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Full Length Research Paper

Carbon sequestration rate and aboveground biomass carbon potential of four young species

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Carbon is sequestered by the plant photosynthesis and stored as biomass in different parts of the tree. Carbon sequestration rate has been measured for young species (6 years age) of *Shorea robusta* at Chadra forest in Paschim Medinipur district, *Albizzia lebbek* in Indian Botanic Garden in Howrah district, *Tectona grandis* at Chilapata forest in Coochbehar district and *Artocarpus integrifolia* at Banobitan within Kolkata of West Bengal in India by Automated Vaisala Made Instrument GMP343 and aboveground biomass carbon has been analyzed by CHN analyzer. The specific objective of this article is to measure carbon sequestration rate and aboveground biomass carbon potential of four young species of *Shorea robusta, Albizzia lebbek, Tectona grandis* and *Artocarpus integrifolia.* The carbon sequestration rate (mean) from the ambient air during winter season as obtained by *Shorea robusta, Albizzia lebbek*, *Tectona grandis* and *Artocarpus integrifolia* were 11.13, 14.86 and 2.57 g/h in overcast skies and 4.22 g/h respectively. The annual carbon sequestration rate from ambient air were estimated at 8.97 t C ha^{-1} by *Shorea robusta,* 11.97 t C ha^{-1} by *Albizzia lebbek,* 2.07 t C ha^{-1} by *Tectona grandis* and 3.33 t C ha^{-1} by *Artocarpus integrifolia.* The percentage of carbon content (except root) in the aboveground biomass of *Shorea robusta, Albizzia lebbek, Tectona grandis* and *Artocarpus integrifolia* were 47.45, 47.12, 45.45 and 43.33, respectively. The total aboveground biomass carbon stock per hectare as estimated for *Shorea robusta, Albizzia lebbek, Tectona grandis* and *Artocarpus integrifolia* were 5.22, 6.26, 7.97 and 7.28 t C ha^{-1}, respectively in these forest stands.

Key words: *Shorea robusta, Albizzia lebbek, Tectona grandis, Artocarpus integrifolia,* carbon sequestration rate, aboveground biomass carbon stock.

INTRODUCTION

Carbon dioxide (CO_2) is a dominant greenhouse gas. Increased atmospheric CO_2 is attributable mostly to fossil fuel combustion and deforestation worldwide (Hamburg et al., 1997). Trees act as a sink for CO_2 by fixing carbon during photosynthesis and storing excess carbon as biomass. The net long term CO_2 source/sink dynamics of forests change through time as trees grow, die and decay. In addition, human influences on forests can further affect CO_2 source/sink dynamics of forests through such factors as fossil fuel emissions and harvesting/utilization of biomass (Nowak and Crane, 2002). As the tree biomass experience growth, the carbon held by the plant also increases carbon stock. The rate of carbon storage increases in young stands, but then declines as the stand ages. An observation from a study on pine species planted on cropland in the southeastern U.S., the rate of carbon storage begins to decline at approximately age 20 and is close to zero by age 100 (Veld and Plantinga, 2005).

Increasing the atmospheric CO_2 concentration stimu-lates the photosynthetic rate of trees and can result in in-creased growth rates and biomass production. Results from free air CO_2 enrichment (FACE) experiments show a 25% increase in growth in twice normal concentrations of CO_2. Growth is therefore almost always higher in air with an elevated concentration of CO_2 (Burley et al., 2004). Scientific evidence suggests that increased atmospheric CO_2 could have positive effect such as improved plant productivity (Schaffer et al., 1997; Pan et al., 1998; Cen-tritto et al., 1999a, b; I dso and Kimball, 2001; Keutgen

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and Chen, 2001). Lal et al. (2000) reported that estimated annual carbon uptake increment by Indian forests and plantations have been able to remove about 0.12 Gt of CO_2 from the atmosphere in the year 1995. Ravindranath et al. (1997) reported the Indian forests based on the for-est sector of the year 1986 could sequester around 5 Tg C (1 Tg = Tera gram, 10^{12} g). A study reported by Warran and Patwardhan on carbon sequestration potential of trees that the standing biomass in India is estimated to be 8375 million tons (M t) for the year 1986, of which the carbon storage would be 4178 M t. The total carbon stor-ed in forests, including soil is estimated to be 9578 M t (Warran and Patwardhan, 2008). Haripriya, 2003 noted on the average biomass carbon of the forest ecosystems in India for the year 1994 was 46 Mg C ha^{-1}, of which nearly 76% was in aboveground biomass and the rest was in fine and coarse root biomass. The total carbon stock (wood only) for India was 1085.06 and 1083.69 M t in 1984 and 1994 respectively. The average carbon stock for the country was 24.94 t C ha^{-1} in 1984 and 24.54 t C ha^{-1} in 1994. *Shorea robusta* forests stocked 24.07 t C ha^{-1} in 1984 and 22.66 t C ha^{-1} in 1994, while *Tectona grandis* forests stocked 11.44 t C ha^{-1} in 1984 and 11.25 t C ha^{-1} in 1994 (Manhas et al., 2006) . In West Bengal, to-tal carbon stock of *S. robusta* and T *. grandis* were 5.49 M t in 1984 and 6.19 M t in 1994, and 0.29 M t in 1984 and 0.30 M t in 1994, respectively (Manhas et al., 2006).

