Carbon sequestration potential of a teak plantation forest in the Eastern Ghats of India

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Abstract

Aim: The present study aimed to estimate the total carbon sequestration potential of a 20-years-old teak (*Tectona grandis*) plantation forest spread over an area of 23 ha (in Odisha under Eastern Ghats stretch) through analysis of above ground and below ground biomass carbon of trees and soil organic carbon (SOC) stock.

Methodology: The sampling was carried out during May to July 2017. Random non-destructive quadrat method was used for vegetation analysis. Based on the girth, height, basal area and bio volume of trees, the above ground carbon (AGC), below ground carbon (BGC) and total carbon storage in biomass (CSB) of teak plantation forest was calculated. Similarly, soil samples were taken by a soil core sampler at different depths and based on their organic carbon, bulk density, stone and gravel contents, soil organic carbon (SOC) stocks of soil was calculated.

Results: The total SOC stock and CSB of the entire teak plantation forest was 489.21 t and 6670 t, respectively, across an area of 23 ha. Taking two carbon pools into account, the total carbon sequestration (TCS) of teak plantation forest patch was 7159.21 t, which arrived to be 311.27 t ha⁻¹ with AGC of 230.16 t ha⁻¹ and BGC of 59.84 t ha⁻¹ and TOC stock of 21.27 t ha⁻¹. The highest contribution in terms of carbon storage was established by above ground carbon (74%) followed by below ground carbon (19%) and SOC (7%).

Interpretation: The current study reflects that teak plantation forest has rich potential of carbon sequestration not only in tree biomass but also in the SOC form and this plantation can act as a potent reservoir of carbon in the Eastern Ghats of India.

Key words: Carbon sequestration, Eastern ghats, Ground carbon, Soil organic, Teak plantation

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Introduction

With increase in industrialization, urbanization, motorization, developmental activities, coupled with human population growth, the concentration of carbon dioxide is increasing rapidly day by day. Carbon dioxide being a potent greenhouse gas is the prime reason for global warming. The land use and land cover change (LULCC) in the past decades have also been responsible for the disturbance of source to sink ratio of carbon dioxide (Canaveira, 2014). Moreover, the land use, land use change and forestry (LULUCF) is different from other sectors like energy, industries, agriculture etc., because it acts as both source and sink of carbon dioxide, serves as carbon stock and is much influenced by natural disasters like flood, droughts, wildfires etc. Terrestrial carbon sequestration is around 27% of the total global CO₂ when compared to 47% of the ocean. It is also reported that when there is an alteration in the land use of an area, carbon sequestration value approaches to the mean average of particular land use (Iversen *et al.*, 2014). Therefore, rapid transformation of forest land use to agricultural land and, subsequently, fallow land has drastically declined the terrestrial carbon sequestration potential (Sahu *et al.*, 2016a). Over the years, several natural and artificial means have been worked out to scrub carbon dioxide from the atmosphere. Forest is one such major terrestrial sink of carbon dioxide that has the capacity to store carbon for long period. Carbon sequestration is, therefore, an integral aspect of forest management (Lal, 2005).

The carbon stock of forest is not only rendered by its above ground and below ground vegetation through biomass accumulation, but also by its biomass deposition (litter) on soil floor (Cardinael *et al.*, 2017). Estimation of carbon stock in various types of forests has been in limelight in recent decades. Many researchers have tried to estimate the carbon sequestration potential of deciduous (Tiwari and Singh, 1987; Haripriya, 2000), mixed (Hall and Uhling, 1991; Garkoti and Singh, 1995; Lal, 2004), temperate (Ravindranath *et al.*, 1997; Sharma *et al.*, 2010 a, b, c), semi-arid (Gao *et al.*, 2014) etc., types of forests to provide an insight into the carbon storage potential of green plants (Zhou *et al.*, 2000; Zhang *et al.*, 2007). Most of these studies are restricted to tree biomass using standard procedures or allometric equations. However, relatively less information is available on the soil organic carbon (SOC) stock of forests floor (Dixan *et al.*, 1994). Moreover, an overall estimation of forest carbon sequestration involving vegetation biomass and soil organic carbon is not only necessary to assess the carbon transaction of an area, but is also considered as an ideal step towards forest management practices (Nowak *et al.*, 2013).

