International Journal of Ecology and Environmental Sciences 48: 59-69, 2022
ISSN: 2320-5199 (Online); https://doi.org/10.55863/ijees.2022.0012

Carbon Stock, Soil CO_2 Flux and Carbon Budgets of Different Forest Ecosystems of Manipur, Northeast, India

A. THOKCHOM* AND P.S. YADAVA
Department of Botany, Wailkhom Mani Girl's College, Thoubal, 795138, India
Email: amrabatithokchom@gmail.com; yadava.ps1@gmail.com
***Corresponding author**

ABSTRACT
Carbon stock and soil CO_2 flux in the vegetation-soil components were assessed in tropical, sub-tropical and temperate forest ecosystems of Manipur, Northeast India. Carbon stock in the aboveground biomass was recorded to be highest in the sub-tropical forest (319.18 Mg ha^{-1}) followed by temperate (54.45 Mg ha^{-1}) and tropical forest (38.35 Mg ha^{-1}) whereas soil organic carbon stock was highest in temperate forest (65.13 Mg ha^{-1}) and lowest in tropical forest (21.64 Mg ha^{-1}) up to the depth of 1m. The rates of carbon sequestration was in the order of the tropical>temperate> sub- tropical forest and the rate of soil CO_2 flux was estimated to be highest in tropical and lowest in temperate forest. Regression analysis shows that annual soil CO_2 flux was highly influenced by soil moisture, soil temperature and soil organic carbon as well as by C stocks in aboveground biomass. The annual carbon budget of the tropical, sub-tropical and temperate forest shows that 11.41 Mg C ha^{-1},9.84 Mg C ha^{-1} and 10.34 Mg C ha^{-1} was captured by the vegetation through photosynthesis, while 10.36 Mg C ha^{-1} ,5.84 Mg C ha^{-1} and 8.07 Mg C ha^{-1} was released into the atmosphere through CO_2 emissions from soil due to root and microbial respiration thereby a net balance of 1.05 Mg C ha^{-1} yr^{-1}, 1.77 Mg C ha^{-1} yr^{-1} and 2.27 not (4.50) Mg C ha^{-1} yr^{-1} was being retained in the forest ecosystems. Thus our study indicates that these forests have a huge potential in the reduction of carbon dioxide levels in the atmosphere and could be used as C-sinks in the Northeast India depending upon the level of protection.

Key words: Carbon sequestration, Carbon budget, Carbon stock, Soil CO_2 flux.

INTRODUCTION

Human activities result in the emission of certain greenhouse gases predominantly CO_2 into atmosphere and that affect the global climate. The forests play a vital role to mitigate the climate changes in reducing the carbon dioxide which is being utilised through process of photosynthesis. Therefore forests are significant reservoir of carbon which is stored in living, dead biomass and soil. The loss of forests on global scale is a significant contributing factor in climate change .Carbon sequestration in forest soil and vegetation has been used to achieve green house gas (GHG) reduction target. The United Nation Framework Convention on Climate Change (UNFCCC) and Clean Development Mechanism (CDM) have considered a new initiatives to reduce emissions from deforestation and degradation in developing countries (REDD). These activities are involved in new plantations and protection of young forests but the old-growth forests are not protected because it is generally thought that they cease to accumulate carbon. Forests maintain high carbon stock by reducing deforestration and promoting sustainable management of all types of forests. Sustainable forest management provides an effective framework for forest-based climate mitigation and adaptation. Thus forests play an important role in climate mitigation and adaptation. As forests store more CO_2 than the entire atmosphere, their role is very critical (Stern, 2006).Carbon sequestration is an important part of an overall carbon management strategy to help in reduction and to mitigate global CO_2 emission. Therefore, it is essential to continue to emphasize the understanding of carbon cycle, which drives future global change scenario and impacts the efficiency of sequestration options in natural ecosystems.

Soil organic carbon (SOC) is also important as the soil is the major pool of organic carbon which remains bound in the soil organic matter in the terrestrial ecosystems. Soil carbon has global significance in carbon cycle as it is also a source of CO_2 emission into the atmosphere. Temperature is an important factor regulating CO_2 release from the soil due to activities of soil organisms and root respiration. Global warming accelerates the decomposition of Soil Organic Matter (SOM), and thus lead to decrease of soil organic carbon and increase in the emission of CO_2 from the soils (Jenkinson et al.1991). The evolution of CO_2 from the soils is the second largest flux in the C budget of forest ecosystems (Gower et al.1969) and is therefore one of the key component in the C cycle at regional and global scale (Raich and Schesinger 1992). It amounts to 60-90% of the total ecosystem (Davidson et al. 2006) and is a major portion of the global C cycle. Soil CO_2 flux is the production of CO_2 by an organism and the plant parts in the soil. Soil CO_2 flux differs among ecosystems and also varies with environmental conditions. Soil CO_2 flux has large variations because of the influences of individual biotic and abiotic factors in the different ecosystems. Small changes in Soil CO_2 flux across forest can produce a great effect on CO_2 atmospheric concentration and provide a potential positive feedback between increasing temperature and enhanced soil CO_2 flux that may ultimately accelerate global warming. Therefore detailed information on soil CO_2 flux and its controlling factors is critical for constraining the ecosystem C-budget and for understanding the response of soils to changing land use and global climate change (Han et al.2007).

A number of studies have been reported on carbon stock in India on the basis of growing stock volume data of forest inventories using conversion factor (Ravindranath et al. 1997, Lal and Singh 2000, Chhabra et al. 2002, Devagiri et al. 2013). However, limited information is available on carbon sequestration potential of the forests of north-eastern India (Baishya et al. 2009, Thokchom and Yadava 2013). Soil organic carbon stock in the north eastern India has been investigated recently by Bhattacharya et al. (2010) and Choudhury et al. (2013). The carbon sequestration potential of forests in terms of soil organic carbon, carbon stock and rate of carbon sequestrartion in the aboveground biomass and soil carbon dioxide flux in different forest ecosystems has been discussed in this study. Thus the study will fill the gap on the current state of knowledge on carbon budget of forest ecosystems of Manipur, Northeast India and to enhance the understanding of the role of forests in mitigation of climate change. The major objectives of the present study were to estimate (i) to quantify the carbon stock in the vegetation and soil components; (ii) to measure the CO_2 emission from the soils; (iii) to determine the rate of carbon sequestration of different forest ecosystems and (v) to determine the annual carbon budget of tropical, subtropical and temperate forests of Manipur, Northeast India.

