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Biomass, Primary Nutrient and Carbon Stock in a Sub-Himalayan Forest of West Bengal, India

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Abstract

Quantitative information on biomass and available nutrients are essential for developing sustainable forest management strategies to regulate atmospheric carbon. An attempt was made at Chilapatta Reserve Forest in Duars region of West Bengal to quantify its above and below ground carbon along with available "N", "P" and "K" in the soil. Stratified random nested quadrats were marked for soil, biomass and litter sampling. Indirect or non-destructive procedures were employed for biomass estimation. The amount of these available nutrients and organic carbon quantified in soil indicates that the forest soil is high in organic carbon and available "K" and medium in phosphorus and nitrogen. The biomass, soil carbon and total carbon (soil C + C in plant biomass) in the forest was 1,995.98, 75.83 and 973.65 Mg ha^{-1}. More than 90% of the carbon accumulated in the forest was contributed by the trees. The annual litter production of the forest was 5.37 Mg ha^{-1}. Carbon accumulation is intricately linked with site quality factors. The estimated biomass of 1,995.98 Mg · ha^{-1} clearly indicates this. The site quality factor i.e. tropical moist deciduous with optimum availability of soil nutrients, heavy precipitation, high mean monthly relative humidity and optimum temperature range supported luxuriant growth which was realized as higher biomass accumulation and hence higher carbon accumulated.

Key Words: biomass, carbon storage, nutrient, litter, eastern himalayas

Introduction

Tropical forest plays an important role in reducing atmospheric CO_2 which contribute to global warming of the earth surface (Nagendra and Gadgil 1999; Behera et al. 2000). Forest soils are also one of the main sinks of carbon on earth (Jha et al. 2003; Hashimoto et al. 2009). Biomass and soil carbon quantification are thus essential for determining carbon accumulation in a forest which will help in understanding the carbon cycling at a regional as well as global level. The quantification of biomass and soil carbon accumulation is not only useful to understand the status of total carbon sink but also will be useful to formulate strategies for sustainable management of this sink by restricting carbon emission through forest conservation and bringing more and more wasteland, degraded land and other unusable land under afforestation programme. Biomass production is also directly and indirectly related to availability of plant nutrients besides the inherent growth capacity of the species. Duars region of West Bengal is one of the most biodiversity rich areas in India and Chilapatta Reserve Forest is one of the major diversity rich areas of the Duars (Pandit 1996; Anon 2001; Das et al. 2003; Pandit et al. 2004; Jana et al. 2009; Shukla et al. 2014). Unfortunately, these quantitative estimates of Chilapatta are lacking. Such quantitative information is essential for developing sustainable forest management strategies to regulate atmospheric carbon. Keeping this in view the present study was con-

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ducted to quantify above and below ground carbon stock of the Chilapatta Reserve Forest along with its available soil "N", "P", and "K" reserve.

Materials and Methods

The study was conducted at Chilapatta Reserve Forest under Cooch Behar Wildlife Division in Terai zone of West Bengal state, India which is located at northern fringe of the state in foothills of the sub-Himalayan mountain belts. The forest is spread in an area of 22 km^2. The forest type ranges from tropical wet evergreen to tropical moist deciduous forest (Champion and Seth 1968). The coordinates of the working site as measured by GPS (Garmin-72) is latitude 26° 32.85' N and longitude 89° 22.99' E. Mean elevation of the area is 47 m above mean sea level. The soil of Terai zone is high in organic carbon (0.95%) and available potash and medium in phosphorus and nitrogen with acidic reaction (Paul 2004; Kaul et al. 2011). The soil texture at 0-30 cm has 70% sand, 19% silt and 11% clay (Paul 2004). The climate of the study area is moist tropical (Anon 2001). On an average total annual rainfall received was 2,942.40 mm of which 80% was recorded during June-August and mean monthly relative humidity ranged from 69.0-91.5%. The summer and winter temperature are mild with highest of 32°C during May and lowest of 8.9°C during January. Stratified random nested quadrat sampling method was adopted. A total of 57 (main), 114 (two each in every main) and 285 (five each in every main) quadrats of size 20 m×20 m, 5 m×5 m and 1 m×1 m were marked for biomass sampling of trees, shrubs and herbs, respectively (Fig. 1).