Tropical forest constitutes more than 50% of total forest cover and plays a major role in mitigating carbon dioxide from the atmosphere. India, being in tropics and rich in biodiversity is in the map of mega diverse nations of the world. Forest is considered as storehouse of biodiversity, and in India there are two long stretches of forests in the Western Ghats and the Eastern Ghats. The stretch of Eastern Ghats extends from the mouth of

Chhotanagpur plateau in the north to the Nilgiri hills in the south. The Eastern Ghats, however, suffers from large scale deforestation due to illegal felling of trees and developmental activities. As a result, Government of India has undertaken massive afforestation programmes as a part of National Forest Policy during the last few decades. Teak being a suitable and commercially important species in this agro-climatic zone is very often considered for plantation activities. Previous studies in India have reported that teak forest has a good potential of carbon sequestration with values ranging from 181 t ha⁻¹ (Sreejesh *et al.*, 2012) to 300 t ha⁻¹ (Reddy *et al.*, 2014). However, these studies are merely based on carbon estimation through tree biomass and no or little information is available related to the contribution of soil in sequestering carbon in teak forest floor. Therefore, it is very difficult to assess the correct picture of entire teak forest in mitigating carbon dioxide. Keeping the above facts in view, a study was undertaken to estimate the carbon sequestration potential of teak plantation forest in Eastern Ghats of India through analysis of above ground, below ground biomass carbon of trees and soil organic carbon stock.

Materials and Methods

Geographical description of study area: The study area comprises 20-year-old teak plantation forest spread over an area of 23 ha consisting of around 2000 teak plants per hectare (which is within the silvicultural norm of teak plantation that permits 2500 teak plants per hectare). It is located in the outskirts of Burla town in Sambalpur district of Odisha state and is a part of Eastern Ghats, India.

Sampling and analysis of above ground and below ground carbon stock of teak plantation forest: The present study was conducted over a period of three months (May - July during 2017) after the shedding season of an artificially developed teak forest was over. Since, litter decomposition forms a part of soil organic carbon, hence, soil organic carbon stock analysis has been considered in addition to above ground and below ground. Sampling was conducted by non-destructive quadrat method (10m X 10m) laying 10 quadrates in randomized block design technique. The girth at breast height (GBH) and height of all trees in the quadrates were individually measured and their basal area and bio volume was calculated (Kumar and Nandini, 2013; Condit, 2008). Based on this figure, further computation was made to estimate the above ground biomass (ABG), below ground biomass (BGB), total biomass (TB), above ground carbon (AGC), below ground carbon (BGC) and total carbon storage in biomass (CSB) of trees following the formula of Kumar and Nandini (2013). Carbon content in trees was taken on an average as 50% of tree biomass. The wood density of individual tree species was also noted down from the literature (Kumar and Nandini, 2013).

Sampling and analysis organic carbon stock of soil under teak plantation forest: Similarly, for the analysis of soil organic carbon (SOC) stock, ten random soil samples (from ten different

quadrates) of teak plantation forest were collected by a soil core sampler. Three replica samples from each quadrate were obtained from the depth of 0–10, 10–20 and 20–30 cm totaling to ninety (10 (quadrates) x 3 (replicas) x 3 (depths)) samples. The organic carbon, bulk density, stone and gravel contents were then measured. The bulk density (g cm^{-3}) of soil was estimated according to McKenzie *et al.* (2004) and calculated from the ratio of weight of the oven dried soil to volume of the soil including solid pore spaces. Soil Organic Carbon (%) was estimated according to Walkley and Black rapid titration method (1934) by oxidizing the organic carbon in a strong oxidant (potassium dichromate) and titrating against standard ferrous ammonium sulphate solution using di-phenyl ammine as indicator. The stone and gravel content was estimated by physical separation method using a sieve of 2mm size.

The total soil organic carbon (SOC) stock was calculated by the following formula:

$$\text{SOC stock (t ha}^{-1}\text{)} = \text{Soil depth (cm)} \times \text{Bulk density (g cm}^{-3}\text{)} \times \text{OC (\%)} \times \text{CFst}$$

$$\text{where, CFst (correction factor for stones and gravels)} = (1 - \{(\% \text{ stone} + \% \text{ gravel})/100\}).$$

After estimating the total SOC stocks of different depths, the total carbon sequestration potential (t ha^{-1}) of soil was calculated.

