Original Research Article

Soil Carbon Sequestration Along Forest Canopy Gradient: Mitigating Climate Change

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Received: December 05, 2017; revised: March 11, 2018; accepted: March 20, 2018

Abstract: Soil carbon sequestration is the process of storing atmospheric carbon in the long lived soil pool in a form that is not immediately re-emitted. Soil carbon is considered to be the largest pool of terrestrial carbon. Carbon sequestration is mainly regulated by the physiographic, edaphic, biotic and climatic factors. Land use change, however, influence the carbon stocks and fluxes. Forest soil plays a vital role in the climate change mitigation by restricting the direct release of carbon into the atmosphere. The quantity and quality of forest litter greatly influence the soil carbon stock. Therefore, it is very important to know the potential of soil carbon sequestration in the different land use sectors including forest ecosystem for global C balancing. The study was carried out in Talle Wildlife Sanctuary, Ziro valley, Lower Subansiri, Arunachal Pradesh to enumerate the carbon sequestration potential of forest soil along the forest canopy gradient. Soil was found to be acidic in nature while acidity increases with increase in forest canopy cover. Soil organic carbon ranges between 3.71% (open canopy) and 5.09% (dense canopy). The contribution of microbial biomass carbon was very low but found higher in dense canopy than the open forest canopies. Total soil carbon also followed similar trend to that of microbial biomass carbon. The study recorded SOC stock 70.79 $MgCha^{-1}$ for the first year (2014) and 91.72$MgCha^{-1}$during second year (2015). Thus, carbon sequestered in the forest soil was 20.93 $MgCha^{-1}Yr^{-1}$. Findings of the present study could be helpful for the policy makers in precise carbon budget, proper management and adaptation strategies for mitigating climate change.

Key words: Carbon sequestration, Climate change, Forest canopy, Microbial biomass carbon.

Introduction

Inevitable climate change and global warming have prompted many researchers to understand and carry out the studies on carbon sequestration potential of various ecosystems from local to global scale. Carbon sequestration is the transfer and secure storage of atmospheric CO_2 into other long-lived pools that would otherwise be emitted or remain in the atmosphere (Lal, 2008). Carbon is present in all forms of life on earth and any imbalance in carbon lead to global imbalance. The soil carbon mainly stored in the form of soil organic carbon (SOC), soil organic matter (SOM) and microbial biomass carbon (MBC). Soil carbon is one of the important variables for determining the future carbon sink. Forest soil plays a vital role in the climate change mitigation by restricting the direct release of carbon into the atmosphere. As we know that, soil is particularly concerned with the cycling of nutrients which is highly governed by the interactions with its surrounding and vegetation. Forest canopy gradient may significantly influence the productivity potential of soil organic content accumulated in the forest soil. Various factors directly or indirectly emitting greenhouse gases causing global warming includes fossil fuel combustion, deforestation, over population, industrial emission, land use change, urbanization etc. But human being is considered to be the most important one for deteriorating climate by various anthropogenic activities shaping their own kind of changed environment. The increase in atmospheric CO_2 concentrations associated with the progression of the anthropogenic impact on forest ecosystems from the molecule to the ecosystem level (Valladares, 2008). Sequestering of carbon helps off-set emissions from fossil fuel combustion and other carbon emitting activities while enhancing soil quality. An increase in the SOC pool is also essential to advancing global food security (Lal, 2004). Nutrient loss, soil erosion, soil conservation, desertification, organic matter decomposition etc. may alter the soil dynamics. The uncertainty in sequestration depends with the decomposition of litter and soil organic matter, their physical composition and the surrounding environment such as microbial activities, flora and fauna (Dewar, 1992).

Soil carbon is also considered to be the largest pool of terrestrial carbon. Forest ecosystems store more than 80% of all terrestrial aboveground C and more than 70% of all soil organic C (Batjes, 1996; Bolin, 2000; Jobbágy and Jackson, 2000; Six 2002a; Jandl, 2007). Soil, however, constitutes higher C density (40%) than the other types of ecosystems (Dixon *et al.,* 1994; Ranabhat*et al.,* 2008). The importance of forest and soil C in mitigating the greenhouse effect have been recognized, an agreement was reached under the Kyoto Protocol to include forest and soil C sequestration in the list of acceptable offsets (UNFCCC, 1997). Lal (2005) have also stated that forest soil carbon sequestration has a potential to decrease the rate of enrichment of atmospheric CO_2. Many researchers have concentrated on the amount of carbon sequestered in the standing trees (Brown and Gaston, 1995; Houghton *et al*., 2001; Malhi *et al*., 2006; Saatchi *et al*., 2007; Chave *et al*., 2008; Yam and Tripathi, 2015) but very few studies have been carried out on soil carbon sequestration. Therefore, it is very important to understand the soil dynamics and potential of soil carbon sequestration for managing terrestrial carbon and global carbon balancing.