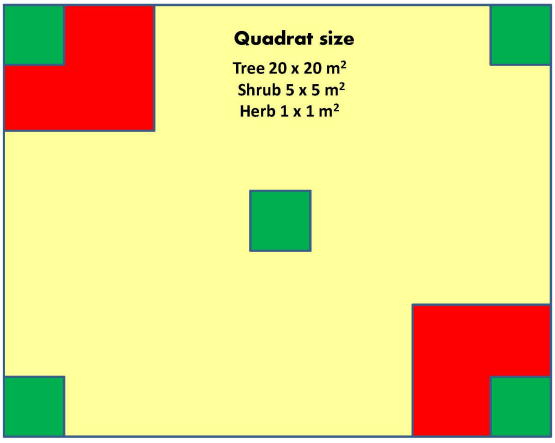

Fig. 1. Quadrat for vegetation analysis.

Litter samples were collected once compositely from three 1 m×1 m marked area in all the main quadrats following the litter sampling procedures suggested by Pande (1986). Oven dried 25 g litter was put in the 2 mm mesh nylon bags of size 15×15 cm^2. A total of nine bags were placed on forest floor for decomposition, three each in sub-quadrats. One bag from each sub-quadrat was retrieved quarterly, decomposed materials were brought to laboratory in polythene bags, air dried in shade, grinded with electric grinder and then analysed (Pande 1986).

Composite soil samples were collected separately from 0-15 and 15-30 cm depth with the help of Dutch augur from all the main quadrats. Soil and litter samples were analyzed following the methods given in Table 1.

The amount of available "N", "P" and "K" in soil for the whole forest is expressed as Mg ha^{-1}. The amount of SOC was quantified by multiplying the organic carbon with weight of the soil (bulk density and depth) for a particular depth and expressed as Mg ha^{-1} following Joao Carlos et al. (2001).

Table 1. Methods of soil and plant analysis

Moisture	Volumetric method (Piper 1966)
pH (1:2 soil: water suspension)	Beckman's pH meter (Jackson, 1967)
Electrical conductivity (EC in m mhos/cm) at 25°C (1:2 soil water suspension)	Solubridge conductivity meter
Bulk density (g cm^{-3})	Core sample method (Piper, 1950)
Soil organic carbon (SOC in %)	Walkley and Black's rapid titration method (Jackson, 1967)
Available 'N' kg ha^{-1}	Modified Kjeldahl method (Jackson, 1967)
Available 'P' kg ha^{-1}	Bray's method-Bray and Kurtz 1945 (Jackson, 1967)
Available 'K' kg ha^{-1}	Flame photometer method (Jackson, 1967)

Indian laws do not permit to cut or harvest any plants especially the trees from any Reserved Forest so direct or destructive methods of estimation of biomass are not possible. Indirect or non-destructive methods are the only alternative left for biomass estimation through assumptions. Ten trees were selected randomly from each main quadrat. The mean biomass was estimated separately for stem, branch, and leaves for these 10 trees. Height of the stem was measured up to its first branch and dbh was measured by a caliper (JEETEKNO Aluminum Tree Caliper) to estimate the biomass. The number of primary branches (originated from bole), secondary (originated from primary branch) and tertiary (originated from secondary branch) was counted from the 10 randomly selected trees in each quadrat. From the selected trees, five primary, secondary and tertiary branches were randomly selected to visually assume their length and mid-diameter (by comparing with a measured branch/stick) for mean biomass estimation. Five tertiary branches were harvested from each selected trees, their leaves plucked and mean fresh weight measured. This mean leaf weight was then multiplied with the total number of branches in a tree to estimate the total leaf weight of a tree. The mean biomass thus estimated separately, added to obtain whole above ground tree biomass and then multiplied with total number of trees to obtain the total above ground tree biomass in a quadrat. Below ground biomass of trees was estimated considering 15% of the above ground biomass (MacDicken 1997). For shrub biomass estimation, five plants were randomly selected from each 5 m×5 m quadrats, uprooted to measure their average fresh weight separately for stems/branches, leaves and roots and then multiplied with the total number of shrubs in a quadrat. But for herbs all the plants from 1 m×1 m quadrats were uprooted to measure their fresh weight separately for roots and above ground parts. The biomass estimated for the whole forest area (22 km^2) was expressed as Mg ha^{-1}. The model developed by Brown et al. (1989) was used to estimate above ground biomass because literature showed that this method is one of the most suitable methods for tropical forest (Alves et al. 1997; Brown 1997; Schroeder et al. 1997; Anon 1997; Alamgir and Al-Amin 2008). The model is Y= exp. {-2.4090+0.9522 ln (D_2HS)}, where 'Exp.' denotes 'e' to the power of …", 'D' is dbh in meter, 'H' is height of the tree (m) and 'S' is density of wood (t/m2) assumed as 0.5 for tropical woods. The plant biomass quantified in a quadrat was converted into carbon by multiplying with a factor of 0.45 as suggested by Woomer (1993). This is also expressed as Mg ha^{-1}.