MATERIAL AND METHOD

Study area

The present study was conducted in tropical, subtropical and temperate forest of Manipur, Northeast India. The present study was conducted in tropical, subtropical and temperate forest of Manipur, Northeast India. Tropical forest site is located at $23^0$132 N and $94^0$172 E at an altitude of 261 -360 m above mean sea level along the Myanmar border in the Chandel district of Manipur which is about 112 km from Imphal, the capital of Manipur. It is dominated by *Dipterocarpus tuberculatus* and co-dominated by *Melannorrhoe ausitata* and is young secondary forest and subjected to biotic disturbances of selective logging and annual fires. Sub-tropical forest site is located at Langol hills (24^0 45’2” N : 93^0 55’2” E) at an altitude of 780-910 m above mean sea level which is about 7 km from Imphal city and dominated by *Quercus serrata* and co-dominated by *Rhus succidanae* and the forest is well protected. Temperate forest is located at 25^0 13’2” N latitude and $94^0$24’2” E longitude at an altitude of 1800 to 1970 m above mean sea level in Shiroy hill, Ukhrul district which is about 105 km from Imphal and dominated by *Alnus nepalensis* and co-dominated by *Rhododendron arboreum* subjected to moderate disturbances.

The climate of the area is monsoonal with a warm moist summer followed by a monsoon rainy season and a cool dry winter. Mean monthly maximum temperature varied from 22.3 (December) to 30.3°C (May) and the mean minimum temperature from 4.8 (January) to 22.3°C (July). Annual rainfall is 1,408 mm mostly received in the rainy season (June October).

Soil Sampling and Analysis of Soil

Five soil samples were collected randomly from the study site at monthly intervals from November 2016 to November 2017 for the analysis of physico-chemical characteristics. Soil moisture, soil temperature, soil organic carbon, total soil nitrogen and total soil phosphorus were determined on monthly basis in all the forest sites. The soil organic carbon was estimated by Walkley and Black method, soil moisture content by Gravimetric method (oven dry at 105°C for 24 hrs). Total soil nitrogen was measured by 2100 Kjeltec system and available soil phosphorus was determined following the method given by Bray and Kurtz (1945). Soil organic carbon stock has been estimated up to 1 metre soil depth i.e. 0-30, 30-50, 50-70 and 70-100 cm in tropical, sub-tropical and temperate forest types).

Data Analysis

Ten replicates plot of 10 X 10m size will be earmarked in the study areas of each of the forest types. In each plot all trees individuals with circumference at breast height (1.37m) greater than 10 cm were measured. The aboveground biomass (AGB) of tree species was estimated in tropical forest, sub-tropical forest and temperate forest ecosystems of Manipur by using regression equation developed by Brown, 1997. The regression model used for the calculation of aboveground biomass is given as

$$Y= 21.297-6.953 (D) + 0.740 (D^2)$$

Where, Y is the aboveground biomass (AGB) and D is the diameter of the tree (cm).

To convert aboveground biomass to carbon stock we assumed that 50% of the dry matter was carbon (Ngo et al. 2013) and the carbon sequestration was calculated as the annual increase in the carbon density per ha at each site by species.

Fine roots were collected from the three forest types by using soil core method (Vogt et al.1996), five randomly located soil corer (8.5 cm diameter) from 0-30 cm depth soil layer were collected on a monthly basis. For litter biomass five plots of 10 x 10 m size in each forest types was fenced and the accumulated litter was cleared. Thereafter litter fall was collected every month and then dried at 80^0C till constant weight. The carbon stock in both roots and litter was estimated from the root biomass and litter biomass based on conversion factor of 0.5 (Ma et al. 2002). The Soil CO_2 flux was measured on monthly basis from November 2013 to October 2014 in the study sites of three different forest types through Soil Respiration System (Q-BOX SR1LP), Canada.

Statistical analyses

All statistical analyses were carried out using the software IBM SPSS 20 and Statistica. ANOVA was used to determine the differences in variables in the different forest ecosystems. Simple linear regression was used to find out the relationship between variable and soil CO_2 flux .Multiple regressions were used to find out the relationship between soil CO_2 flux rate and soil organic carbon stock, litter carbon and root carbon.

RESULT AND DISCUSSION

Physico-chemical properties of soil

Soil texture is sandy loam, loam and clay loam in tropical forest, subtropical forest and temperate forest respectively. Soil is acidic with pH ranging from 3.90 to 6.74 across the forest study sites. The soil temperature was found to be lowest in temperate forest and highest in the tropical forest where it was reverse trend in the case of soil moisture. Soil organic and total nitrogen were highest in temperate forest and lowest in the tropical forest owing to the slow rate of litter decomposition coinciding with low temperature at higher altitude (Table 1). Similar trends were also reported by Kitayama and Aiba (2002) and Takyu et al. (2003) in Borneo forest.

Forest structure, vegetation carbon density and rate of carbon sequestration

Across the three sites a total of 47 plant species were recorded and among all the forest sites subtropical forest exhibited a maximum number of species. Highest stand density was recorded in the tropical forest (2170 trees ha^{-1}) followed by subtropical forest (1630 trees ha^{-1}) and temperate forest (1230 trees ha^{-1}). Analysis of variation shows a significant variation in the density distribution across the forest types ($F_{2,19}$=6.47; p<0.005). The density of tree species decreased steadily with the increase of the DBH class (Fig. 1). In tropical and temperate forest 52% and 60% of stand density where recorded in the low DBH class (0-30cm) whereas in subtropical forest 50% of stand density where found in the 0-30

Table 1. Physico-chemical properties of soil in tropical, subtropical and temperate forests of Manipur, Northeast India

Parameters	Tropical	Sub -tropical	Temperate
Soil texture	Sandy loam	Loam	Sandy loam
Sand (%)	71.30	60.00	72.78
Silt (%)	16.81	20.15	22.67
Clay (%)	11.13	19.85	4.55
Soil pH	4.15-6.74	4.21-5.98	3.90-4.51
Soil temperature(°C)	19.68-31.98	16.02-24.87	9.20-20.70
Soil moisture (%)	8.23-17.67	18.48-35.22	18.80-59.20
Bulk density(g cm^{-3})	1.38-1.56	1.37-1.67	0.74-1.10
Organic carbon (%)	0.95-1.62	0.90-2.70	1.05-3.78
Total Nitrogen (%)	0.28-0.70	0.40-1.22	0.41-1.80
Total phosphorous (%)	0.11-0.22	0.14-0.19	0.21-0.56

and 30-50 cm DBH class.

