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Carbon, Litter and Nutrient Status in Teak Stands of a Foothill Forest in Indian Eastern Himalayas

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ABSTRACT

A study was conducted in teak stands of sub-humid foothill forest to estimate carbon storage, NPK status, litter production and decomposition. The litter production was 5.61 Mg ha^{-1} with turnover rate of litter decomposition in teak stands was only 12 months. The highest NPK and C availability was during September (269.54, 118.68 &163.09 Mg ha^{-1} and 1.86 %, respectively). Carbon stock is intricately linked with site quality, nature of land use, choice of species and other silivicultural practices adopted. These factors ultimately influence plant growth which is reflected into its biomass (1938.28 Mg ha^{-1}). Total carbon accumulated including soil, litter and biomass estimated was 911.27 Mg ha^{-1}. The site quality factors of the stands like tropical moist deciduous with soil having high organic carbon and available nitrogen and heavy precipitation, high mean monthly relative humidity and optimum temperature supported luxuriant growth supporting biomass production and carbon storage. Drawing CO_2 out of air and sequestering it into biomass is the only known practical way to remove large volume of greenhouse gases from atmosphere and thus indicates the importance commercially planted timber species like teak towards maintenance of atmospheric CO_2 efficiently which is permanently stored in its biomass for a longer period of 20-100 years or even more.

Keywords:

Biomass, carbon sequestration, eastern Himalaya, litter NPK, teak,

INTRODUCTION

The demand of high value timber is ever increasing day by day, thus the plantation of tropical timber species is increasing momentum to meet the demand of timber. Tropical tree plantations may play important role in mitigating CO_2 emissions through their potential to capture and sequester carbon from the atmosphere as well as improve the nutrient status through decomposition of litter (Derwisch et al. 2009). Teak (*Tectona grandis*) is a well known species grown between 9° to 26° N latitude 73° to 140° E longitude including India, Myanmar, Thailand and Laos (White 1991). The species is suitable for speedy production of large volumes of timber, poles and fuel wood and is widely used as lumber for ship building and general carpentry work. Today, teak ranks among the top five tropical hardwood species in terms of plantation area established worldwide (Krishnapillay 2000). A number of factors such as global decline of tropical timber supply from natural forests, increasing reliance on plantations to meet the growing demand for hardwood, involvement of private sectors in plantation activities, growth in international timber trade etc. are responsible for this drastic reduction in exploitation age (Nair and Souvannavong 2000). Carbon accumulation is related to biomass production in vegetation. Scientific management of forest in India and particularly the commercially important exploited species has become difficult due to lack of proper understanding of structural and functional relationships of forest ecosystem. There is a lack of data on biomass, litter production and nutrient status of plantations in India especially in West Bengal. The present study was an attempt to get an initial understanding about the nutrient status, biomass, litter production and carbon storage in teak stands within a forest.

MATERIALS AND METHODS

The present study was conducted at teak stands under Chilapatta Reserve Forest that lies within the forests of Cooch Behar Wildlife Division at Terai zone of West Bengal. These stands were in fact plantations as cent per cent individuals were of teak but as they are within the jurisdiction of Chilapatta Reserve Forest, the term 'stand' is used. The forest is located at northern fringe of the state in foothills of the sub-Himalayan mountain belts. The elevation of the working site as measured by GPS (Germin 72) was latitude 26° 32.85' N and longitude 89°22.99'E. Altitude of the area was 47 m above mean sea level. The climate is moist tropical (Anon. 2001) while soil is high in organic carbon and available nitrogen, medium in phosphorus and potash with acidic reaction having structure at 0-30 cm depth of about 70 % sand, 19 % silt and 11 % clay (Paul 2004). On an average total annual rainfall received was 2942.40 mm of which 80 % was recorded during June-August and mean monthly relative humidity ranged from 69.0-91.5 %. Rain fall in the zone is due to south-west monsoon. The summer and winter temperature are mild with highest of 32°C during May and lowest of 8.9°C during January. The temperature was normal during the study period.