The main quadrats were categorized visually as barren, discontinuous, tufts/bunches and continuous canopy cover (Sagwal 1995). Photosynthetic Active Radiation (PAR) was recorded with the help of Lp-80 Accu PAR (PAR/LAI Ceptometer Decagon Devices, Inc.) Unintercepted PAR above the forest canopy was impossible to record at the height of tree canopy so this PAR was recorded at clear spots on the road just before entering the quadrat. Beneath the forest canopy PAR was recorded at three heights i.e. above the shrubs, below the shrubs and at ground level. For PAR observation 10 spots were selected randomly and then average PAR was calculated separately for different heights for estimating the interception per cent as A-B/A×100 (where, A is PAR above tree/shrub/herb canopy and B is PAR below tree/shrub/herb). The PAR utilization by the vegetation can be an indicator for accumulation of biomass.

Results and Discussion

Canopy cover and PAR interception

There were no quadrats in the forest with barren canopy cover. About 60% of the quadrats were continuously covered and rest discontinuous or patchy. Based on this observation, Chilapatta Reserve Forest can be classified as dense forest as major proportion of the sampled area had more or less continuous canopy. This was further evidenced from the PAR interception by the forest canopy (Fig. 2).

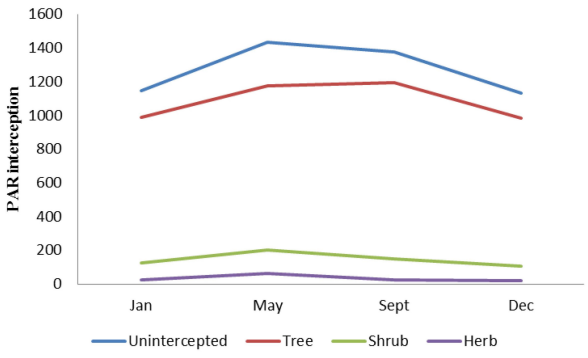

Fig. 2. PAR interception in different canopy strata (μmol$m^{-2}s^{-1}$).

The forest canopy intercepted more than 80% of incident PAR. The total intercepted PAR by all strata in the forest was more than 98% of the incident PAR. Of the penetrated PAR, more than 90% was intercepted by the under storey vegetation. The PAR utilization by the vegetation of this forest explains the enormous biomass and thereby carbon accumulated indicating the excellent growth status of the forest.

Biomass accumulation and partitioning

Quantitative estimates of biomass and partitioning at the time of observation on unit area basis and whole forest are given in Table 2. The biomass accumulated per hectare of Chilapatta Reserve Forest was 1,995.98 MgC. Almost all the biomass in the forest was contributed by trees (99.69%) while a negligible amount was contributed by shrubs (0.25%) and herbs (0.06%). The biomass partitioned to stem, branch, leaves and roots in perennial component while it partitioned as foliage and root in herbs. In trees, stem biomass contributed the most (58.74%) followed by branches (28.04%), roots (12.90%) and least by the leaves (0.32%). The trend was similar in shrubs except where the contribution of root (19.80%) is next to the stem (48.16%) followed by branches (19.39%) and least by the leaves (12.65%). Similarly the contribution of foliage or above ground biomass in herbs was 68.91% and rest by the roots. The contribution of above ground biomass in both the trees and shrubs accounted to more than 80% i.e. (87.10 and 81.20%, respectively) while the rest was contributed by the below ground biomass i.e. roots. Some earlier studies also similarly quantified the biomass of forest vegetation (Koul and Panwar 2008; Sharma et al. 2008). The amount of biomass estimated for whole forest was 4391191 MgC. The total biomass was also quantified separately for trees, shrubs and herbs in the forest along with partitioning to stems, branches, leaf/foliage and roots.