The aboveground carbon density was 38.35 Mg ha^{-1} in the tropical forest, 319.18 Mg ha^{-1}in subtropical forest and 54.45 Mg ha^{-1} in the temperate forest. Analysis of variation shows a significant difference in the carbon density distribution across the forest types ($F_{2,33}$=24.05; $p<0.001$). In our study we find that there was a wide variation in the aboveground carbon density among the forest sites. The carbon density in the subtropical forest was eight times more than the tropical forest and six times the temperate forest (Fig. 2). It is obvious as subtropical forest site being a sacred grove was well protected by local people and consists of matured, fully stocked and old growth forest. The low value of carbon density in tropical forest is due to being of young secondary forest at early succession stage and also subjected to mild biotic disturbances. Similar finding was also reported for the tropical forest of Singapore (Ngo et al. 2013). The present tropical forests lies in the lower altitude and moderately disturbed, large trees more than 70 cm DBH were not available in this forest while temperate forest having high altitude is subjected to least disturbance. Thus it is important to note that altitude and level of disturbance also play a very important role in the storage of carbon in the vegetation as Similar studies were also reported by Do et al. (2017), Murthy et al. (2016) and Sharma et al. (2010).

The range of aboveground carbon density (38.9-329.7Mg ha^{-1}) in the present study were lower than that the data reported by Singh and Singh (1991) in dry tropical forest of India (19-35 Mg ha^{-1}). The value of the carbon density in the sub-tropical forest were comparable with data reported by Rai, 1981 in the tropical evergreen forest of India (304 Mg ha^{-1}) and the value of the tropical and temperate forest were comparable with the data reported by Jaramillo et al. (2003) and Návar (2009) from the tropical dry deciduous forest of Mexico (37-58 Mg ha^{-1}).

Soil organic carbon stock (SOC) in different forest types

SOC was recorded to be highest in temperate forest (65.13 t C ha^{-1}) followed by sub-tropical forest (57.91 t C ha^{-1}) and tropical forest (21.64 t C ha^{-1}) in the upper soil depth. SOC decreased with increase in soil depth in all the forest type (Table 2). Out of total SOC, 54.9, 41.4 and 47.2 % was contributed by the upper soil depth of 0-30 cm in tropical, sub-tropical and temperate forests, respectively.

In temperate forest, carbon stored in the soil was greater than in the aboveground biomass owing to slow decomposition of plant litter being low temperature whereas in case of tropical and subtropical forest a large portion of organic carbon was accumulated in aboveground biomass. It shows that in these forests, the nutrient are highly leached out due to high rainfall and rapid decomposition plant materials due to high temperature and finally resulted in poor nutrients in the soil and sediments.

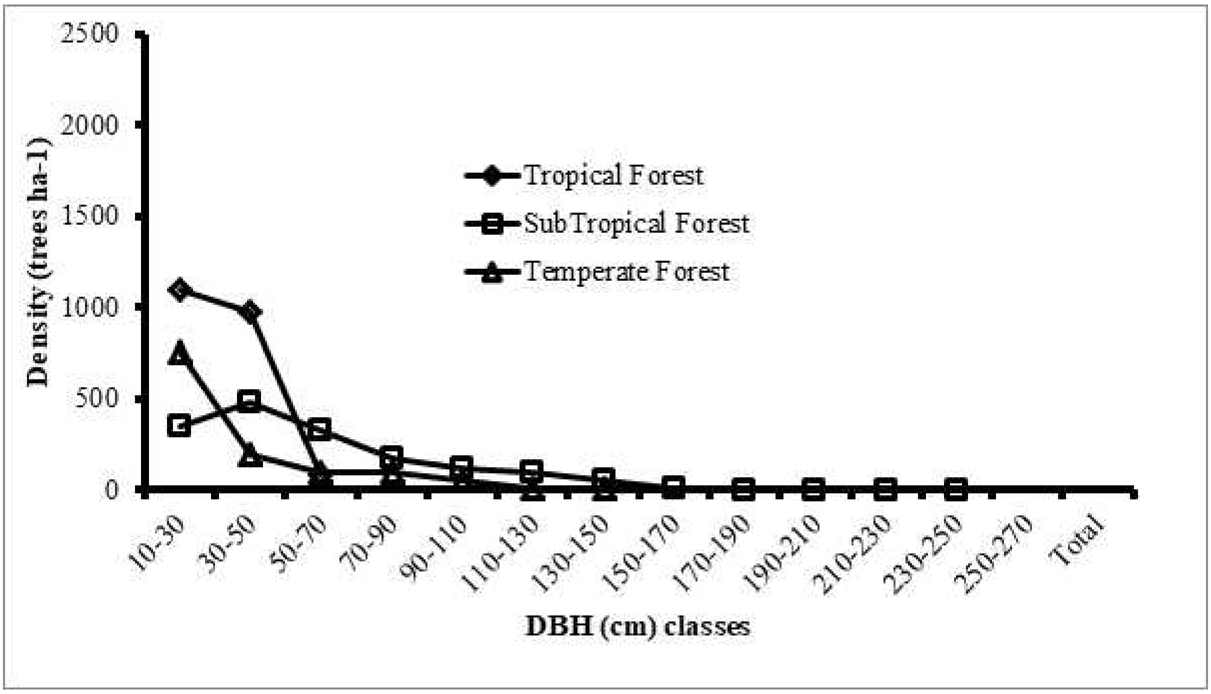

Figure1. Distribution of trees density (tree ha^{-1}) in different DBH classes (cm) at different sites