Materials and methods

Study site

The present study was carried out in the Talle Wildlife Sanctuary (TWS) which is situated in Ziro valley (1,700 m to 3000 m above sea level). TWS is about 30 km from the Ziro valley, the headquarter of Lower Subansiri district of Arunachal Pradesh. It covers an area of 337 km^2 and lies between $27^0$34'4"N and $27^0$35'14"N latitude and $93^0$58'58"E and $93^0$59'49"E longitude. The forest of TWS is almost considered to be untouched, well managed, and protected by the Apatani tribe and complex in structure and function. The high precipitation, fertile soil conditions, and lack of disturbance have given a scope to the growth of luxuriant vegetation. Forests vegetation are mostly dominated by *Michelia champaca*, *Castanopsis* spp, *Quercus* spp, *and Rhododendron* spp. at woody layer (Yam and Tripathi, 2016). *Cinnamomum verum*, *Mahonia nepalensis, Impatiens* spp. and *Berberies*spp. at the shrub/sapling layer. Ground vegetation of the forest was mainly composed of *Begonia roxburghii*, *Rubus ellipticus, Houttuynia cordata* (Yam and Tripathi, 2015).

Sites were selected in three replicates considering different canopy density percentage as open and dense canopy for comparative study. Taking care not to disturb the soil surface or sub-surface, the sample sites were cleared of living plants, plant litter and surface rocks prior to sample collection. Soil collection has been done through collecting soil samples using a soil corer on monthly basis from 0-20 cm depths in replicates (five). Soil was collected from different locations (12 composite samples, 6 samples each from open and dense forest) on monthly basis for two consecutive years (2014-2015). Altogether, 288 soil samples were collected. Composite soil samples were brought to the laboratory and dried, homogenized by grinding and sieved (<2 mm). Their physico-chemical and microbiological characteristics were analyzed. Soil organic carbon has been determined by method of Walkey and Black (1934). SOM was calculated by multiplying the SOC content by 1.724 assuming that soil organic matter contains 58% carbon (Allen *et al.,* 1974).

Microbial biomass carbon was estimated in field moist soil by chloroform fumigation–incubation method (Jenkinson and Powlson, 1976) as modified slightly by Srivastava and Singh (1988).

SOC % was calculated using formulae:

$$\text{SOC (\%)} = \frac{10(B-T)}{B} \times 0.003 \times \frac{100}{S}$$

SOC ($MgCha^{-1}$) = 10,000 m^2 in 1ha. x soil depth (m) x bulk density (g/cm^3) x SOC%

Bulk density (D_b) is the dry weight of a known volume of soil. Bulk density was determined using the core method as described by Anderson and Ingram (1993). It was recorded for two years and used for calculating soil organic carbon stocks in Megagram carbon per hectare ($MgCha^{-1}$).

Volume of corer = $\eth r^2 h$

Bulk density= Weight of dried soil sample / Volume of soil corer

Results

Light intensity was measured inside the forest considering different forests canopy cover and outside the forest to measure the forest canopy. Average light intensity outside the forest was recorded as 8000 ±95 lux. As per the Forest Survey of India (FSI) report (2013) crown cover for the open and dense forest, the recorded light intensity (LI) was observed (5000-6500 lux) in the open forests and (2300-2900 lux) in the dense forests. It results the crown cover range of about 25%-36% in open and 52%-71% in the dense forests respectively (Table 1).