Litter production and decomposition

The annual litter production of the forest was 5.37 Mg ha^{-1}. The litter decomposition was observed periodically. The periodic decomposition of litter over the year recorded was 43.76%, 77.09% and 95.03% (Table 3), respectively

Table 2. Quantitative estimates of biomass accumulated in different life forms and its partitioning in Chilapatta Reserve Forest

Life form	Stem	Branch	L/F	Agb	Root	Total
	Unit area biomass (Mg ha^{-1})					
Trees	1,168.78 (2571316)*	558.01 (1227657)*	6.34 (13948)*	1,733.13 (3812921)*	256.76 (564872)*	1,989.89 (4377793)*
Shrub	2.36 (5192)*	0.95 (2090)*	0.62 (1364)*	3.93 (8646)*	0.97 (2134)*	4.90 (10780)*
Herb	-	-	0.82 (1804)*	0.82 (1804)*	0.37 (814)*	1.19 (2618)*
Total	1,171.14 (2576508)*	558.96 (1229747)*	7.78 (17116)*	1,737.88 (3823371)*	258.10 (567820)*	1,995.98 (4391191)*

Agb, above ground biomass; L/F, leaves/foliage.
*Figures in parenthesis are biomass quantified for whole forest in MgC.

Table 3. Quantitative estimates of available "N", "P" and "K" in fresh and decomposing litter in Chilapatta Reserve Forest periodically over the year

	Jan (initial in fresh litter)		After periodic decomposition						Return to Soil*
			May		Sept		Dec		
	%	A	%	B	%	C	%	D	
"N"	1.58	0.085	1.26	0.038	0.55	0.0068	0.210	0.0006	0.084
"P"	0.42	0.023	0.20	0.0025	0.018	0.0005	0.004	0.00001	0.023
"K"	1.12	0.060	0.91	0.027	0.31	0.0040	0.140	0.00038	0.060

*Return to soil: [(A-B)+(B-C)+(C-D)]; content in %; A, B, C and D are quantity in Mg ha^{-1}.

from the total litter. The periodic litter material decomposed was 2.35 Mg ha^{-1}, 1.79 Mg ha^{-1} and 0.96 Mg ha^{-1}, litter decomposed. After a year over 90% of the total litter got decomposed (i.e. 5.10 Mg ha^{-1}). Similar quantum of litter fall in tropical dry deciduous, tropical dry evergreen, temperate evergreen and temperate moist deciduous forests was also reported (Pande and Sharma 1993; Dhadwal et al. 1997; Hasse 1999; Pande 1999; Rajagopal et al. 2005; Shadangi and Nath 2006). Generally, the turnover rates of leaf litter in tropical and subtropical broad-leaved forests and pine trees are from 1.0 to 1.75; for example, the turnover rate (time required to decompose 95% of litter) of leaf litter decomposition is 1.7-3.0 years (Brown and Lugo 1982; Cuevas et al. 1991; Zhang et al. 2009a). It requires 1.5 years in tropical rain forests of China (Ren et al. 1999) and 35 years (Zhang et al. 1999) or 8-14 years in temperate deciduous broad leaved forests (Wang and Huang 2001). This indicates that the material turnover of this forest was faster as compared to these forests. Faster turnover rate in this forest was due to optimum temperature, rainfall and relative humidity in the area with abundant moisture in the soil (Table 4). Chilapatta Reserve Forest was categorized as moist deciduous forest (Champion and Seth 1968) which supports the report by Pastor (1987) that deciduous forests are believed to have faster nutrient turnover as compared to any other forests.

Positive effects of deciduous trees on nutrient cycling are usually attributed to their high quality litter causing faster decomposition and faster nutrient cycling (Scott and Binkly 1997). The differences in turnover rates may have been affected by the environment (soil and climate) and are mainly due to biological actions (Zhang et al. 2009b). It is widely believed that plant litter decomposes rapidly and completely in humid tropics because the condition of humidity and temperature favour the microbial activity (Singh and Gupta 1977). It seems that the higher rate of litter production and its subsequent decomposition under tropical climate contributed rapid turnover of nutrients and affect the nutrient cycling, in cases where growth period and uptake are not synchronized with leaf fall and its subsequent decomposition (Pande et al. 2002) as in the case of present study area where the most of the trees were either semi-deciduous or deciduous.