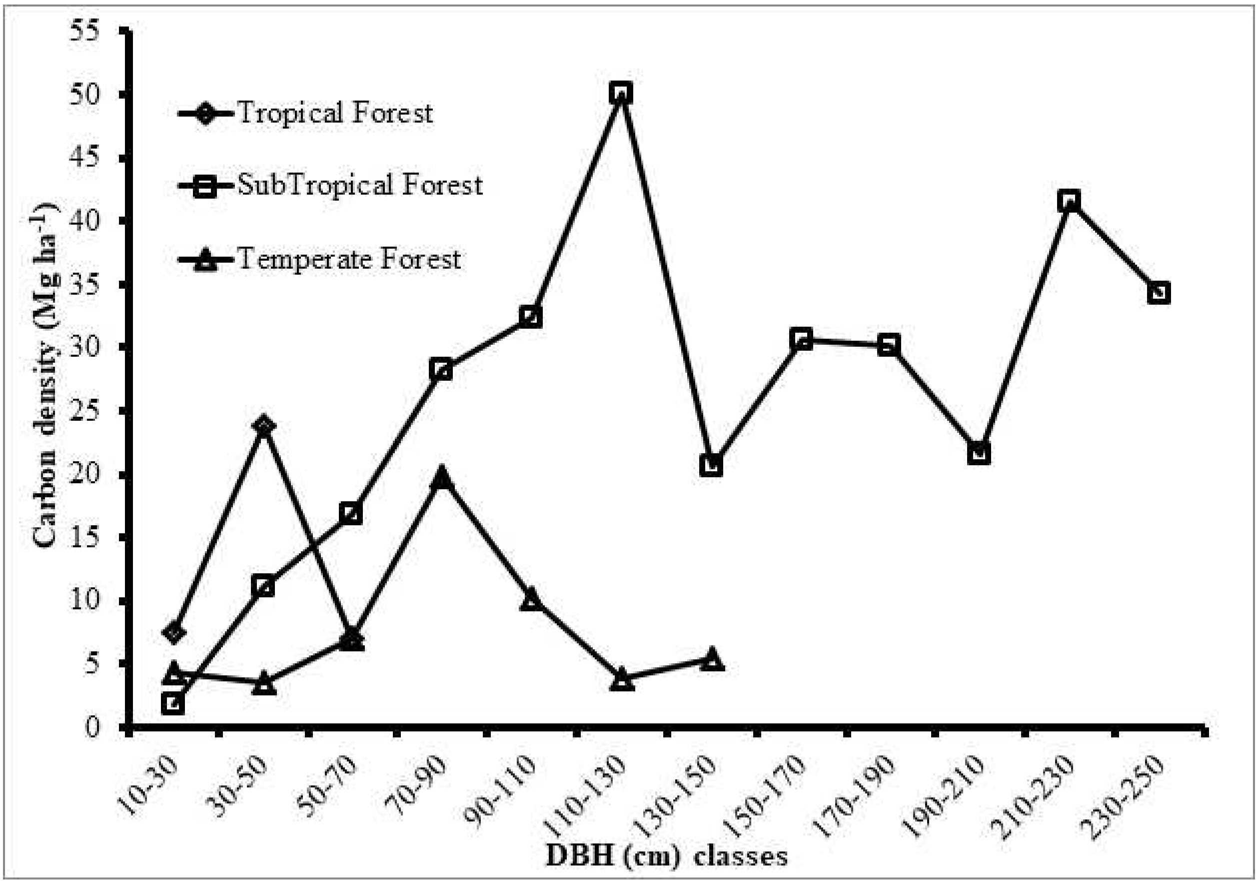

Figure 2. Carbon density (Mg ha^{-1}) at different DBH classes (cm) at different forest sites

Table 2. Profile of soil organic carbon stock in forest ecosystems of Manipur, N.E. India (Mg C ha^{-1})

Soil Depth (cm)	Tropical Forest	Sub-tropical Forest	Temperate Forest
0-30	11.90	24.00	30.8
30-50	4.14	16.80	12.4
50-70	3.90	8.81	7.20
70-100	1.70	8.30	4.73
Total	**21.64**	**57.91**	**65.13**

Table 3.Tree Density (tree ha^{-1}), Carbon density (Mg ha^{-1}) and Carbon Sequestration rate (Mg ha^{-1} yr^{-1}) in different forest types of Manipur

Forest types	Tree Density	Carbon density	Carbon Sequestration
Tropical forest	2170	38.35	11.41
Sub-tropical forest	1630	319.18	9.84
Temperate forest	1230	54.45	10.34

Rate of carbon sequestration

Annual rate of carbon sequestration was estimated to be highest in tropical forest (11.41Mg C ha^{-1}) followed by temperate (10.34 Mg C ha^{-1}) and sub-tropical (9.84 Mg C ha^{-1}) forests (Table 3) which is just a reverse with the carbon stock being lowest in tropical and highest in sub-tropical forest. Thus large carbon stock does not necessary for high carbon sequestration potential and similar result was also reported by Yadav et al. (2017) in the mid hills of Indian Himalaya.

Relationship between annual DBH increment and mean DBH class for the different forests shows an exponential decline model for all the species indicating highest increments for trees in the lowest DBH class (Fig. 3). Thus it shows that the rate of carbon sequestration was high in the young forest rather than the mature forest as there will be net addition to standing biomass to carbon storage. Thus the young forest needs to be protected and conserved for mitigating the climate change. Similar studies were also reported in dry tropical forest of India (Chaturvedi et al. 2011) and tropical deciduous forests of Central India (Salunkhe et al. 2016).

Soil CO_2 flux

The soil CO_2 flux ranged between 95.23-964.41 mg CO_2 m^{-2} hr^{-1} in the tropical forest, from 120.15 to 455.5 mg CO_2 m^{-2} hr^{-1} subtropical forest and from 79.06 to 409.37 mg CO_2 m^{-2} hr^{-1} in temperate forest (Fig. 4). It attained maximum value during raining months and minimum in cool and dry winter months across the forest types. Analysis of variation shows a significant difference in the rate of soil CO_2 flux in the different forests ecosystems ($F=2.59$; $p=0.005$). The mean annual soil CO_2 flux was found to be highest in tropical forest followed by subtropical and temperate forest. This may be due to high temperature in tropical forest which lead to the rapid decomposition of the organic matter present in the soil and leads to the increase of the emission of CO_2.Our reported data are comparable with the study reported by La Scala et al. (2000) in the tropical bare soil of Brazil (231-444 mg CO_2 m^{-2} hr^{-1}) but lower than that reported by Kursar (1989) and Schwendenmann et al. (2003) in forest of Panama (464-91 mg CO_2 m^{-2} hr^{-1}) and forest of Costa Rica (430-675 mg CO_2 m^{-2} hr^{-1}).