In the teak stands of the forest, 15 (main) quadrates of 20 m x 20 m for trees, whitin which two quadrates of 5 m x 5 m at diagonal corner of every main quadrate for shrubs and five quadrates of 1 m x 1 m at all corners and centre of every main quadrate for herbs were marked randomly for biomass, soil and litter sampling. The stands were scattered all around the Reserve Forest, located mainly around the periphery of forest bordering National Highway and Torsa River while some plantations inside the forest bordering forest roads, with no stand no more than 5 ha of forest area. Almost all individuals in all the stands were of similar height and diameter at dbh, therefore no diameter class could be classified. Indirect or nondestructive methods were adopted for biomass estimation (Shukla 2010). About 10 trees were selected randomly from each quadrat for biomass sampling. The average total biomass, stem biomass and branch biomass of these 10 trees were calculated than multiplied with total number of trees/stem/branch to obtain the total biomass of trees/stems/branches in a quadrat. The height of the stem was measured up to its 1st branch and dbh was measured by a caliper. The number of primary, secondary and tertiary branches was counted from the 10 randomly selected trees in a quadrat. Again five branches in each category were selected from each tree and their length and mid-diameter were measured roughly on a visual estimate by comparing with an exactly measured branch/stick. From five randomly harvested branches of each selected trees all the leaves were plucked to measure their average fresh weight and then multiplied with the total number of branches to estimate the total mass of the leaves in a tree. For shrub biomass estimation, five plants were randomly selected from each 5x5 m quadrat, 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 x 1 quadrates were uprooted to measure their fresh weight separately for roots and above ground parts. The fresh biomass of seedlings of trees and shrubs found in the plots were also directly estimated from a few plots only where they were available in numbers to avoid destruction of the seedlings and it was found that their contribution was very negligible as compared to the total mass of the tree/shrub, so ignored while estimating the total biomass present in an unit area.

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; Alamgir and Al-Amin 2008). Below ground biomass was calculated considering 15 % of the above ground biomass (MacDicken 1997). Average total biomass estimated in available in the forest was expressed as Mg ha^{-1} was obtained by adding the average above ground biomass and 15 % of the average above ground biomass as below ground biomass. Above ground biomass was separately estimated for stems, branches and leaves. Further the total biomass in a plot and the total herb, shrub and total tree biomass was converted into carbon by multiplying with a factor of 0.45 as suggested by Woomer (1999). This was also expressed for the whole forest as Mg ha^{-1}. 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. Litter samples were collected (cleared and swept of any deposited debris) once compositely from 1 m × 1 m marked area in all the main quadrats following the litter sampling procedures for analysis suggested by Pandey (1986). Soil and litter samples were analyzed for per cent organic carbon using Walkley and Black Rapid Titration Method (Jackson 1967). The average total litter biomass and carbon in soil and litter of the forest was expressed as Mg ha^{-1}.

RESULTS AND DISCUSSION

Biomass production and carbon storage and partitioning at the time of observation of the teak stands are presented in Table 1. Total biomass stored in the teak stands was 1938.28 Mg ha^{-1}, out of this above and below ground contribution was 1685.38 and 252.90 Mg ha^{-1}, respectively. Contribution by the trees in total biomass was 99.69 % while a negligible amount was contributed by shrubs (0.25 %) and herbs (0.06 %). The biomass partitioned in to stem, branch, leaves and roots in perennial component while it partitioned as foliage and root in herbs. Tree stem had contributed maximum biomass (1205.26 Mg ha^{-1}) followed by branches, roots and least by the leaves (Table 1). The trend was similar in shrubs except where the contribution of root is next to the stem followed by branches and the least contributed by the leaves. Similarly the contribution of foliage or above ground biomass in herbs was about 68 % and rest by the roots. The contribution of above ground biomass in both the trees and shrubs accounted to more than 80 % while the rest was contributed by the below ground biomass i.e. roots. Another report from the same study area (Koul and Panwar 2008) also support the rate of biomass storage and trend of partitioning estimated in the present study. In a similar study from a reserve and protected temperate forest in Western Himalaya where

Table 1. Biomass production and carbon storage and partitioning in the teak stands

Component	Stem	Branch	Leaves	Aboveground	Below ground	Total
Biomass production (Mgha^{-1})						
Trees	1205.26	472.82	6.75	1684.82	252.72	**1937.55**
Shrubs	0.11	0.04	0.02	0.18	0.07	**0.24**
Herbs	-	-	0.38	0.38	0.11	**0.49**
Total Biomass						**1938.28**
Carbon storage (Mgha^{-1})						
Trees	542.91	212.98	3.04	758.93	113.84	**872.77**
Shrubs	0.05	0.02	0.01	0.08	0.03	**0.11**
Herbs	-	-	0.17	0.17	0.05	**0.22**
Total Carbon						**873.10**