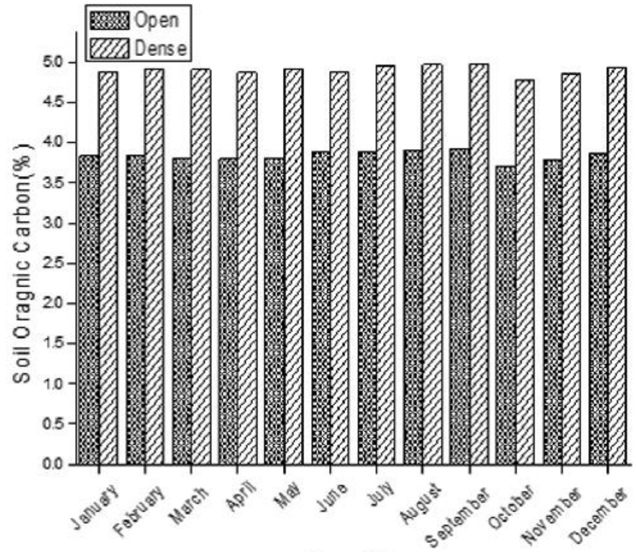

Fig. 1. a (Year 2014)

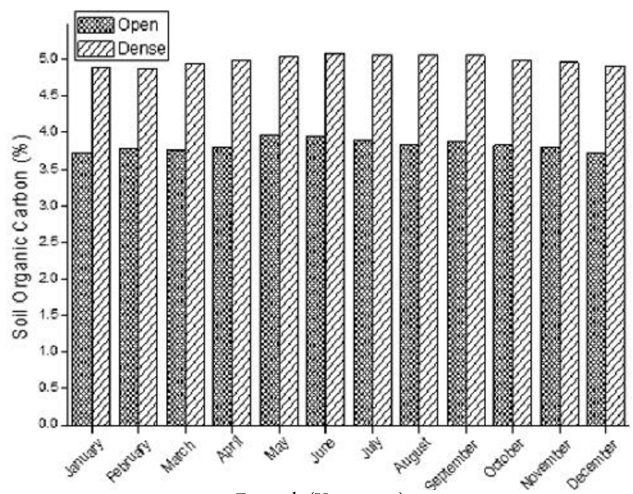

Fig. 1. b (Year 2015)

Fig. 1. a, b. Monthly variation of soil organic carbon in open and dense canopy.

Table 1. Forest crown class, light intensity (lux) and canopy cover in TWS.

Forest	Canopy density range	Average outside LI (Lux)	LI inside the forest	*Canopy Density (%)
Open	Canopy density (10-40%)	8000 ±95	6045 - 5150	24.49 - 35.63
Dense	Canopy density (>40%)		2315 - 3881	71.06 - 51.49

*Canopy%= 100-(lux meter reading inside forest /average outside forest LI*100)

Soil samples were collected keeping forest canopy class (dense and open) into account and analyzed. Bulk density was recorded with an average of 0.81 g cm^{-3} for the first year and 1.04 g cm^{-3} for the second year. Soil temperature was recorded to be 1.4°C to 2.7°C. Soil texture percentage of sandy, clay and silt were found to be 1:5:11 respectively. Water holding capacity ranges between 58.62% and 67.62%. Soil was found to be slightly acidic in nature with a pH range between 4.1 and 5.8. Acidity was recorded highest for the month of June (4.1) and lowest in the month of November (5.8). There was, however, not much variation in the acidity among the years. It is also found that acidity was higher in the case of dense forest canopy than in open forest canopy. Thus, acidity increases with increase in forest canopy cover.

Soil organic carbon (SOC), Soil organic matter (SOM) and Microbial biomass carbon (MBC)

Soil organic carbon in the forests ranges from 3.71% (open canopy) to 4.98 % (dense canopy) in the first year and 3.73 %

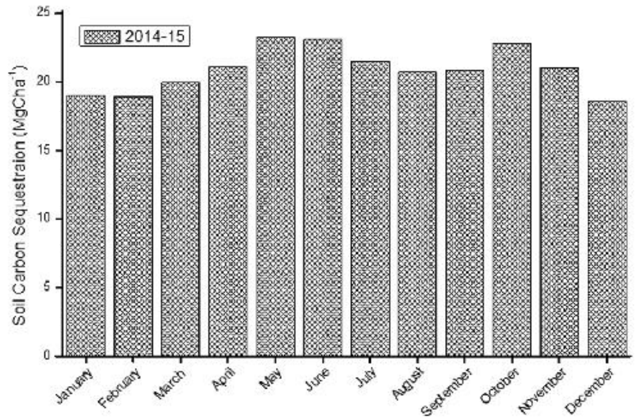

Fig. 2. Soil carbon sequestration (t ha^{-1} Y^{-1}) in TWS.