Litter "N", "P" and "K"

The available "N", "P" and "K" content (%) of fresh litter and amount of its periodic release in the soil (Mg ha^{-1}) from the decomposing litter over the year is given in Table 3. Their available content in fresh litter of forest was estimated at 1.58, 0.42 and 1.12%, respectively. The annual return was in the order "N" > "K" > "P" was also observed by Pande (2001). The content decreased periodically as decomposition progressed. The availability and periodic release of these nutrients exhibited similar behaviour as was

Table 4. Quantitative estimates of soil available "N", "P" and "K" with soil pH, EC and moisture in Chilapatta Reserve Forest periodically over the year

Month	15 cm					
	"N" (Kg ha^{-1})	"P" (Kg ha^{-1})	"K" (Kg ha^{-1})	pH	EC (m mhos cm^{-1})	Moisture (%)
Jan (initial)	260.96 (574.11)*	107.94 (237.47)*	154.88 (340.74)*	5.47	0.050	32.44
May	271.61 (597.54)*	115.51 (254.12)*	161.14 (354.51)*	5.54	0.074	30.72
Sept	279.24 (614.33)*	128.41 (282.50)*	173.12 (380.86)*	5.72	0.074	36.64
Dec	261.70 (575.74)*	109.21 (240.26)*	156.60 (344.52)*	5.50	0.054	32.93
Mean	268.38 (590.43)*	115.27 (253.59)*	161.44 (355.16)*	5.56	0.063	33.18
			30 cm			
Jan (initial)	249.97 (549.93)*	93.76 (206.27)*	135.96 (299.11)*	5.68	0.060	35.39
May	257.43 (566.35)*	98.60 (216.92)*	147.94 (325.47)*	5.72	0.088	34.39
Sept	263.47 (579.63)*	115.93 (255.05)*	150.17 (330.37)*	5.85	0.086	38.82
Dec	250.78 (551.17)*	94.88 (208.74)*	137.87 (303.31)*	5.71	0.064	35.51
Mean	255.41 (561.77)*	100.79 (221.75)*	142.99 (314.57)*	5.74	0.74	36.03

*Figures in parenthesis are quantity of whole forest in MgC.

exhibited by their content. The return of these available nutrients from litter through decomposition to the soil in the forest after a year was 0.084, 0.023 and 0.060 Mg ha^{-1}, respectively which are equal to the amount available in fresh litter. This means there was no change of these available nutrients in the system indicating their cycling in a sustainable manner. This is also evident from the fact that there is no significant change in amount of these available nutrients in soil also after a year (Table 4). The complete release of these nutrients back to the soil that was stored in the litter after a year reflects self sustaining or homeostasis of this forest ecosystem (Odum 1971).

A gradual decomposition of litter and its incorporation into the soil amounts a step further in the process of mineralization and subsequently its availability. It is largely governed by chemical composition of litter, environmental conditions, soil flora and fauna (Singh and Gupta 1977). Environmental conditions (temperature and moisture) play important role in governing the rate of litter decomposition (Upadhyay and Singh 1981). It is evident from the trend of periodic change in content of these available nutrients in litter. Initially there was slow rate of "N" and "K" release which increased as decomposition progressed gradually but no such trend was observed for "P" release from the litter. This pattern of release of nutrients from the decompositing litter has also been recorded from other tropical forests (Chacon and Dezzeo 2007). The released of these nutrients are nearly equal to the amount available initially in the litter before decomposition. This means that there was no net major increase or decrease of these available nutrients in the forest and which indicate it's cycling in a sustainable manner. The higher nutrient was associated with higher litter fall and litter nutrient concentrations (Pande 2001).