Seasonally the rate of soil CO_2 was recorded to be maximum in rainy season followed by summer and minimum in the winter season (Table 4, Fig. 4). Minimum rate of soil CO_2 flux in winter season in all the forest types resulted due to low temperature and soil moisture thereby inhibiting the microbial activity and thus leading to low CO_2 emission from the soil. However the maximum rate of soil CO_2 flux the rainy season in all the study sites may be due to burst mineralization of labile soil organic matter that has been accumulated during the dry period and which is available to micro-organism afters re-wetting of the soil. Thus it promoted the physiological activities of soil microbes and the root respiration and resulted in the increase of the soil CO_2 flux. Annually the rate of soil CO_2 was highest in tropical forest (431.7 $mgCO_2mg^{-2}hr^{-1}$) followed by subtropical forest (336.6 $mgCO_2mg^{-2}hr^{-1}$) and temperate forest (243.7 $mgCO_2mg^{-2}hr^{-1}$) .In the temperate forest because of low temperature there is slow litter decomposition while in the case of tropical there is rapid mineralisation of the organic matter present in the soil because of high temperature which leads to the increase of soil CO_2 flux. The similar seasonal pattern of soil respiration rate has also been reported in sub-tropical forest (Devi and Yadava 2009), temperate forest (Mo et al. 2005), tropical

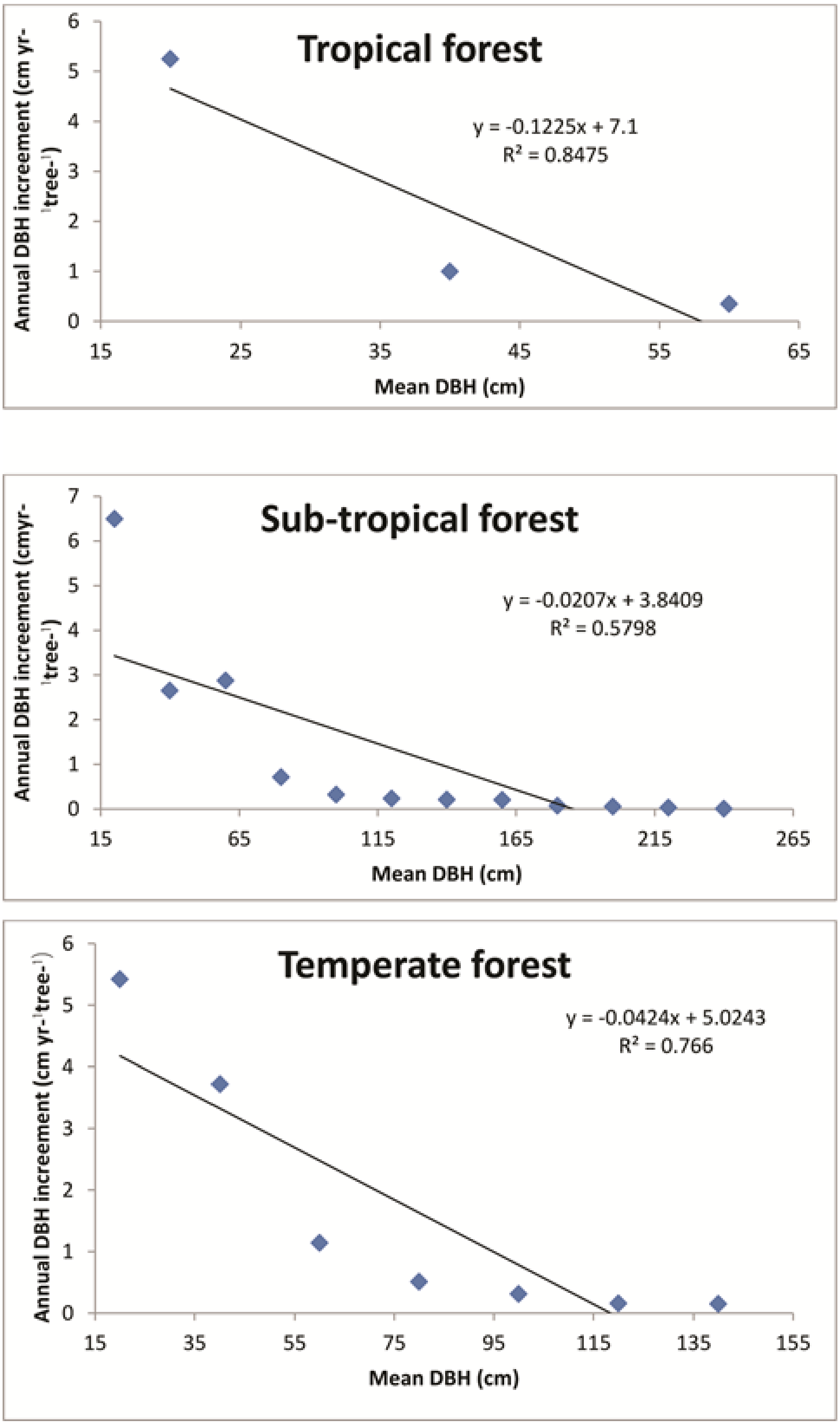

Figure 3. Relationship between DBH increment (cm yr^{-1} tree^{-1}) and mean DBH (cm) in temperate, sub-tropical and tropical forest

Table 4. Seasonal changes in the rate of soil CO_2 flux (mg CO_2 m^{-2} h^{-1}) in different forests of Manipur, Northeast India

Season	Tropical forest	Temperate forest	Sub-tropical forest
Summer(Mar-May)	368.2 ± 243.6	218.7 ± 154.4	295.8 ± 2.78
Rainy (Jun-Oct)	687.0 ± 206.1	373.9 ± 148.5	496.1 ± 38.5
Winter(Nov-Feb)	160.4 ± 66.6	99.5 ± 17.0	217.8 ± 76.6
Annual	**431.7 ± 291.4**	**243.7 ± 166.9**	**336.6 ± 99.2**

forest (Thokchom and Yadava 2014) and mixed forests (Chen et al. 2013, Takahashi et al. 2011).