(open canopy) to 5.09 % (dense canopy) in the second year. Mean value was found 4.37% and 4.41% in the first year and second year respectively. Therefore, average soil organic matter (SOM) was also calculated as 122.05 $MgCha^{-1}$(7.53%) in the first year (2014) and 158.14 $MgCha^{-1}$(7.60%) in the second year (2015). The highest soil organic carbon (5.09%) was recorded in the month of June which is 105.87 Mg C ha^{-1} (Fig.1b) and the lowest was recorded in the month of October (3.71%) which is 60.10 $MgCha^{-1}$ (Fig.1a). SOM results the similar concentration trends to that of soil organic carbon.

Microbial biomass carbon was recorded 0.01% to 0.02% and it was higher in dense canopy than the open forest canopy. Total soil carbon also followed similar trend to that of microbial biomass carbon. The study recorded SOC with an average 70.79 $MgCha^{-1}$ for the first year and 91.72 $MgCha^{-1}$ for the second year. Thus, carbon sequestered in the forest soil during the study period was recorded 20.93 $MgCha^{-1}Yr^{-1}$ (Fig.2).

Discussion

The present study reveals that soil organic carbon stock increases with increase in crown cover from open to dense canopy. It was also observed that the SOC stock has increased with increase in soil bulk density. Ranabhat *et al.,* (2008) have also reported that carbon sequestration is higher in middle altitude and denser vegetation. The higher organic carbon content in the denser canopy may be due to rapid decomposition of forest litter by soil microbial organism. Maintaining continuous living plant cover on soils year round can quickly lead to increases in soil carbon that may be highly useful in drawing down atmospheric CO_2 (Kane and solutions, 2015). In the present study, SOC stock at 0-20 cm depth fromforest ranged in between 60.10 $MgCha^{-1}$-105.87 $MgCha^{-1}$ which corroborates the findings of SOC stock reported in the temperate forests which was 96 $MgCha^{-1}$ (Lal, 2015; Dixon *et al.,* 1994) whereas, FSI (2013) reported 71.577 Mg ha^{-1} from the Himalayan moist temperate forest. However, 62.7-88.7 $MgCha^{-1}$ by Zhu *et al.,* (2010) and 93.70-220.10 $MgCha^{-1}$ by Zang and Wang (2010) were reported in temperate forest of China. But SOC stock obtained in the present study was higher than the range of 50-55 $MgCha^{-1}$ reported by Dar and Sundarapandian (2014) in temperate forest of Western Himalaya and Lower than 180$MgCha^{-1}$SOC stock reported in Garhwal temperate forest (Sheikh *et al.,* 2009). The fluctuation in the range of SOC could be due to surrounding floral characteristics, decomposition of plant and animal residues, root exudates, living and dead micro organisms and soil biota. Soil organic carbon content is often related to soil fertility. This layer generally improves physical (soil aeration, water retention, resistance to erodibility etc.) and biological properties (build-up of soil microorganisms, nutrients etc.), which enhance the productive capacity of the soil.

Conclusion

The present effort consists of an inventory of carbon sequestration potential in Talle Wildlife Sanctuary of Ziro valley, Arunachal Pradesh, India. Experimentation has been carried out on a monthly basis for two consecutive years (2014 and 2015). The annual carbon stock during the first year was recorded 70.79 $MgCha^{-1}$ and 91.72 $MgCha^{-1}$ in the second year respectively. The cumulative potential of soil carbon over a year is 20.93 $MgCha^{-1}$. To estimate C sequestration, assessing soil C storage is important (McCarty *et al,* 2002). It refers to the withdrawal of atmospheric carbon dioxide through soil and trees and storing the carbon soil in the form of soil organic matter, or as the tree biomass in trees. Carbon sequestration therefore, could likely be more successful if they are integrated with socio economic, ecological and political objectives. Better understanding of SOC can also help evaluate and classify soils, and assist in application of best management practices for irrigation, fertilization and pesticide application (Mehlich, 1984). Assimilation of carbon conservation and sequestration strategies with biodiversity conservation and biomass based opportunities for the regional people is therefore, significant, otherwise reducing diversity will challenge our holding ability to use forest soil as part of CO_2 emissions control strategy. Findings of the present study can be corroborated with the trend of national GHG (Green House Gas) emissions to work out the proportion of national level emissions by forests in India. It will also be helpful for the policy makers in precise carbon budget, proper management and adaptation strategies for mitigating climate change.

Acknowledgements

The authors are thankful to the officers and staffs of the Department of Forest and Environment, Government of Arunachal Pradesh, for granting permission and support during our study in Talle Wildlife Sanctuary. Gyati Yam is grateful to University Grant Commission, New Delhi, for the award of fellowship during the course of study.

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