Soil physico-chemical profile

The forest soil available "N", "P", "K", pH, EC and moisture estimated at 0-15 cm and 15-30 cm depth with its periodic change are given in Table 4. The pH of the forest at both the depth was moderately acidic. The acidity of forests soils were also reported earlier (Chavan et al. 1995; Contractor and Badnur 1996; Raina et al. 2001; Koul 2004). At both the depths acidity decreased gradually but very nominally from first three months to ninth month and then decreased again at last three months of the year to the same level as was initially estimated in the first three months. This may be attributed to similar trend of periodic change in soil moisture, EC and subsequent increase of materials through litter decomposition (Table 3). Presence of high organic matter along with leaching of bases and enhancement of weathering process due to decomposition of litter increases the soil EC and moisture which in turn lowers the pH in forest soil (Paudel and Sah 2003). Due to subsequent release of nutrients in to the soil by mineralization after decomposition along with release of water as by-product of decomposition also explains the increase of EC and moisture in the soil and then decreased after nine months. After nine months almost all the litter in soil had decomposed thereby decreasing mineralization which decreased EC, moisture and ultimately increasing acidity again (Johnston 1986; Sheikh and Kumar 2010). Moisture regime in forest soil depends upon many biotic (structure and function of forest cover) and abiotic (rainfall, amount of radiation received on the forest floor, its aridity, humidity, temperature) factors (Pande 2001). The study area has humid climatic conditions due to high rainfall and humidity. Moreover due to higher proportion of continuous canopy cover in the forest, less than two per cent of incident radiation reached the forest floor causing less evaporation thereby conserving high soil moisture.

The average available amount of "N", "P" and "K" over the yearly period in the forest soil on a unit area basis at 15 cm depth was 268.37, 115.27 and 161.44 Kg ha^{-1} while at 30 cm depth it was 255.40, 100.79 and 142.99 Kg ha^{-1}, respectively. Correspondingly, the average available amount of these nutrients estimated for the whole forest at 15 cm soil depth was 590.43, 253.59 and 355.16 MgC while at 30 cm depth it was 561.77, 221.74 and 314.57 MgC, respectively (Table 4). This much amount of these available nutrients suggests that the forest soil is high in available potash and medium in phosphorus and nitrogen (Baruah and Barthakur 1997) as was earlier reported by Paul (2004) for whole Terai region of West Bengal.

The soil nutrient availability trend observed as "N" > "K" > "P" was also reported by Pande (2001). Available amount of these soil nutrients in the whole forest increased gradually during first nine months but decreased finally during last three months of the year to the same level as was observed initially at both the depths. This can be attributed

to addition of these available nutrients by decomposition of litter in similar trend as was observed for soil availability (Table 3). Subsequently due to consumption by plants, the initial and final availability over the yearly cycle of these nutrients in the soil is nearly equal.

The availability of soil nutrients is more closely related to litter nutrient content than to litter decomposition rate (Prescott 2002) which explains the homeostasis of these nutrients. Plant tissues (above and below ground litter) are the source of soil organic matter which influence the physico-chemical characteristics of soil such as texture, water holding capacity, pH and nutrients availability (Johnston 1986). Physico-chemical characteristics of forests vary in space and time because of variation in topography, climate, weathering process, vegetation cover and microbial activities (Paudel and Sah 2003). The nutrients thus, returned in the soil, exerts a strong feedback on the ecosystem processes (Pastor et al. 1984). Nutrients supply varies widely among ecosystems (Binkly and Vitousek 1989) resulting in differences in plant community structure and its production (Ruess and Innis 1977). It is therefore; forest soils strongly determine the composition of forest stand and ground cover, rate of plant growth, vigour of natural reproduction, other silviculturally important factors (Bhatnagar 1965) and also the carbon sequestration.

Carbon accumulation

The forest SOC content, amount and its periodic change over the yearly period is given in Table 5. The SOC in the forest soil at 0-15 cm and 15-30 cm soil depth estimated was 1.80 and 1.59% which amounts to 40.27 and 35.56 Mg ha^{-1}, respectively. Earlier studies also similarly quantified forest SOC similar to this amount (Jha et al. 2003; Chhabra and Dadhwal 2005; Koul et al. 2011). This indicates that the forest soil is high in organic carbon (Baruah and Barthakur 1997; Paul 2004). For both the depths, SOC content and amount also increased gradually during first nine months of the year but after this period it decreased up to the level similar to what was estimated initially. This might be due to its synchronization with decomposition of litter (Table 3) as discussed earlier which released carbon into the soil. The increase in SOC to their initial value is believed to be due to the effect of litter addition (Singh et al. 2004). Accumulation of SOC through litter fall might have regulated organic matter decomposition and the formation of stable and labile soil organic matter pool. Moreover, SOC store has great importance to conserve carbon and restrict the carbon emission (Vitousek and Sanford 1986).