Results and Discussion

The present study area experiences extreme climatic conditions, *i.e.*, hot summer and cold winter with mean average temperature fluctuating between 8°C – 46°C . The area experiences annual rainfall >1500 mm, while relative humidity of the area varies between 30 % during pre-monsoon to 75% during monsoon (Sahu and Sahu, 2019). Since, the area lies in a part of

Eastern Ghats stretch and falls under the Eastern plateau and hills agro-climatic zone of India, the soil of the region is mainly red and lateritic type and invariably conducive for teak plantation. Table 1 shows the above ground biomass, below ground biomass and carbon storage in biomass of teak plantation forest in the Eastern Ghats of India. The above ground biomass, below ground biomass, total biomass and carbon storage in biomass varied from $38.75 - 53.33$, $10.08 - 13.87$, $48.83 - 67.20$ and $24.41 - 33.60$ kg m^{-2} during sampling period with average being 46.17 , 12.01 , 58.17 and 29.09 kg m^{-2} , respectively. The average carbon storage in biomass of trees was to 0.029 t m^{-2} .

Estimation of biomass is an essential aspect for studying carbon stocks and global balance (Ketterings *et al.*, 2001). Trees capture carbon dioxide during photosynthesis and fix the same in their body biomass, and as the biomass of tree increases, the diameter of tree also increases, and in consequence the potential of tree to sequester carbon dioxide from atmosphere also increases (Pandya *et al.*, 2013). The basal area and tree size is significantly correlated with high biomass and carbon sequestration (Vilanova *et al.*, 2018). Teak being a deciduous species does not have the ability to fix carbon through photosynthesis during its shedding season. This period is marked with a conservative approach to sustain dry period. Therefore, accumulation of biomass during this phase is also low.

Assessment of various soil parameters at different depths under teak plantation forest in the Eastern Ghats of India is presented in Table 2. From the table it is evident that the organic carbon content ranged from $0.30 - 1.26$ %, $0.48 - 1.48$ % and $0.14 - 1.02$ % at $0 - 10$ at $10 - 20$ and $20 - 30$ cm depth with average value of 0.59 %, 0.80 % and 0.40 % at their respective depths. However, irrespective of depth, the mean value of organic carbon was 0.60 %. The rate of litter fall and dynamics associated with it regulate the litter decomposition in soil and assist in organic carbon storage (Lugo *et al.*, 1990). Organic carbon content regulates the fertility and biological activity of soil (Sahu *et al.*,

Table 1: Above ground biomass, below ground biomass and carbon storage in biomass of teak plantation forest in the Eastern Ghats of India

Area of quadrate (m^2)	No. of trees	Kg m^{-2}				t m^{-2}	
		AGB	BGB	TB	CSB	CSB	Average CSB $\pm$ SD
100	20	38.75	10.08	48.83	24.41	0.024	0.029 ± 0.003
100	20	41.40	10.76	52.16	26.08	0.026	
100	20	42.26	10.99	53.25	26.62	0.027	
100	20	48.60	12.64	61.24	30.62	0.031	
100	20	47.53	12.39	59.92	29.95	0.030	
100	18	44.38	11.54	55.92	27.96	0.028	
100	22	53.33	13.87	67.20	33.60	0.034	
100	21	51.85	13.48	65.33	32.67	0.033	
100	20	46.22	12.02	58.24	29.18	0.029	
100	19	47.33	12.30	59.63	29.82	0.030	
Average $\pm$ SD		46.17 ± 4.58	12.01 ± 1.19	58.17 ± 5.77	29.09 ± 2.89		

AGB- above ground biomass; BGB- below ground biomass; TB- total biomass; CSB- carbon storage in biomass

Table 2: Soil parameters at different depths under teak plantation in the Eastern Ghats of India