The total area of the World's forests at 3.952 billion hectare (more or less same as 1948) (FRA, 2005), which was about 30% of the total land area of the world. It is estimated that the world's forests store 283 G t of Carbon in their biomass alone, and 638 G t of carbon in the eco-system as a whole including dead wood, litter and soil up to 30 cm depth. As per FRA (2005) the total forest cover in India was 677088 sq km which constituted 20.60% of the geographic area of the country. The forest cover of West Bengal, based on Satellite data of Nov. - Dec, 2004, was 12413 sq km, which was 13.99% of the geo-graphic area (FSI, 2005). Vast forest areas in India as well as its different provincial states accumulated a large amount of carbon as CO_2 from the atmosphere and play an important role for sequestering carbon in the regional, national and world scenarios. Terrestrial (plant and soil) carbon was estimated at 2000 ± 500 Pg, which repre-sented 25% of global carbon stocks. The analysis of C stocks from various parts of the world showed that signi-ficant quantities of C (1.1 - 2.2 Pg) could be removed from the atmosphere over the next 50 years if agro fores-try systems are implemented on a global scale (FSI, 2005). Studies carried out by different scientists for diffe-rent countries in the earth showed that United States for-ests 12.1 Pg (Turner et al., 1995), European forests ac-cumulated 7.5 Pg of carbon (Kaupii et al., 1992), Chi-nese forests stocked 4.63 Pg (Fang et al., 2001) and Ja-panese forests accumulated 1.39 Pg carbon (Alexandrov et al., 1999). Alexeyev et al. (1995), Isaev et al. (1995) and Krankina et al. (1996) noted that Russian forest ac-cumulated a large amount of carbon which was 28.04, 35.07 and 42.1 Pg respectively (Manhas et al., 2006).

Earlier carbon sequestration works were made based on the concept of static biomass carbon with a longer time scale where diurnal carbon sequestration rate (mi-nute scale) has not been considered. Earlier works have only considered a concept of linear (proportionate) car-bon sequestration as well as biomass, which is practically not feasible in the natural system. As per the knowledge of authors, the determination of diurnal carbon seque-stration rate of any plant species is hitherto undone and this work has been attempted for the first time in this field. This study emphasizes the diurnal carbon sequestration rate and biomass carbon content of young (6 years age) *S. robusta* (Sal), *Albizzia lebbek* (Sirish), *T. grandis* (Se-gun) and *Artocarpus integrifolia* (Jackfruit) analyzed through CHN Analyzer. The sites were located at Chadra in Paschim Medinipur district for *S. robusta,* at Indian Bo-tanic Garden in Howrah districts for *Albizzia lebbek*, at Chilapata forest in Coochbehar district for *Tectona grandis* and at Banobitan within Kolkata for *Artocarpus in-tegrifolia* of the state of West Bengal in India.

The study has been carried out by the Regional Centre of National Afforestation and Ecodevelopment Board (NAEB), Ministry of Environment and Forest, Government of India, Jadavpur University in association with the Sch-ool of Water Resources Engineering, Jadavpur University in Kolkata. The specific objective of this study is to mea-sure carbon sequestration rate and aboveground bio-mass carbon potential of these young plant species.

The site and study area

The sites and study areas for measurement of carbon se-questration rate and aboveground biomass carbon poten-tial of *S. robusta* (Sal), *Albizzia lebbek* (Sirish), *Tectona grandis* (Segun) and *Artocarpus integrifolia* (Jackfruit) are described one by one. The study area of *S. robusta* is a tropical dry deciduous forest, located at Chadra in the Paschim Medinipur district of West Bengal and situated at 22°25'N latitude and 87°19'E longitude (DSH, 2004). The general climate of the area is seasonal tropical. Dur-ing summer period the mean daily ambient temperature varied from 12°C to 39°C with mean relative humidity ranged from 46 - 89% at 8:30 h. During the monsoon pe-riod, the area received an average rainfall of 1490 mm (DSH, 2005) . The soil of the study area belongs to red la-teritic ultisol which was derived from parent pegmatic rock.

Texturally it is classified as loam, sandy loam or clay loam type (Mallick et al., 2007). The location of Chadra forest is shown in Figure 1. The selected plant species was *S. robusta* of 6 years age. The study has been car-ried out on 10 *S. robusta* trees of 6 m height (approx) and average diameter at breast height of 11.1 cm. The forest was mainly consists of same aged *Shorea robusta* spe-cies. The study considered 4 numbers quadrates of 30