Table 2. Available nutrient released from litter through decomposition in the teak stands

Initial		May		Sept		Dec		*Return to Soil $Mgha^{-1}$
Content (%)	Amount Mg/ha A	Content (%)	Amount Mg/ha B	Content (%)	Amount Mg/ha C	Content (%)	Amount Mg/ha D	E
Available nitrogen								
1.39	0.078	1.30	0.045	0.69	0.0120	0.32	0.00120	**0.077**
Available phosphorus								
0.36	0.020	0.22	0.0037	0.014	0.0005	0.006	0.00002	**0.020**
Available potassium								
1.01	0.057	0.88	0.030	0.38	0.006	0.18	0.00067	**0.056**

Table 3. Soil available N, P & K ($Kg\ ha^{-1}$), carbon content (%), total carbon ($Mgha^{-1}$) and pH, EC (m mohos cm^{-1}) & moisture (%) in the teak stands

Depth	N	P	K	C %	Total C	pH	EC	Moisture
January								
15 cm	251.22	101.02	144.69	1.61	36.08	5.29	0.06	31.86
30 cm	239.14	88.89	131.92	1.38	30.91	5.49	0.07	34.92
May								
15 cm	263.09	109.54	153.04	1.72	38.53	5.34	0.08	30.08
30 cm	252.88	96.99	142.83	1.49	33.38	5.56	0.09	34.11
September								
15 cm	269.54	118.68	163.09	1.86	41.66	5.57	0.08	35.89
30 cm	258.99	11.83	146.28	1.60	35.84	5.71	0.09	37.19
December								
15 cm	251.69	103.92	146.09	1.64	36.74	5.26	0.05	31.81
30 cm	242.31	87.79	134.88	1.43	32.03	5.67	0.06	35.23

comparatively lesser total aboveground biomass storage of 1149.78 and 674.61 Mgha^{-1}, respectively was reported (Sharma et al. 2008).

An estimate of total carbon storage and partitioning at the time of observation in the teak stands is given in Table 1. Converting biomass into carbon stored in teak stand, the trend remained almost the same. The carbon storage was 872.77 Mg ha^{-1}, out of this above ground contributed 759.18 Mg ha^{-1} and rest was from below ground. Shrubs and herbs contributed negligible amount of carbon as compared with trees. Perennial components were partitioned into stem, branch and leaves where as in herbs foliage and roots. Stem biomass contributed maximum amount of carbon followed by branch, root and least by leaves/foliage. Stems contributed 542.91 Mg ha^{-1}, followed by branches, roots and least by leaves. Sum of the stem, branch and leaves/foliage are called above ground, these parts together contributed about 85 % of accumulated carbon and remaining was contributed by roots. Similar report regarding carbon stock in biomass of 891.02 Mg ha^{-1} and its similar trends of partitioning was also reported by Koul and Panwar (2008), Pal and Panwar, 2013 and Jana et al. (2009) from the same study site. Carbon stock is intricately linked with site quality, nature of land use, choice of species and other silivicultural practices adopted (Swamy et al. 2003) which explains higher biomass in the present study and hence more carbon stock in the forest.

Litter production and proportion of its subsequent decomposition with periodic change are given in Table 2. The litter production of the stands was 5.61 Mg ha^{-1} at the time of leaf fall. The return to soil through decomposition from total litter was highest during second quarter of the year followed by first quarters. The decomposition gradually increased with time and after 12 month more than 90 % of the total litter got decomposed i.e. 5.13 Mg ha^{-1} litters decomposed. The rate of litter decomposition (Mg ha^{-1} per month) in terms of quarterly intervals was highest (0.59) during first quarter followed by second quarter (0.44) and lowest (0.24) in the last quarter. This may be due to favorable temperature, optimum rainfall and soil moisture regime prevailed in the forest. The lowest rate of decomposition during last quarter even after favorable conditions may be attributed to less amount of litter left for decomposition (22.90% of the initial litter) after the first two quarters.