Parameter	Range & Mean	Soil depth (cm)			
		0 – 10	10 – 20	20 – 30	0 – 30
OC (%)	Range	0.30 - 1.26	0.48 - 1.48	0.14 - 1.02	0.14 – 1.48
	Mean $\pm$ SD	0.59 $\pm$ 0.33	0.80 $\pm$ 0.37	0.40 $\pm$ 0.30	0.60 $\pm$ 0.33
Bulk density (g cm ⁻³)	Range	1.14 - 1.23	1.16 - 1.27	1.23 - 1.30	1.14 – 1.30
	Mean $\pm$ SD	1.21 $\pm$ 0.03	1.23 $\pm$ 0.03	0.74 $\pm$ 0.55	1.23 $\pm$ 0.03
SOC stock (t ha ⁻¹)	Range	3.39 - 15.30	5.41 - 17.74	1.62 - 12.24	1.62 – 17.74
	Mean $\pm$ SD	7.05 $\pm$ 3.97	9.51 $\pm$ 4.38	4.65 $\pm$ 3.66	7.07 $\pm$ 3.98

OC= organic carbon; SOC = soil organic carbon

Table 3: Total SOC stock (t ha⁻¹) at different depths of soil under teak plantation in the Eastern Ghats of India

SOC Stock (t ha ⁻¹)				
0 - 10 cm	10 - 20 cm	20 - 30 cm	Cumulative total 0 – 30 cm	Average total 0-30 cm
12.89	17.32	10.58	40.79	21.27
15.30	17.74	12.24	45.28	
7.51	8.27	4.43	20.21	
3.70	7.02	2.21	12.93	
5.14	8.11	3.25	16.50	
3.39	5.41	1.62	10.42	
4.55	6.89	2.61	14.05	
6.57	8.33	3.31	18.21	
6.54	9.49	4.00	20.03	
4.90	6.51	2.82	14.23	

2016b). Higher the biomass deposition (litter), more is the addition of organic carbon in soil and greater is the microflora and soil fauna activity with enhanced decomposition in tropics, as a result there is a decreasing trend in the soil carbon storage. Whereas in temperate climate, although biomass deposition and organic input remains high, however, due to low temperature activity of soil organisms slow down the decomposition rate, as a result there is a increase in the soil carbon storage (Gregorich *et al.*, 2017). The present study showed that the middle zone (10–20 cm) had high organic carbon content than the surface zone (0–10 cm), due to the fact that the surface organic carbon is likely to get decomposed faster by microorganisms resulting in loss of organic carbon in the form of surface carbon dioxide emissions, while on the other hand, subsurface zone is a safer area for the accumulation of organic carbon because they remain stable for longer duration (Mbah and Idike, 2011).

The bulk density varied between 1.14 to 1.23 g cm⁻³, 1.16 to 1.27 g cm⁻³, 1.23 to 1.30 g cm⁻³ at 0–10 cm, 10–20 cm, 20–30 cm depths, respectively, during the sampling period with the average value of 1.21 g cm⁻³, 1.23 g cm⁻³ and 0.74 g cm⁻³ at their respective depths. However, irrespective of depths, the mean value of bulk density was 1.23 g cm⁻³ (Table 2). Bulk density is a

property that ultimately regulates the amount of organic carbon storage capacity of soil. The present study showed that there was increase in the value of bulk density with the increase in soil depth, due to the increase in compaction of soil. Further, the presence of organic carbon (or organic matter) in soil makes the soil loose and porous, thereby decreasing the bulk density of soil (Yihenew and Getachew, 2013). Recent studies have also confirmed this antagonistic relationship between organic matter and bulk density in forest (Ouyang *et al.*, 2018) and agricultural soils (Gebeheyu and Soromessa, 2018), probably illustrating the reason for obtaining lower bulk density value at upper horizon (0 – 10 cm) in the present study.

The SOC stock content at different depths was calculated taking soil depth (cm), bulk density (g cm⁻³), OC (%) and correction factor (CFst derived from percentage of stones and gravels) into consideration (Table 2). The SOC stock content varied from 3.39 - 15.30 t ha⁻¹, 5.41 - 17.74 t ha⁻¹ and 1.23 - 1.30 t ha⁻¹ at 0 – 10 cm, 10 – 20 cm and 20 – 30 cm depths, respectively. The average value at the respective depths was 7.05 t ha⁻¹, 9.51 t ha⁻¹ and 4.65 t ha⁻¹. Irrespective of depths, the average value of SOC stock under teak plantation was 7.07 t ha⁻¹. In the present study, the highest SOC stock (9.51 t ha⁻¹) was recorded in the middle horizon (10 – 20 cm),

which might be due to greater accumulation of organic carbon in the middle zone which had a significant bearing with total SOC stock (Mohanty *et al.*, 2017). Moreover, the high quantity of organic carbon and SOC stock and lower bulk density at top and middle zone of soil confirms good decomposition and porous condition of top soil (Gebeyehu *et al.*, 2019).