Table 5. Quantitative estimates of soil organic carbon in Chilapatta Reserve Forest periodically over the year

Month	15 cm		30 cm	
	Content (%)	Quantity (Mg ha^{-1})	Content (%)	Quantity (Mg ha^{-1})
Jan (initial)	1.74	38.98	1.52	34.05
May	1.82	40.77	1.62	36.29
Sept	1.88	42.11	1.62	36.29
Dec	1.75	39.20	1.59	35.62

Similarly the amount of SOC in other tropical moist deciduous forest in India up to 50 cm soil was quantified at 8.9-176.1 Mg ha^{-1} (Chhabra and Dadhwal 2005). The amount of SOC quantified in this study was far lesser than the national average of 182.94 Mg ha^{-1} which was attributed to higher rates of decomposition due to favourable climatic conditions (Jha et al. 2003). Temperate forests have unique feature to accumulate high quantity of soil organic matter and litter because of slow decomposition rate due to low temperature (Jha et al. 2003) and the reverse was true for the conditions in our study area which explains the lesser SOC.

The amount of carbon quantified for plant biomass, SOC and litter together along with its partitioning on unit area basis and in the whole forest is given in Table 6. The amount quantified was 973.65 Mg ha^{-1} and 2148168 MgC, respectively. Pibumrung et al. (2008) has also reported highest amount of total carbon stock in forests (357.62± 28.51 Mg/ha) as compared to reforestation (195.24±14.38 Mg/ha) and the agriculture land (103.10±18.24 Mg/ha). This is clearly indicated from the enormous value of carbon quantified in 2,200 ha area of Chilapatta Reserve Forest ecosystem. Almost all the quantified carbon in the forest was contributed by the trees (91.97%). In trees, stem contributed the most (58.74%) followed by branches (28.04%), roots (12.90%) and least by the leaves (0.32%). The trends was similar in shrubs except where the contribution of root (19.91%) is next to the stem (47.96%) followed by branches (19.46%) and the least contributed by leaves (12.67%).

Table 6. Quantitative estimates of carbon accumulated in different plant life forms and its partitioning along with SOC in Chilapatta Reserve Forest

Life form	Stem	Branch	Leaves/Foliage	Above ground	Root	Total biomass C	Litter	SOC (0-30 cm)	Total carbon
				Quantity of unit area carbon (Mg ha^{-1})					
Trees	525.95 (1157090)*	251.11 (552442)*	2.85 (6270)*	779.91 (1715802)*	115.54 (254188)*	895.46 (1970012)*	-	-	-
Shrubs	1.06 (2332)*	0.43 (946)*	0.28 (616)*	1.77 (3894)*	0.44 (968)*	2.21 (4862)*	-	-	-
Herbs	-	-	0.37 (814)*	0.37 (814)*	0.17 (374)	0.54 (1188)*	-	-	-
Total Carbon	527.01 (1159422)*	251.54 (553388)*	3.50 (7700)*	782.06 (1720532)*	116.15 (255530)*	898.21 (1976062)*	2.41 (5302)*	75.83 (166804)*	976.45 (2148168)*

SOC, soil organic carbon.

*Figures in parenthesis are quantitative estimates of carbon in whole forest.

Similarly the contribution of foliage or above ground biomass in herbs was 68.52% and rest by the roots. The contribution of above ground biomass in both the trees and shrubs was more than 80% i.e. (87.10 and 80.10%, respectively) while the rest was contributed by the below ground biomass i.e. roots. Similar amount of carbon was also quantified by Koul and Panwar (2008) and Jana et al. (2009).

Many factors may affect the carbon budget of an ecosystem: biotic features including the leaf size, photosynthesis rate, plant architecture and type of forest (evergreen or deciduous), and abiotic features such as solar radiation, temperature, water supply, soil property and the length of growing season. Biomass and carbon stock is intricately linked with site quality, nature of land use, choice of species and other silivicultural practices adopted (Swamy et al. 2003). These factors ultimately influence plant growth in the forest which is reflected in its total biomass accumulation (1,995.98 Mg ha^{-1}). This is because of the site factor i.e. tropical moist deciduous climate with soil having high organic carbon and available potash, medium nitrogen and phosphorus, heavy precipitation (2,942 mm annual rainfall), high mean monthly relative humidity (69.0-91.5%) and optimum temperature range (9-32°C). These site quality factors supported luxuriant growth supporting biomass accumulation and hence higher carbon quantified (Shukla et al. 2014). Higher biomass in the forest can also be explained because of efficient utilization of space due to presence of grasses/ferns, shrubs and trees on the same unit area of land indicating efficient utilization of solar radiation (Fig. 2) effecting luxuriant growth. Moreover higher SOC in forest soil also leads to higher rate of plant growth increasing the biomass.