The annual litter fall for deciduous and semi-deciduous forests of Brazil (Haase 1999) was 4.86-7.71 Mg ha^{-1} which were comparable to the present study. The material turnover through litter decomposition was 5.55 Mg ha^{-1} within 12 months in this study i.e. more than 90 % of the total litter produced because Chilapatta Reserve Forest was categorized as moist deciduous forest (Champion and Seth 1968) which support the report by Pastor (1987) that deciduous forests are believed to have faster nutrient turnover than 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). Wang and Huang (2001) observed 8-14 month for litter decomposition in temperate deciduous broad leaved forests as compared to turnover rate of only 12 months for the forest in this study which may be due to optimum temperature, rainfall and relative humidity in the area with abundant moisture in the soil (Table 3). The differences in turnover rates may be affected by the environment (soil and climate) and are mainly due to biological actions (Zhang et al. 2009). 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).

The NPK content (%) of fresh and decomposing litter with their total NPK (Mg ha^{-1}), its release in the soil (Mg ha^{-1}) and their periodic change is given in Table 2. The NPK content in fresh litter in teak was recorded as 1.39, 0.36 and 1.01 %, respectively. The annual return of nutrient was in the order N > K > P as was also observed by Pandey (2001). The NPK content decreased periodically as the decomposition progressed. The total NPK and its periodic change also showed similar behaviour as exhibited by its content. The return of NPK by litter decomposition cumulated over the period of 12 months coincided with what was recorded as total NPK from the fresh litter. The return of available NPK from litter through decomposition to the soil in the stand after one year was 0.077, 0.020 and 0.056 Mg ha^{-1}, respectively which is equal to the amount of available NPK in the fresh litter. This means there was no net increase or decrease of NPK in the system and which indicate it's cycling in a sustainable manner. 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 of NPK content in litter that 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 NPK release from the decomposing litter has been also recorded from other tropical forests (Chacon and Dezzeo 2007). In general the magnitude of total nutrient return was in order to the total litter fall. The higher nutrient was associated with higher litter fall and litter nutrient concentrations (Pande 2001).

The physical and chemical parameters of the teak stands at two depths with its periodic change are given in Table 3. The pH of the stands at both the depths was moderately acidic as was also reported by Koul (2006) from the same study area. At both depths, the 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 in the first three months. Chavan et al. (1995) and Contractor and Badnur (1996) have also reported low soil pH under forest plantations. This may be attributed to similar trend of periodic change in soil moisture, EC and subsequent increase of materials through litter decomposition (Table 2). Due to subsequent release of nutrients in to the soil by mineralization after decomposition along with release of water as byproduct of decomposition also explains the increase of EC and moisture in the soil and then decreased after nine months because by this time 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).

The availability of nutrient in soil was in the order N > K > P as was also reported by Pande (2001). The available NPK in teak stands also increased from first three months to ninth month and again decreased during last three months of the year to the same level as was in the first three months of the year at both the depths. This can be attributed to addition of nutrients by decomposition of litter in similar trend as nutrients in the soil increased and then decreased over the quarterly periods (Table 2) and subsequently being drawn up by the plants for their nutrition. This was indicated from the fact that though decomposing litter released NPK over time which simultaneously increased the soil NPK but due to consumption by plants the initial and final available NPK in the soil over the yearly cycle was nearly equal. Prescott (2002) also reported that soil NPK availability is more closely related to litter NPK content than to litter decomposition rate. 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).

The carbon content, total carbon and the periodic change in carbon recorded in soil of the teak stands are presented Table 3. For both the depths, carbon content also increased gradually up to nine month and then decreased up to the level similar to that recorded for the first three months which was due to its synchronization with decomposition of litter (Table 2) as discussed earlier subsequently releasing carbon into the soil up to nine months and then decreased. Similarly the total carbon also changed periodically. 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 (Vitousek and Sanford 1986). The SOC content (1.86 %) was recorded during the month of September and lowest value was recorded during January (1.61 %) in the stands over the period of 12 months at 0-15 cm depth. Similar trend was also recorded in 30 cm soil depth. Total SOC in Mg ha^{-1} was thus directly proportional to the SOC content of the stand which is similar to that reported by Koul (2006) from the same study area.

Total carbon is the sum of soil carbon (71.29), biomass carbon (873.1) and litter carbon (2.52) accumulated over a year and it was estimated at 946.91 Mg ha^{-1}. The value of carbon stock within the teak stands indicates the importance commercially planted timber species towards maintenance of atmospheric CO_2 efficiently because of the permanency of carbon being stored in biomass for a longer period of 20-100 years or even more along with its post-harvest life (George 2008).

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