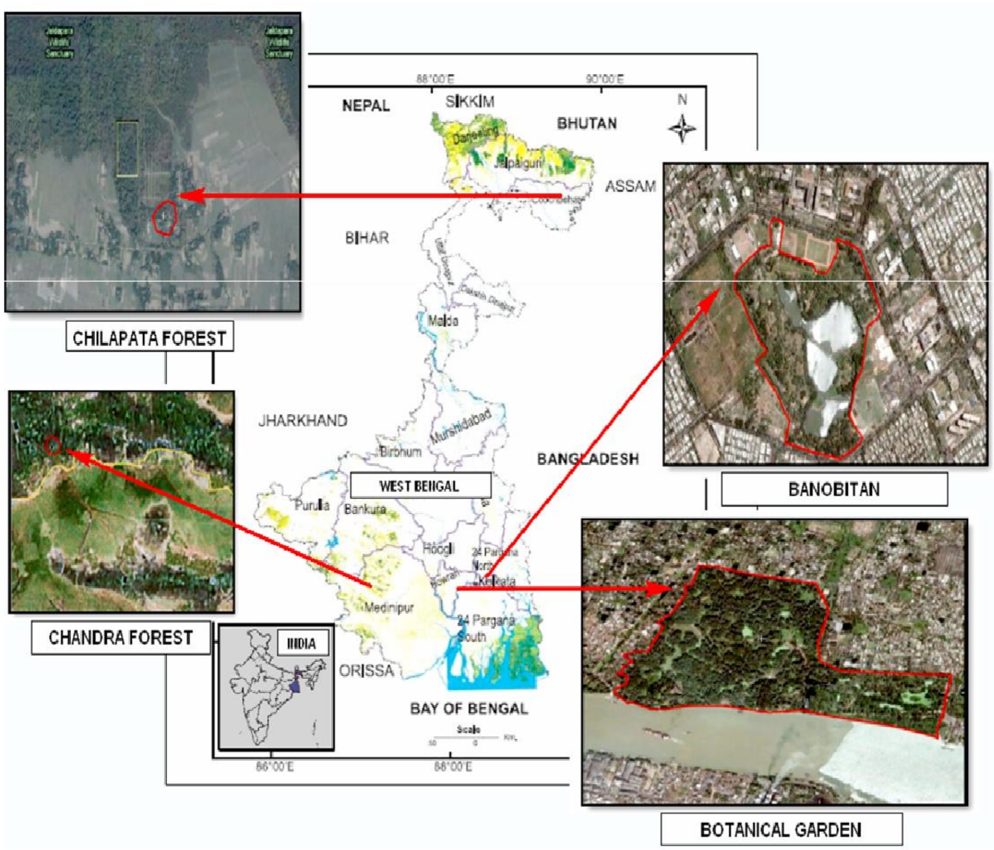

Figure 1. Location of all sites.

x 30 m area within which average 81 *S. robusta* tree species of same age and height were available. Since the forest and the quadrates consist of only Shorea robusta species, we have listed the numbers of trees within each quadrate. Selected *S. robusta* tree was located at 3 km away from the existing road on which vehicular movement on the road was less.

The Indian Botanic Garden, established in 1787, is situated on the west bank of the river Ganga (Hooghly) in Howrah district of West Bengal, India at a distance of 8 km from Howrah railway station and 25 km from Calcutta International Airport (Netaji International Airport) (Figure 1). The Indian Botanic Garden covered an area of about The Indian Botanic Garden covered an area of about 110.52 ha and divided into 25 sections or divisions. There were 24 lakes in the garden. The garden was the living respiratory of more than 12000 trees, shrubs and climbers representing over 1400 species together with a large number of wild and cultivated herbs (Chowdhery, 2001,).

Four numbers of Albizzia lebbek of 6 years age and average height of 5m were selected for the study. The garden consisted mixed type of man made plantations of different species. It was situated just in front of the Central National Herbarium (CNH) building. This monitoring site was located at a distance of 500 m from the main gate. The Elevation of the working site, as measured by GPS, was Latitude 22° 33.42'N and Longitude 88° 17.25'E. Altitude of the area was 12 m above MSL. The general climate of the area was seasonal tropical. The climatological data has been collated from Alipur observatory, Indian Meteorological Department (IMD, 1991-2005). The mean daily ambient temperature in the area varied from 15 - 35°C with mean relative humidity ranged from 53 - 86%. The area received an average annual rainfall of 1823 mm texturally the soil of the study area was classified as silty clay.

Chilapata Forest in Coochbehar District had an area of 1975.18 ha. The Elevation of the working site, as measured by GPS, was Latitude 26° 32.85'N and Longitude 89° 22.99'E. Altitude of the area was 47 m above MSL. The location of Chilapata forest is shown in Figure. 1. The forest was surrounded by Malangi and Hasimara ri-vers in east and south. The forest had northern dry and mixed deciduous forest. Most of the trees present in the forest were tall and flourished. The forest was mainly composed of Sissoo, Khair, Segun, Chatim, Sal, etc. The selected plant species were *Tectona grandis* (Segun) of 6 years age and have been studied on 10 number of Tec-tona grandis species.

Banobitan is one of the largest man-made urban forest at Salt Lake in Kolkata metro city under the Forest Department of Government of West Bengal. It is also known as Central-Park. The location of Banobitan is shown in Figure 1. It has varieties of plant species among which few were very rare and uncommon. But as it is used for a visiting place in Kolkata, that’s why the plant species were not so dense. The garden was very well- maintained to the plant species. It has a large-lake inside the garden. 4 numbers of *Artocarpus integrifolia* of 6 years age have been selected for the study. The trees were located at a distance of around 250 m from the main entrance of the forest and 20 m from the lake and situated on left side of the lake. The plant species had a suitable height of 5 m.

MATERIALS AND METHODS

Carbon dioxide measurement

Carbon dioxide (CO_2) has been measured by Automated Vaisala Made Instrument, GMP343 and the data has been collected continuously for 24 h basis. CO_2 has been measured for: (i) ambient air within and outside the forest areas and (ii) carbon sequestration rate from ambient air of 4 young species. Ambient CO_2 monitoring has been carried out for 24 h within and outside the forest areas depending upon the wind direction to measure the CO_2 intake by the forest patch. Carbon sequestration rate of different species has been measured in Closed Top Chamber (CTC) covered with transparent plastic, within which carbon sequestration rate measured by GMP343. It is to be noted that photosynthesis and respiration occurs simultaneously during day and only respiration during night time. Therefore, CO_2 absorption and CO_2 emission both occurs during daytime and only CO_2 emission occurs during night time. Carbon sequestration rate by the plant has been evaluated by considering the photosynthesis and respiration during day and night time. The respirated CO_2 emission by the plant has been eliminated from the total concentration of CO_2 with respect to time. The volume of covered plastic for the tree has been calculated. The bottom portion of the plastic was dipped into the soil to avoid any CO_2 contamination with the ambient air. So, soil respiration CO_2 has been eliminated to estimate the actual carbon sequestration rate of the plant.

Like other factors, influence of humidity on carbon sequestration rate of the plant has been ignored to emphasize the carbon sequestration study.