The total SOC stock of soil under teak plantation forest is presented in Table 3. The cumulative total SOC stock at 0–30 cm depth varied from 10.42–45.28 t ha⁻¹ during the sampling period and the average total soil organic carbon stock up to that depth was 21.27 t ha⁻¹. SOC stock has direct implication on atmospheric carbon concentration, as a small fluctuation in SOC stock may alter the atmospheric carbon. Moreover, they are potent quality, fertility and productivity indicators of soil (Jimenez *et al.*, 2011). The result of present study are comparable to the results of other forests in the world like the oak forest in Iran (Eshaghi *et al.*, 2018) and confirms that teak has good potential to offer carbon sequestration through its soil. This also suggests that forest transformation into man-intervened (grazing) and man-engineered (cultivable) fields can lead to huge emission of carbon dioxide into the atmosphere (Gebeyehu *et al.*, 2019). Carbon storage in biomass and soil carbon are two major carbon pools so far total carbon sequestration potential of forests is concerned (IPCC, 2006). In the present study, the total SOC stock and total carbon storage in biomass (CSB = AGC + BGC) of the entire teak plantation forest was worked out to be 489.21 and 6670 t, respectively. Hence, the total carbon sequestration for 23 ha of teak plantation forest, taking two carbon pools into account, was 7159.21 t, which arrives to be 311.27 t ha⁻¹ with above ground carbon of 230.16 t ha⁻¹ and below ground carbon of 59.84 t ha⁻¹ and TOC stock of 21.27 t ha⁻¹.

Comparative analysis of carbon sequestration potential of forests across the globe suggest that AGC, BGC, CSB and SOC stock varied from 5.22 (Jana *et al.*, 2009) – 450 (Singh *et al.*, 1994), 14.61 (Ullah and Amin, 2012) – 18.55 (Justine *et al.*, 2015), 106.08 (Justine *et al.*, 2015) – 120.2 (Kraenzel *et al.*, 2003) and 60 (Hooker and Compton, 2003) – 411 t ha⁻¹ (Gao *et al.*, 2014), respectively, in different forests of world, and the present findings with respect to these parameters are more or less comparable. Further, when compared with a similar research on teak plantation forests of Panama (Kraenzel *et al.*, 2003), the AGC, BGC and CSB stock of our findings was respectively 2.2, 3.8 and 2.4 fold higher. This reflects high carbon sequestering potential of teak plantation forest in the Eastern Ghats of India. The present study for CSB showed a carbon sequestering value of 290 t ha⁻¹, whereas it ranged from 181 (Sreejesh *et al.*, 2012) – 330 t ha⁻¹ (Reddy *et al.*, 2014) when compared with other teak forests of India. This corroborates that the climatic conditions in this part of the Eastern Ghats is well suited for the plantation of teak forest and it can be judiciously used to mitigate the rising carbon dioxide concentration in the atmosphere. The present study also reveals that the maximum contribution was made by above ground biomass storing 74% of carbon followed by below ground biomass storing 19% of carbon. The soil offered only 7%

contribution through SOC stock in the carbon sequestration of teak plantation forest. The present finding corroborates the report of IPCC (2006). According to this report, out of five identified terrestrial carbon pools (above ground biomass, below ground biomass, deadwood, litter and soil organic carbon), AGB had the highest potential for carbon sequestration, followed by BGB and SOC stock. Studies have also reported that tree biomass and soil carbon sequestration is high at higher altitude since decomposition is usually slow at low temperatures (Hoffmann *et al.*, 2014; Selmants *et al.*, 2014). Teak being a commercially important species is very often considered for plantation in the Eastern Ghats stretch at higher elevation. It is because of the fact that teak releases less carbon dioxide to the atmosphere and has higher efficiency to store more carbon for a longer duration of time in its tissue (Sreejesh *et al.*, 2012).

The present work shows that teak species not only have a good carbon sequestration potential through its above and below ground biomass but also offers significant assistance through its soil to scrub the carbon from the atmosphere, thereby serving as potent reservoir of carbon in the Eastern Ghats of India. This study can be useful in forest management practices and for developing strategies to mitigate carbon under Indian climatic condition.

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