A C:N ratio of about 30:1 in litter layer (C- 2.41 Mg ha^{-1}, Table 6; N- 0.085 Mg ha^{-1}, Table 3) was observed in the present study. Highest values of organic carbon, N and C: N ratio have been reported in forest landuse as compared to barren land, intermediate in cultivated well managed soil and cultivated unmanaged land Gupta et al. (2001). The ecological impact of carbon and nitrogen dynamics in the litter layer is considerable in forest ecosystems (Xiao-wen et al. 2009). Fresh litters can uptake or immobilize nitrogen because it is relatively rich in carbon and poor in nitrogen. Thus the litter layer can become a significant sink for nitrogen. As decomposition proceeds mineralization predominates over immobilization influencing litter to gradually release nitrogen and become a source for nitrogen. In addition, the dissolved organic carbon and dissolved organic nitrogen originated from litter decomposition is the most important source of dissolved organic matter in forest soils (Qualls and Haines 1991; Park et al. 2002) which is considered to be an energy and nutrient source of microbial metabolism (Magill and Aber 2000).

Moreover, the response of carbon fluxes to environmental variables such as air, humidity (or dryness) and temperature has been reported (Hollinger et al. 1994; Fan et al.

1995; Hollinger et al. 1998; Chen et al. 1999; Clark et al. 1999). Furthermore litter CO_2 respiration can account for 10-30% of total soil CO_2 flux and it is important for the balance of forest carbon budgets (Buchmann 2000). In general, evergreen broad-leafed forest ecosystems have a high capacity for carbon sequestration (Waring and Running 1998). At Chilapatta Reserve Forest, carbon dioxide measured in ambient air was 380.43 ppm while the rate of daily CO_2 sequestration with annual CO_2 sequestration ranged from 2.42 to 5.02 g/hr and 2.07 to 3.33 Mg C ha^{-1}, respectively (Jana et al. 2009). This means that the net carbon storage of the forest was between 973.12 and 974.38 Mg C ha^{-1}.

Conclusion

The plant biomass estimated in the forest was 1995.98 Mg ha^{-1}. Biomass of forest vegetation can be used to quantify the amount of carbon and carbon cycling at a regional as well as global level for planning viable options to mitigate CO_2 increased climate change. Total carbon in this study is the sum of soil organic carbon (75.83 Mg ha^{-1}), plant biomass carbon (898.21 Mg ha^{-1}) and litter carbon (2.41 Mg ha^{-1}) accumulated over a year and it was estimated at 976.45 Mg ha^{-1}. This much amount of carbon accumulated per unit area of forest indicates the importance of forest ecosystems towards maintenance of atmospheric CO_2 efficiently because of the permanency of carbon being stored in its biomass for a longer period especially in its perennial woody components. This is because almost all the biomass (99.69%) and carbon (91.97%) was contributed by the trees in the forest. About 8% of carbon stored in the forest was contributed by its soil. Forest SOC also has great importance to conserve carbon and restrict carbon emission along with the carbon stored in forest vegetation biomass. Thus forests are rightly believed as the most important carbon pool on land. The biomass separately quantified for trees, shrubs and herbs in the forest along with partitioning to stems, branches, leaf/foliage and roots will help to determine the whole-plant net carbon gain in the forest. Biomass allocation quantified will greatly improve the understanding of plant life history strategies and thus can help the forest managers to develop silvicultural techniques to manage the forest efficiently and sustainably. With this information the productivity of dominant tree species can be quantified in the forest. The information on dominant species is vital to develop an efficient management plan because these species significantly influences the magnitude and pattern of energy flow that is stored in its various organs in the form of various organic substances and material remained in continuous circulation between biotic and abiotic components of the forest ecosystem. Moreover, the enormous biomass accumulation in this forest was also due to prevailing site quality factors supporting luxuriant growth which include favourable soil and climatic conditions. Further due to higher litter production (5.37 Mg ha^{-1}) and faster nutrient turnover period of only one year due to favourable soil and climatic conditions sustained nutrient cycling maintaining availability of the primary nutrients in the soil for good growth and development of plants in the forest.

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