Measurement of above ground biomass of the tree

The biomass of the tree within a forest includes above ground biomass which include all above ground living materials (stem, branches, leaves) and below ground or root biomass which consist of coarse roots and stumps. The estimation of the biomass in the stem was performed by knowing the tree height, diameter, and girth size at different heights, etc. These have been measured by Spiegel Relascope and wood volume of the whole tree has been calculated by these data. Weight of the wood biomass has been calculated by multiplying volume of biomass and specific gravity (SG) of the wood, as per the below mentioned calculation where specific gravity (SG) is the ratio of oven dry weight and green volume of the pieces of wood samples. Leaf biomass has been calculated by the gravimetric method. Total number of leaves present in the tree has been counted from total number of branches and average number of leaves present in a branch. Few of the leaves of the tree were taken and their fresh weight was measured as well as dry weight after properly dried at 70°C for 7 days to a constant weight. From this the biomass of those leaves has been measured /calculated by gravimetric method.

The root biomass has not been measured at this moment as the other research works will be conducted on this tree in future.

In the present study we have estimated the aboveground biomass stock and aboveground biomass carbon of four species by taking volume of biomass and specific gravity (SG) of the tree, as per Rajput et al. (1996) and Negi et al. (2003).

Biomass (g) = Volume of biomass (m^3) X Specific gravity (SG)

Where;
SG = Oven dry weight / Green volume
Carbon = Biomass X carbon %

Carbon content in above ground biomass

The carbon content of different biomass such as stems, branches and leaves has been measured by taken samples and sent them to Indian Association for Cultivation of Science for estimation of carbon content by CHN Analyzer (PerkinElmer 2400 series II CHNS/O Elemental Analyzer) . A certain amount of biomass samples have been collected from the particular stems, branches and leaves and after being properly dried at 70°C for about 7 days to a constant weight, the carbon content of the samples have been analyzed and carbon content has been estimated as per the above calculation.

RESULTS AND DISCUSSION

Ambient CO_2 level

At Chadra, ambient CO_2 has been measured during winter season at two locations, one at outside forest and other at inside forest near the tree. Distance between the two locations was about 150 m. It could be observed that average CO_2 levels in ambient air were 414.98 ppm at outside the forest and 402.10 ppm near the *S. robusta* tree. In between the two locations CO_2 concentration decreased to 12.88 ppm. This may be concluded that 12.88 ppm CO_2 concentration decreased due to the forest patch between two locations.

Likewise, ambient CO_2 has been measured at two locations in Indian Botanic Garden, one at outside the garden near the gate and other within the garden near the tree. Distance between the two locations was 500 m. It is observed that average CO_2 levels in ambient air were 383. 82 ppm at outside the garden near Bakultala gate and 359.13 ppm near the *Albizzia lebbek* tree. This is expected that roadside CO_2 level at Bakultala gate was higher than inside garden near the tree. In between the two locations, CO_2 concentration decreased to 24.69 ppm. This reveals that 24.69 ppm CO_2 was sequestered by the plants between two locations.

At Chilapata, ambient CO_2 has been measured at two locations, one at inside the forest and other outside the forest. Distance between the two locations was about 300 m. It is observed that CO_2 levels in ambient air were 379.50 ppm at outside forest and 380.43 ppm inside the forest. It is noticed that the trees were mostly without leaves. Hence, the difference of ambient CO_2 level inside and outside the forest was negligible. It may be expected that in calm and clear sunny day this may have a definite

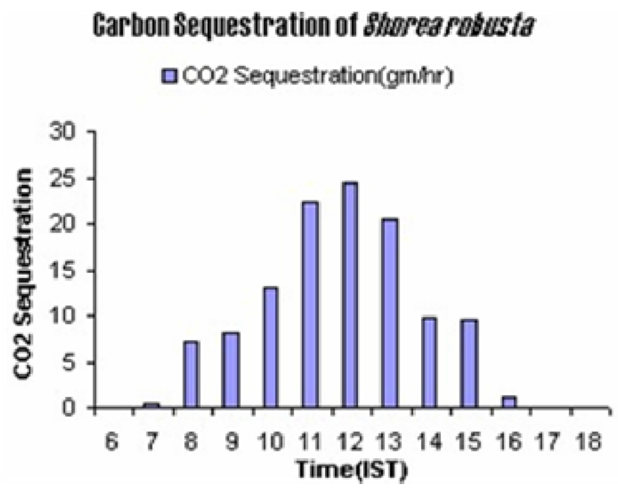

Figure 2. Carbon sequestration rate by *Shorea robusta.*

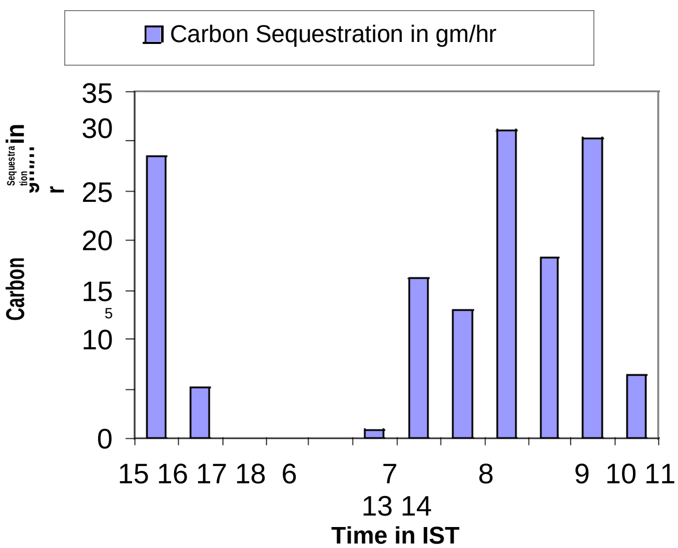

Figure 3. Carbon sequestration rate by *Albizzia lebbek.*

difference of CO_2 level.