Relationship of soil CO_2 flux with abiotic and biotic variables

The relationships between the rates of soil CO_2 flux (mg CO_2 m^{-2} hr^{-1}) and soil properties, i.e. soil temperature (X_1), soil moisture (X_2) and soil organic carbon (X_3) have been analysed by multiple regression as follows:

a)Tropical forest

$Y=7.875 + 0.796X_1+0.225 X_2 -0.15X_3$

(r_1=0.65; r_2=0.86; r_3=0.57) at $p<0.01$.

Table 5. Annual C-budget in different forest types of Manipur, N.E.India (Mg ha^{-1})

Components	Tropical forest	Sub-tropical forest	Temperate forest
C-stock in Above ground Vegetation	38.35	319.18	54.45
C-stock in soil up to depth of 1 m	21.64	57.91	65.13
C-stock in litter	0.33	1.04	2.26
C-stock in roots	4.62	3.77	1.39
Soil CO_2 flux	10.36	8.07	5.84
Rate of carbon sequestration	11.41	9.84	10.34
Net carbon balance	1.05	1.77	4.50

b) Sub-tropical forest

$Y= -47.925 + 0.425X_1+0.465 X_2 +0.032X_3$

(r_1=0.72; r_2=0.61; r_3=0.85) at $p<0.01$.

c) Temperate forest

$Y=-98.75-0.061X_1+0.641X_2+0.201X_3$

(r_1=0.54; r_2=0.83; r=0.72) at $p<0.01$

The significant positive relationship between soil CO_2 flux rates and soil moisture, soil temperature

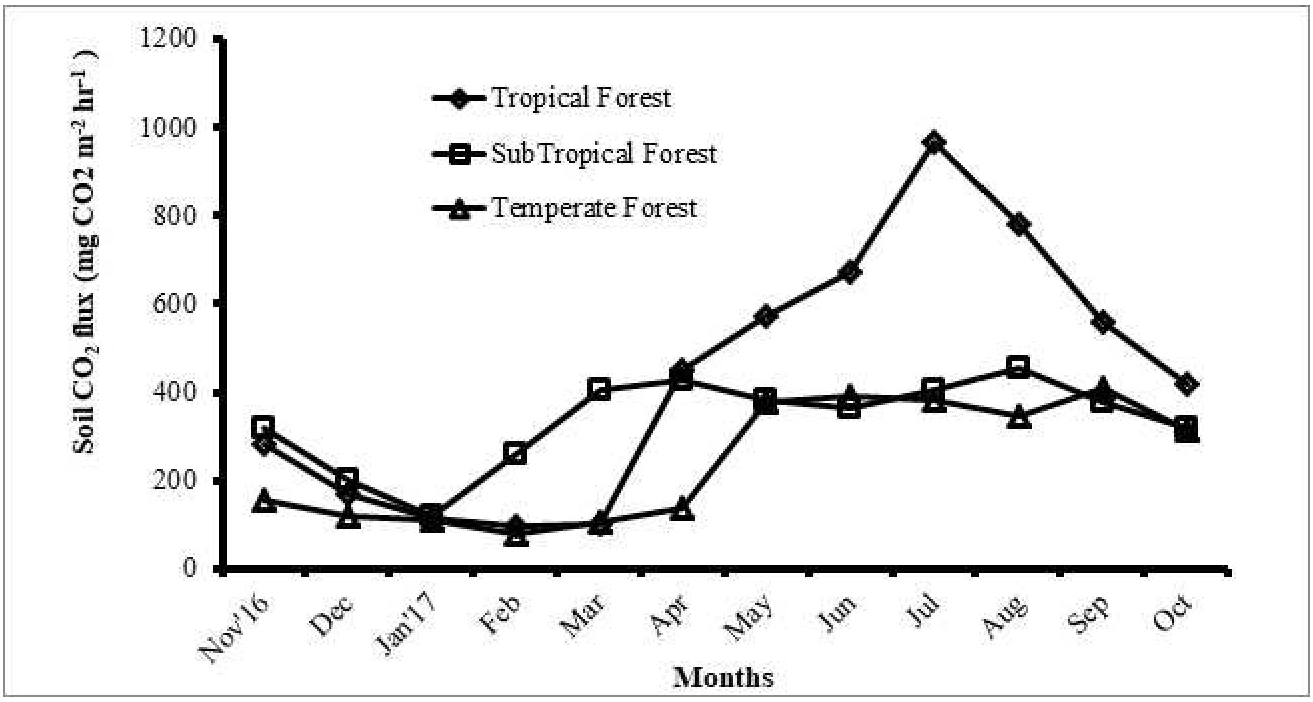

Figure 4. Soil CO_2 flux (mg CO_2 m^{-2} hr^{-1}) in different months in different forest ecosystems

and soil organic carbon levels reveals that these parameters have a strong influence on CO_2 emissions into the atmosphere, as also reported for different forest ecosystems by other workers (Oishi et al. 2013, Zhao et al. 2013).

Annual C-budget in different forest types

Annual carbon pool and carbon flux rate in different components of three forest ecosystems are given in Table 5. C-stock in the aboveground biomass was estimated to be highest in subtropical forest, being a sacred grove, well protected followed by temperate forest and tropical forest while the soil organic stock was recorded to be highest in the temperate forest and lowest in the tropical forest. Annually vegetation components stored more carbon than the soil components in the tropical forest and subtropical forest which partly may be due to rapid decomposition dead biomass in the warm, humid condition and leaching out of nutrients in the soil. However in case of temperate forest more carbon was stored in the soil component than the vegetation components because slow of decomposition plant debris due to low temperature.

The carbon stock in the root biomass was highest in the tropical forest which led to increase of soil CO_2 flux as root biomass also plays a very important role in emission of CO_2. In the temperate forest, the carbon stock in the soil and litter was highest and was strongly affected by litter thickness and litter sequestration in the soil and slow rate of litter decomposition.

