis, Azadirachta indica, Dalbergia sissoo* and *Tectona grandis* planted under shelter belt in Northern transitional zone of Karnataka.

- Present study shows that superior growth performance by *Acacia auriculiformis, Azadirachta indica* and *Dalbergia sissoo*.

- Results shows that higher potentials of carbon sequestration by *Acacia auriculiformis, Azadirachta indica*, *Dalbergia sissoo* and *Tectona grandis* practically growing this species by farmer in his farmland could gain more economical benefits in carbon sequestration activities through afforestation and reforestation programmes. It promotes for carbon credit by individual farmer.

- In the present study form factor of ten year old trees was standardized that can be used in volume calculation of standing trees such as *Acacia auriculiformis, Azadirachta indica. Dalbergia sissoo, Pongamia pinnata* and *Tectona grandis.*

FUTURE LINE OF WORK

- In the present study carbon sequestration is estimated for five different species at ten year old tree that can be studied at different ages up to rotation age.

- Study must be carried out in different trees species which are fast growing in nature in different agroforestry systems and in different ecological zone of Karnataka.

- Carbon sequestration is important tool for reducing global warming; much emphasis of multi disciplinary research should be given in forestry and also farmers should be encouraged for shelterbelt establishment.

6. SUMMARY AND CONCLUSIONS

Studies on carbon sequestration are gaining lot of importance to reduce global climate change. Main reason for climate change is higher concentration of green house gases in atmosphere. Among them carbon dioxide is the most important green house gas. Therefore it is necessary to identify the sink to reduce the carbon concentration in the atmosphere and withhold in a form, other than CO_2 and help in reducing the global warming. Trees are measure sink to absorb the carbon from the atmosphere and it will store as carbon form in wood for longer period. Trees in shelter belt are capable for carbon capturing and it is stored in their biomass along with it can protect crop against the winds and it improve the micro climatic condition.

The present study was conducted at Agriculture College, Hanumanamatti on shelter belt trees. Shelter belt has five different tree species and each tree species considered as a treatment and five trees were selected for observation likewise there was five replications. The observations were taken on girth at breast height (gbh) (cm) and height (m) at three months interval. By this observations basal area (m^2/tree), volume (m^3/tree), biomass (above ground biomass and below ground biomass) (ton/ha) and carbon sequestration was calculated using standard formulae. Statistical analysis was made by using RBD to know the significant difference among the tree species.

The superior performance was observed in case of *A. auriculiformis* and *A. indica* with respect to gbh at initial (120 months after planting) and three months after initial reading *A. auriculiformis* showed maximum gbh of about 39.13cm and 40.78cm respectively. At 6, 9 and 12 months after initial reading maximum gbh were observed in *A. indica* followed by *A. Auriculiformis* and least was noticed in *P. pinnata.*

Among the five different tree species planted under shelter belt *A. auriculiformis* is superior with respect to height performance of about 7.06 m, 7.13m, 7.40 m, 7.52 m and 7.60 m at initial (120 months after planting), 3, 6, 9 and 12 months after initial reading respectively followed by *D. sissoo* and *A. indica.*

It was observed that *A. auriculiformis* showed maximum basal area (m^2/tree) at initial, 3 and 6 months after initial reading of about 0.0129 m^2/tree, 0.0138 m^2/tree and 0.0150 m^2/tree respectively. In 9 and 12 months after initial reading maximum basal area was observed in case of *A. Indica* of about 0.0164 m^2/tree and 0.0172 m^2/tree respectively and lowest was observed in *P. pinnata*.

A. auriculiformis was showed maximum volume at initial, 3, 6, 9 and 12 months after initial reading of about 0.046 m^3/tree, 0.051 m^3/tree, 0.056 m^3/tree, 0.060 m^3/tree and 0.065 m^3/tree respectively followed by *A. indica* and *D. sissoo*.

It was observed that in biomass production *A. auriculiformis* is superior in both above and below ground biomass production. Maximum above ground biomass of about 103.19 ton/ha, 112.64 ton/ha, 124.03 ton/ha, 134.27 ton/ha and 144.68 ton/ha at initial (120 months after initial reading), 3, 6, 9 and 12 months after initial reading respectively followed by *A. indica* and *D. sissoo* and maximum below ground biomass production was observed in case of *A. auriculiformis* at initial (120 months after initial reading), 3, 6, 9 and 12 months after initial reading followed by *A. indica* and *D. sissoo*.

Maximum carbon sequestration was observed in case of *A. auriculiformis* at initial reading, 3, 6, 9 and 12 months after initial reading of about 65.01 ton/ha, 70.96 ton/ha, 78.14 ton/ha, 84.59 ton/ha and 97.15 ton/ha respectively followed by *A. indica, and D. sissoo*.

Among the different tree species planted under shelter belt maximum form factor was noticed in *A. auriculiformis* (0.55) and lowest was noticed in *P. pinnata* (0.51) and maximum wood density was observed in *A. auriculiformis* 0.90 (g/cc) followed by *D. sissoo* 0.83 g/cc.

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CARBON SEQUESTRATION OF TEN YEAR OLD DIFFERENT TREE SPECIES PLANTED IN SHELTER BELT OF NORTHERN TRANSITIONAL ZONE OF KARNATAKA

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ABSTRACT

The study was conducted at the college of Agricultural Hanumanammatti of Haveri District to assess the performance of ten year old shelterbelt trees with respect to girth, height, volume, biomass (above and below ground biomass) and carbon sequestration. *Acacia auriculiformis*, *Azadirachta indica* and *Dalbergia sissoo* were found to be superior over the other species with respect to growth performance. *Acacia auriculiformis* showed higher biomass production with higher above and below ground biomass of 103.19 ton/ha, 26.83 ton/ha at 120 months after planting respectively. At 132 months after planting (11 year old) above and below ground biomass production increased to 144.68 ton/ha, 37.62 ton/ha respectively; about 65.01 ton/ha and 91.15 ton/ha at 10 and 11 year old trees respectively in *Acacia auriculiformis*.

Among the five tree species considered form factor ranged from 0.51 to 0.55. Highest tapering was observed in *Pongamia pinnata* followed by *Tectona grandis* and least was noticed in *Acacia auriculiformis*. This study suggests that *Acacia auriculiformis*, *Azadirachta indica* and *Dalbergia sissoo*, latter two species are preferred because of other advantages such as nitrogen fixation and traditional use as bio-pesticide.