At Banobitan, ambient CO_2 has been measured at two locations, one at near the *Artocarpus integrifolia* tree inside the forest and other near the Banobitan Gate. It is observed that CO_2 level in ambient air were 419.62 ppm at Banobitan Gate and 377.65 ppm near the *Artocarpus integrifolia* tree. This is expected that roadside CO_2 level at Banobitan Gate was higher than inside garden near the tree and difference of these two observations was 41.97 ppm. This means 41.97 ppm CO_2 was sequestered by the plants between two locations.

Carbon sequestration rate (CSR) by *Shorea robusta*, *Albizzia lebbek*, *Tectona grandis* and *Artocarpus integrifolia*

Carbon sequestration rate is to measure how much carbon can be sequestered by a tree over a certain period (example, hour or day or month or year). In a forest ecosystem, the CSR is closely related to climatic conditions, soil properties, tree species, stand age and the forest rotation length (Graham et al., 1992; and Niu and Duiker, 2006).

Carbon dioxide is captured by the plant during photosynthesis. Carbon dioxide taken up by the Sal tree (*Shorea robusta*) has been measured for 24 h during winter season and the observations are shown graphically in Figure 2. It is observed that at 7:00 h carbon dioxide sequestration rate was 0.52 gm/h. CO_2 sequestration rate increased to a level of 8.13 gm/h at 9:00 h. At 12:00 h, CO_2 sequestration rate reached to 24.30 gm/h to its maxi-mum. In the afternoon, sunlight decreased rapidly. So, that time CO_2 emission through respiration was higher than the CO_2 absorption by the plant. At 17:00 h sunlight absolutely was absent and the photosynthesis process turned to an end. Therefore, during 17:00 h to 7:00 h CO_2 level increased due to plant respiration. CO_2 concen-tration increased by respiration during nighttime in ab-sence of photosynthesis process. At 14:00 h CO_2 seque-stration rate reached to 9.82 gm/h and at 16:00 h CO_2 se-questration rate decreased to 1.17 gm/h.

Similarly, carbon dioxide taken up by the *Albizzia lebbek* was measured (Figure 3). It is observed that on the starting day at 15:00 h carbon dioxide sequestration rate was 28.49 gm/h. CO_2 sequestration rate decreased to the level of 5.16 gm/h at 16:00 h.
At 17:00 h sunlight was absent. Therefore, during 17:00 h to 7:00 h on the next day CO_2 level increased due to plant respiration. In the afternoon, sunlight was decreased rapidly. So, that time CO_2 emission through respiration was higher than the CO_2 absorption by the plant. The CO_2 concentration was increased by respiration during night time in absence of photosynthesis process. At 7:00 h, CO_2 sequestration rate reached to 0.89 gm/h. At 8:00 h CO_2 sequestration rate reached to 16.25 gm/h and at 10:00 h CO_2 sequestration rate increased to the maximum at 31.10 gm/h. The rate of sequestration at 13:00 h reached to 30.19 gm/h and at 14:00 h, CO_2 sequestration rate attained to a level of 6.24 gm/h. The rate of CO_2 sequestration sometimes varied may be due to presence of solar light and other factors affecting photosynthesis.

At Chilapata, we have started monitoring from 12:00 h at CO_2 sequestration rate 2.42 gm/h. Maximum CO_2 sequestration observed 5.02 gm/h at 13:00 h. CO_2 sequestration rate decreased to 2.82 gm/h at 15:00 h and 2.86 gm/h at 17:00 h. At 7:00 h in the next day, no CO_2 sequestration observed due to overcast skies. At 8:00hour CO_2 sequestration rate reached to 2.17gm/h and at 10:00 h CO_2 sequestration rate decreased to 1.86 gm/h. Due to rainfall and bad weather (in overcast skies), CO_2 released by respiration was higher than the CO_2 received by the photosynthesis and hence the CO_2 level increased during daytime (Figure 4.).

Carbon dioxide taken up by the *Artocarpus integrifolia* has been measured during winter season and carbon se-

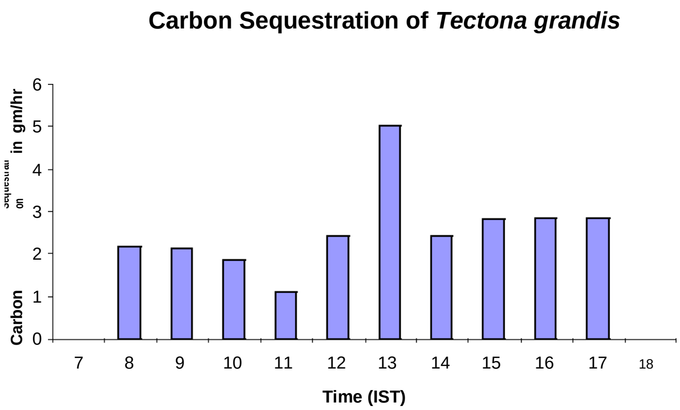

Figure 4. Carbon sequestration rate of *Tectona grandis.*

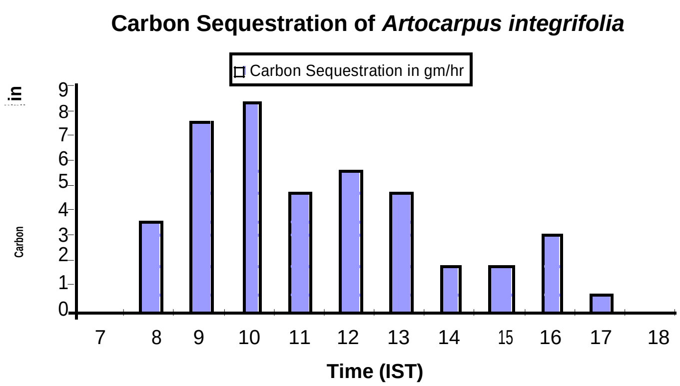

Figure 5. Carbon sequestration rate of *Artocarpus integrifolia.*

questration rate of *Artocarpus integrifolia* is shown graphically in Figure 5. We have started monitoring from 12:00 h at CO_2 sequestration rate 5.56 gm/h. CO_2 sequestration reached to 2.12 gm/h at 15:00 h and 0.61 gm/h at 17:00 h. Between 6:00 - 9:00 h CO_2 sequestration rate reached to 7.48 gm/h and at 10:00 h, CO_2 sequestration rate reached to maximum of 8.52 gm/h with the increase of sunlight.