The annual carbon budget of the tropical, sub-tropical and temperate forest shows that 11.41 Mg C ha^{-1}, 9.84 Mg C ha^{-1} and 10.34 Mg C ha^{-1} was captured by the vegetation through photosynthesis, out of which 10.36 Mg C ha^{-1}, 8.07 Mg C ha^{-1} and 5.84 Mg C ha^{-1} returned to the atmosphere via soil respiration. A net balance of 1.05 Mg C ha^{-1} yr^{-1}, 1.77 Mg C ha^{-1} yr^{-1} and 4.50Mg C ha^{-1} yr^{-1} was retained in the tropical, subtropical and tropical ecosystems. In the tropical forest the soil CO_2 flux was high owing to rapid decomposition couple with high temperature but since the rate of carbon sequestration was high so it can couple with the increasing CO_2 flux. Thus forests have a potential in the reduction of carbon dioxide levels in the atmosphere and could be used as C-sinks in provided these are protected from deforestation.

CONCLUSIONS

We studied the carbon density and rate of carbon sequestration in the vegetation and soil in the tropical, subtropical and temperate forests of Manipur, North-East India. Our study showed that most of the vegetation carbon resides more in the old-growth (high DBH) trees in well protected forests than the young secondary forests having low DBH. But the rate of carbon sequestration was high in the young tropical forest while comparing with the mature forest of the sub-tropical .We also found that tropical and subtropical forests stored more carbon in the vegetation component than in the soil while in the temperate forest stored more carbon in the soil component because of slow litter decomposition. The present study shows that seasons have a strong influence on the soil CO2 flux with highest rate in rainy season and lowest in cool and dry winter season in three forest ecosystems. Soil temperature, soil moisture and soil organic carbons are the predominant variables controlling soil CO2 flux in all the forest types. These present findings will enable us to accurately estimate regional carbon stock, fluxes and carbon budget by taking into the consideration the biotic and abiotic variables in different forests ecosystems of NE India. The carbon budget of all the present forests shows that the forests have a huge potential in the reduction of CO_2.Thus these forests play a vital role in carbon sequestration in the soil-vegetation system. Therefore to mitigate the increasing atmospheric CO_2 efforts are also needed to protect the young forest from lodging and fire and reforestation and afforestation programme could be recommended to enrich the forest stock.

ACKNOWLEDGEMENTS

We thank Department of Science and Technology, New Delhi for providing financial support under a National Programme on Carbon Sequestration Research.

Conflict of interest: The authors declare that they do not have any conflict of interest.

Authors Contributions: AT conducted the fieldwork, analysed the data and participated in the manuscript preparation and review. PSY supervised the work and finalized the manuscript.

REFERENCES

Brown, S. 1997. Estimating biomass and biomass change of tropical forests. A primer. FAO Forestry Paper 134. Food and Agriculture Organization of the United Nations, Rome, Italy.

Baishya, R., Barik, S.K. and Upadhaya, K. 2009. Distribution pattern of aboveground biomass in natural and plantation forests of humid tropics in northeast India. Tropical Ecology, 50(2), 295-304.

Bhattacharya, T., Sarkar, D., Pal, D.K., Mandal, C., Baruah, C., Telpande, D. and Vaidhya, P.H. 2010. Soil information system for resource management-Tripura as a case study. Current Science, 99, 1208-1217.

Chhabra, A., Palasia, S. and Dahwal, V.K. 2002. Spatial distribution of phytomass carbon in the Indian forests. Global Change Biology, 8, 1230-1239.

Chaturvedi, R.K., Raghubanshi, A.S. and Singh.J.S. 2011. Carbon density and sequestration in woody species of tropical dry forest in India. Forest Ecology Management, 262, 1576-1588.

Chen, W., Jia, X., Zha, T.,Wu, B., Zhang, Y., Li, C., Wang, X., He, G., Yu, H. and Chen, G. 2013. Soil respiration in a mixed urban forest in China in relation to soil temperature and water content. European Journal of Soil Biology, 54, 63-68.

Choudhury, B.V., Mohapatra, K.P., Das, A., Das, P.T., Nongkhlaw, L., Fiyaz, R.A., Ngachan, S.V., Hazarika, S., Rajkhowa, D.J. and Munda, G.C. 2013. Spatial variability in distribution of organic carbon stocks in the soils of North East India. Current Science, 104(5), 604-614.

Davidson, E.A., Janssens I.A. and Luo, Y. 2006. On the variability of respiration in terrestrial ecosystems: moving beyond Q10. Global Change Biology, 12, 154–164.

Devi, N.B. and Yadava, P.S. 2006. Emission of CO_2 from the soil and immobilisation of carbon in microbes in a subtropical mixed oak forest ecosystem, Manipur, Northeast India. Current Science, 96, 1627-1630.

Devagiri, G.M., Money, S., Singh, S., Dadhwal, V.K., Patil, P., Khaplek, A., Devakumar, A.S. and Hubballi, S. 2013. Assessment of aboveground biomass and carbon pool in different vegetation types of south western part of Karnataka, India using spectral modelling. Tropical Ecology, 54(2), 149-165.

Do, T.V., Sato, Y., Hai, V.D., Thang, N.T., Binh, N.T., Son, N.H., Thuyet, D.V., Doi, B.T., Thang, H.V., Hung, T.T., Con, T.V., Kozan, O., Thanh, L.V., Cam, N.V. 2017. Aboveground biomass and tree species diversity along altitudinal gradient in Central Highland, Vietnam. Tropical Ecology, 58, 95-104.

Gower, S.T., Songracic, S. and Landsberg, J.J. 1996. A global trend in belowground carbon allocation: can we use the relationship at smaller scales. Ecology, 77, 1750–1755.

Han, G., Zhou, G., Xu, Z., Yang, Y., Liu, J. and Shi, K. 2007. Biotic and abiotic factors controlling the spatial and temporal variation of soil respiration in an agricultural ecosystem. Soil Biology and Biochemistry, 39, 418-425.

Jaramillo, V.J., Kauffman, J.B., Renteria-Rodriguez, L., Cummings, D.L. and Ellingson, L.J. 2003. Biomass, carbon, and nitrogen pools in Mexican tropical dry forest landscapes. Ecosystems, 6, 609–629.