It could be observed from the result of carbon sequestration rate during winter season that the average CO_2 sequestration rate from the ambient air obtained by *Shorea robusta* at Chadra forest, *Albizzia lebbek* at Botanical Garden, *Tectona grandis* at Chilapata forest and *Artocarpus integrifolia* at Banobitan were 11.13 gm/h (equivalent to 3.03 gm C/h), 14.86 gm/h (equivalent to 4.05 gm C/h), 2.57 gm/h (equivalent to 0.70 gm C/h) and 4.22 gm/h (equivalent to 1.15 gm C/h)(Jana et al., 2008), respectively. This may be expected a little change of carbon sequestration rate by these species during summer season due to long duration of sunlight. The rate of carbon sequestration depends on the growth characteristics of the tree species, the conditions for growth where the tree is planted, and the density of the tree's wood. This can be observed that carbon sequestration rate of *A. lebbek* from ambient air was highest, followed by *S. robusta, A. integrifolia* and *T. grandis.* Annual carbon sequestration rate from ambient air estimated for all young *species* of 6 years age by considering annual mean duration of effect-tive sunlight for photosynthesis at the rate of 9 h in a day was 0.99 X 10^{-2} t C per tree and 8.97 t C ha^{-1} in this forest stand. Similarly, annual carbon sequestration rate from ambient air estimated for young *A. lebbek* of 6 years age was 1.33 X 10^{-2} t C per tree. As the Botanical garden has mixed type of plantation, we have considered 81number of *A. lebbek* species present in 30 m X 30 m quadrate to compare with the carbon sequestration rate of *S. robusta.* Therefore, annual carbon sequestration rate from am-bient air estimated for young *A. lebbek* of 6 years age was 11.97 t C ha^{-1} (as per the consideration). This carbon sequestration rate may be expected to increase with the increase of forest stand ages. Similarly, the carbon se-questration rate have been evaluated as per the above consideration for *Tectona grandis* and *Artocarpus inte-grifolia* and annual carbon sequestration rate from am-bient air estimated for young *species* of 6 years age were 0.23X 10^{-2} t C per tree with 2.07 t C ha^{-1} for *Tectona grandis* and 0.37X 10^{-2} t C per tree with 3.33 t C ha^{-1} for *Artocarpus integrifolia.* It could be noted that carbon se-questration rate of *Tectona grandis* from ambient air might be increased during the clear sunny days.

Biomass carbon content

The above ground biomass of the tree such as stems, branches and leaves (except root) have been collected and dried at laboratory, and the dry biomass of the different sections of the tree are presented in Table 1. The result of biomass analysis through CHN Analyzer is presented in Table 2. It is observed for *Shorea robusta* that leaf and stem contained 49.09 and 46.88% carbon, respectively. For *A. lebbek*, leaf and stem contained 48.84 and 46.12% carbon. For *T. grandis* and *A. integrifolia*, leaf contained 43.98 and 41.01% carbon and stem contained 46.93 and 45.65% carbon respectively. Total carbon stock of a tree has been evaluated by adding all the carbon contents of stems, branches and leaves of the tree. Carbon content of the tree was established by the works of different Scientists and Researchers, the carbon content in the plant was approximately 50% of the dry matter (WB, 1998). The carbon concentration of different tree parts was rarely measured directly, but generally assumed to be 50% of the dry weight (Losi et al., 2003). Work of Losi et al. (2003) obtained that measured carbon content of dry sample was 47.8% for *A. excelsum* and 48.5% for *D. panamensis*. West (2003) reported in his paper that "Extensive studies in Australia recently of a variety of tree species showed above ground dry biomass generally contain 50% carbon. These proportions of carbon in aboveground biomass agreed closely with values of 49 and 47% reported from other parts of the world for

Table 1. Total above ground dry biomass of the tree.

Study area	Tree	Total weight of dry stem and branch biomass (gm)	Total weight of dry leaves biomass (gm)	Total dry biomass(gm) of the tree (except root)
Chadra forest	*Shorea robusta*	9035	3187	12222
Botanical garden	*Albizzia lebbek*	9309	5463	14772
Chilapata forest	*Tectona grandis*	9690	9800	19490
Banobitan	*Artocarpus integrifolia*	7599	11286	18885

Table 2. Biomass analysis results.

Tree	Parts of the Plant	C (%)
Shorea robusta	Leaf	49.09
	Stem	46.88
Albizzia lebbek	Leaf	48.84
	Stem	46.12
Tectona grandis	Leaf	43.98
	Stem	46.93
Artocarpus integrifolia	Leaf	41.01
	Stem	45.65

Pinus taeda (Kinerson et al., 1977) and *Populus* spp. (Deraedt and Ceulemans, 1998)". The total carbon content in *Shorea robusta*, *Albizzia lebbek, Tectona grandis* and *Artocarpus integrifolia* are presented in Table 3.

It is observed from Table 3 that the total carbon content of the whole tree (excluding root) of *Shorea robusta*, *Albizzia lebbek* , *Tectona grandis* and *Artocarpus integrifolia* trees were 5800, 6961, 8857 and 8097g, respectively. This may be concluded that the percentage of total carbon content in the biomass was 47.45 in *S. robusta,* 47.12 in *A. lebbek,* 45.45 in *T. grandis* and 43.33 in *A. integrifolia.* Negi et al. (2003) reported that carbon content in *Shorea robusta* tree was 46%, while our analyzed data has shown leaf and stem contained 49.09 and 46.88% in *Shorea robusta* tree which were slightly higher. Percentage of carbon content of *A. lebbek* was lower than *S. robusta* followed by *Tectona grandis* and *A. integrifolia.* Total aboveground biomass carbon stock per hectare has been estimated from the aboveground biomass carbon content in 81 *S. robusta* trees (6 years age) within 30m X 30 m quadrate in the study area and total aboveground biomass carbon per hectare as estimated was 5.22 t C ha^{-1}. Likewise, total aboveground biomass carbon stock per hectare has been estimated from the aboveground biomass carbon content in 81 *A. lebbek* trees (6 years age) present in 30m X 30m quadrate (as per consideration) . It is estimated that total aboveground biomass carbon per hectare for *A. lebbek* was 6.26 t C ha^{-1}. Likewise, for other two species total aboveground biomass carbon per hectare for *Tectona grandis* and *A. integrifolia* were 7.97 t C ha^{-1} and 7.28 t C ha^{-1} respectively. It may be concluded that total above ground biomass carbon per hectare of *T. grandis* was higher than *A. integrifolia,* followed by *A. lebbek* and *S. robusta*.

Carbon pool partition of 6 years age *Shorea robusta*, *Albizzia lebbek, Tectona grandis* and *Artocarpus integrifolia* is shown in Figure 6. Maximum carbon pools in a forest ecosystem primarily stored in aboveground tree biomass (Haripriya, 2003). It is estimated that annual above ground biomass carbon pools of 4 young species were observed to yield 0.87 t C ha^{-1} yr^{-1} for *S. robusta,* 1.04 t C ha^{-1} yr $^{-1}$ for *A. lebbek,* 1.33 t C ha^{-1}yr^{-1} for *T. gran-dis* and 1.21 t C ha^{-1}yr^{-1} for *A. integrifolia.* A short rotation plantation of 20 years age of hybrid poplar (Populus spp.) in Minnesota was estimated to average yield 1.8- 3.1 t C ha^{-1}yr^{-1} (Updegraff et al., 2004) and our estimated annual above ground biomass carbon pools were lower than above research. Niu et al. (2006) estimated that in 20 years after afforestation a total of about 52 t C ha^{-1} could be sequestered in above ground tree biomass carbon of both conifers and deciduous forests. Our estimated above ground tree biomass carbon at 20 years age (by li-near/ proportionate estimation) will be 17.4 t C ha^{-1} for *S. robusta*, 20.86 t C ha^{-1} for *A. lebbek,* 26.6 t C ha^{-1} for *T. grandis* and 24.2 t C ha^{-1} for *A. integrifolia* which were lower to the Niu et al. (2006) estimation. Earlier estima-tion was made based on linear /proportionate calculation. Normally tree biomass growth increases rapidly up to 20 - 50 years, not following any linear equation. According to Marland and Marland (1992), it could be expected from our study that tree growth above ground biomass of *S. robusta*, *A. lebbek* , *T. grandis* and *A. integrifolia* will reach to the close value of Niu et al. (2006) estimation. A simp-lified model proposed by Marland and Marland (1992) was used to simulate aboveground tree biomass carbon growth, in which the biomass carbon accumulates linearly until half of the maximum yield is reached and the growth slows down subsequently to reach the maximum yield asymptotically. A cumulative growth of aboveground tree biomass over time is illustrated in Figure 7 (Niu et al., 2006). At 6 years age, average above ground tree biomass carbon (accumulative biomass carbon) was esti-mated to 18 t C ha^{-1} from Marland and Marland work, whereas our average aboveground tree biomass carbon (accumulative biomass carbon) for *Shorea robusta, A. lebbek*, *T. grandis* and *A. integrifolia* were estimated to 5.22 t C ha^{-1}, 6.26 t C ha^{-1}, 7.97 t C ha^{-1} and 7.28 t C ha^{-1} resp-ectively. It could be concluded that above ground tree

Table 3. Carbon content of the aboveground biomass.

Tree	Carbon content in	Carbon content in individual sample (%)	Total carbon content in the plant species (g)
Shorea robusta	Leaf	49.09	1564.49
	Stem	46.88	4236.00
Total carbon content in the plant			5,800.49
Albizzia lebbek	Leaf	48.84	2668.12
	Stem	46.12	4293.49
Total carbon content in the plant			6961.61
Tectona grandis	Leaf	43.98	4310.04
	Stem	46.93	4547.69
Total carbon content in the plant			8857.73
Artocarpus integrifolia	Leaf	41.01	4628.38
	Stem	45.65	3469.31
Total carbon content in the plant			8097.69

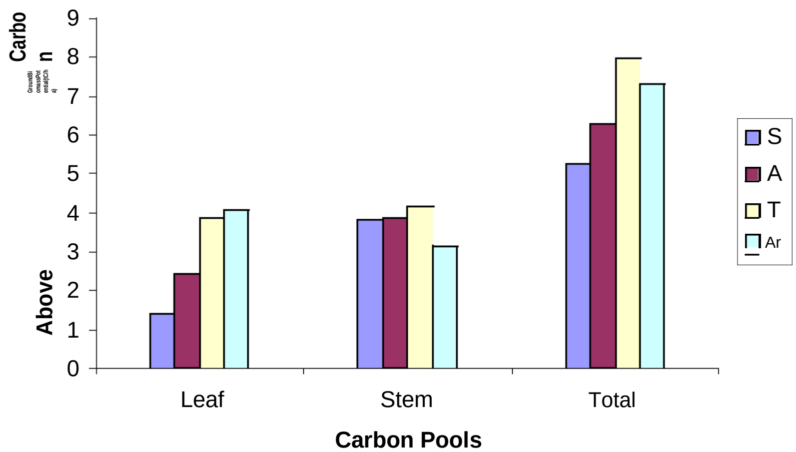

Figure 6. Portioning of above ground biomass carbon pools of 6 years age *Shorea robusta, Albizzia lebbek, Tectona grandis* and *Artocarpus integrifolia.*