Jenkinson, D.S., Adams, D.E. and Wild, A. 1991. Model estimates of CO_2 emissions from soils in response to global warming. Nature, 351, 304-306.

Kitayama, K. and Aiba, S. 2002. Ecosystem structure and productivity of tropical rain forests along altitudinal gradients with contrasting soil phosphorus pools on Mount Kinabalu, Borneo. Journal of Ecology, 90, 37–51.

Kursar, T.A. 1989. Evaluation of soil respiration and soil CO_2 concentration in a lowland moist forest in Panama. Plant Soil, 113, 21–29.

La Scala, J.N., Marques, J.J., Pereira, G.T. and Cora, J.E. 2000. Carbon dioxide emission related to chemical properties of a tropical bare soil. Soil Biology Biochemistry, 32, 1469–1473.

Lal, M. and Singh, R. 2000. Carbon sequestration potential of Indian forests. Environmental Monitoring and Assessment, 60(3), 315-327.

Ma, Q.Y., Chen, X.L., Wang, J., Lin, C., Kang, F.F., Cao, W.Q., Ma, Z.B. and Li, W.Y. 2002. Carbon content rate in constructive species of main forest types in Northern China. Journal of Beijing Forestry University, 24, 96-100.

Mo, W., Lee, M.S., Uchida, M., Inatomi, M., Saigusa, N., Mariko, S. and Koizumi, H. 2005. Seasonal and annual variations in soil respiration in a cool – temperate deciduous broad – leaved forest in Japan. Agricultural Forest Meteoroogy, 134, 81-94.

Murthy, I.K., Bhatt, S., Sathyanarayan, V., Patgar, S., Beerappa, M., Bhat, P.R., Bhat, D.M., Ravindranath, N.H., Khalid, M.A., Prashant, M., Iyer, S., Bebber, D.M. and Saxena, R. 2016. Vegetation structure and composition of tropical evergreen and decidouous forests in Uttara kannada District, Western Ghats under different disturbance regimes. Tropical Ecology, 57, 77-88.

Návar, J. 2009. Allometric equations for tree species and carbon stocks for forests of northwestern Mexico. Forest Ecology Management, 257, 427–434.

Ngo, K.M., Turner, B.L., Muller-Landau, H.C., Devies, S.J., Larjavaara, M., Hassan, N.F.M. and Lum, S. 2013. Carbon stocks in primary and secondary tropical forests in Singapore. Forest Ecology Management, 296, 81-89.

Odum, E.P. 1969. The strategy of ecosystem development. Science, 164, 262–270.

Oishi, A.C., Palmroth, S., Butnor, J.R., Johnsen, K.H. and Oren, R. 2013. Spatial and temporal variability of soil CO_2 efflux in three proximate temperate forests ecosystems. Agriculture Forest Meteorology, 171, 256-269.

Rai, S.N. 1981. Producitivity of tropical rain forests of Karnataka. Ph.D.Thesis, University of Bombay, Bombay, India.

Raich, J.W. and Schesinger, W.H. 1992. The global carbon dioxide flux in soil respiration and its relation to vegetation and climate. Tellus, 44, 81-99.

Ravindranath, N.H., Somashekhar, B.S. and Gadgil, M. 1997. Carbon flow in Indian forests. Climate Changes, 35, 297-320.

Salunkhe, O., Khae, P.K., Sahu, T.R. and Singh, S. 2016. Estimation of tree biomass reserves in tropical deciduous forests of Central India by non-destructive approach. Tropical Ecology, 57, 153-161.

Schwendenmann, L., Veldkamp, E., Brenes, T., O'Bien, J. and Mackensen, J. 2003. Spatial and temporal variation in soil CO_2 efflux in an old-growth neotropical rain forest, La Selva, Costa Rica. Biogeochemistry, 64, 111–128.

Sharma, C.M., Baduni, N.P., Gairola, S., Ghildiyal, S.K. and Suyal, S. 2010. Tree diversity and carbon stocks of some major forests of Garhwal Himalaya, India. Forest Ecology Management, 260, 2170-2179.

Singh, L. and Singh, J.S. 1991. Species structure, dry matter dynamics and carbon flux of a dry tropical forest in India. Annals of Botany, 68, 263–273.

Stern, N. 2006. Stern Review: the economics of climate change. H.M. Treasury, Cambridge University Press. U.K.

Takahashi, M., Hirai, K., Limtong, P., Leaungvutivirog, C., Panuthai, S., Suksawang, S., Anusontpornperm, S. and Marod, D. 2011. Topographic variation in heterotrophic and autotrophic soil respiration in a tropical seasonal forest in Thailand. Soil Science Plant Nutrition, 57, 452-465.

Takyu, M., Aiba, S. and Kitayama, K. 2003. Changes in biomass, productivity and decomposition along topographical gradients under different geological conditions in tropical lower montane forests on Mount Kinabalu, Borneo. Oecologia, 134, 397–404.

Thokchom, A. and Yadava, P.S. 2014. Soil CO_2 flux in the different ecosystems of North East India. Current Science, 107, 99-105.

Thokchom, A. and Yadava, P.S. 2013. Biomass and carbon stock assessment in the sub-tropical forests of Manipur,North East India. International Journal of Ecology and Environmental Sciences, 39(2), 107-113.

Vogt, K.A., Vogt, D.J., Palmiotto, P.A., Boon, P., Hara, J.O. and Asbjoransen, H. 1996. Review of root dynamics in forest ecosystems grouped by climate, climatic forest type and species. Plant Soil, 187, 159-219.

Watson, R.T. 2002. Land use, land-use change, and forestry: A special report of the IPCC. Cambridge: Cambridge University Press, 377pp.

Yadav, R.P., Bisht, J.K. and Bhatt, J.C. 2017. Biomass, carbon stock under different production systems in the mid hills of Indian Himalaya. Tropical Ecology, 58, 15-21.

Zhao, Z.M., Zhao, C.Y., Yan, Y.Y., Li, J.Y., Li, J. and Shi, F.Z. 2013. Interpreting the dependence of soil respiration on soil temperature and moisture in an oasis cotton field, Central Asia. Agriculture Ecosystem Environment, 168, 46-52.

Received:8th September 2021
Accepted:12th November 2021