S = *Shorea robusta*, A = *Albizzia lebbek,* T = *Tectona grandis, Ar = Artocarpus integrifolia*

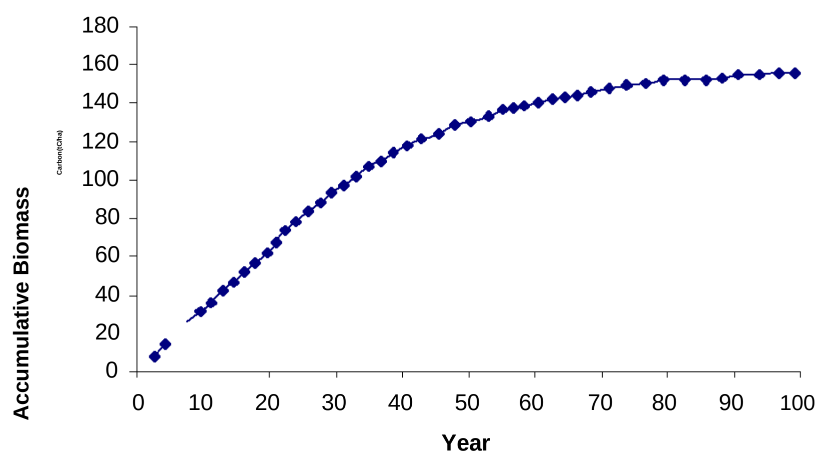

Figure 7. A general tree growth model (Adopted from Marland and Marland, 1992).

Table 4. Different research works on carbon stock per hectare in India.

Year	Components	Carbon stock (t C ha^{-1})	References
1985	AG+BG	31.07	Dadhwal and Nayak (1993)
1986	AG+BG	58.77	Ravindranath et al. (1997)
1988	AG+BG	54.52	Chhabra et al. (2002)
1993	AG+BG	61.06	Chhabra et al. (2002)
1995	AG+BG	31.72	Lal and Singh (2000)
1984	Wood	16.98	Manhas et al. (2006)
1994	Wood	17.12	Manhas et al. (2006)
2008	AG	5.22	Present study on *Shorea robusta* of 6 yrs age
2008	AG	6.26	Present study on *Albizzia lebbek* of 6 yrs age
2008	AG	7.97	Present study on *Tectona grandis* of 6 yrs age
2008	AG	7.28	Present study on *Artocarpus integrifolia* of 6 yrs age

AG = aboveground and BG = belowground

tree carbon biomass of *S. robusta*, *A. lebbek, T. grandis* and *A. integrifolia* were lower than the Marland and Marland (1992) estimation. This may be due to different forest types, site qualities, climatic conditions, non hybrid species and only 6 years age species (stand age). Different Scientists on their research works were find out carbon stock per hectare in India (Table 4) and carbon stock per hectare find out by our study has been compared.

Earlier estimates by different scientists were higher than our estimate. The reasons for low carbon stock as estimated by our work may be due to: consideration of only above ground biomass, only one tree from each species considered for this estimation, very young S. robusta, A. lebbek, T. grandis and A. integrifolia of 6 years age and worked in similar agro-climatic areas. Earlier works were estimated mostly based on aboveground and below ground carbon biomass, considered different age groups, different species and different agro- climatic areas, for which carbon stock per hectare may be in higher side. With the progress of the forest stand ages, canopy cover and biomass of the trees will experience more rapid growth to a certain age (20 - 50 years) and the carbon held by these plants will also increase more biomass carbon stock to its optimum level (Marland and Marland, 1992).

Conclusion

This study illustrates diurnal carbon sequestration rate and aboveground biomass carbon potential of young *S. robusta*, *A. lebbek, T. grandis* and *A. integrifolia*. The article concludes that carbon sequestration rate from the ambient air as obtained by *S. robusta* at Chadra forest, *A. lebbek* at Botanical Garden, *T. grandis* at Chilapata forest and *A. integrifolia* at Banobitan during winter season were 11.13 g/h with annual carbon sequestration rate 8.97 t C ha^{-1} ' 14.86 g/h with annual carbon sequestration rate 11.97 t C ha^{-1} , 2.57 g/h with annual carbon sequestration rate 2.07 t C ha^{-1} in overcast skies and 4.22 g/h with annual carbon sequestration rate 3.33 t C ha^{-1} respectively.

Percentage of carbon content in the aboveground biomass of *S. robusta*, *A. lebbek*, *T. grandis* and *A. integrifolia* were 47.45, 47.12, 45.45 and 43.33 respectively. Total aboveground biomass carbon stock per hectare for *S. robusta*, A. *lebbek, T. grandis and A. integrifolia* as estimated were 5.22 t C ha^{-1}, 6.26 t C ha^{-1}, 7.97 t C ha^{-1} and 7.28 t C ha^{-1} respectively. It could be concluded that our estimated results were lower than the previous works done by different scientists, may be due to consideration of one tree from each species, very young ages plant, only aboveground biomass carbon considered, chosen similar agro- climatic areas for study, similar soil characteristics, etc. More outcomes from this study may be expected if this study can be carried out in longer time scale with more species in different agroclimatic zones.

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