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TRENDS IN SOIL CARBON STOCKPILE OF THREE MAJOR FORESTS ALONG AN ALTITUDINAL GRADIENT IN INDIAN CENTRAL HIMALAYA

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ABSTRACT

Current investigation reveals the stock of soil organic carbon (SOC) along with altitudinal gradients in Oak (*Quercus leuchotrichophora*), Pine (*Pinus roxburghii*) and Sal (*Shorea robusta*) dominant forests in Shiwalik region of Kumaun Himalayas in India. The estimated soil organic carbon was found 16.0 ± 4.3 to 19.4 ± 6.4 g kg^{-1} for Oak, 17.8 ± 2.0 to 25.6 ± 1.6 g kg^{-1} for Pine and 15.8 ± 2.2 to 21.4 ± 1.9 g kg^{-1} for Sal forests, respectively in 0-10, 10-20 and 20-30 cm soil depths. SOC stock was found to be in decreasing pattern with increasing altitude from 193.6 to 166.4, 146.4 to 137.6 and 159.2 to 141.6 t C ha^{-1} in Oak, Pine and Sal forests, respectively. It is an indicator of higher biological activity or anthropogenic disturbance associated with top layers of these forest areas. Higher SOC was recorded in Sal forest compared to Oak. In Sal forest, high tree density leads to higher accumulation of SOC compared to conifers while it was low in wide spread Pine forest, resulting in less storage of carbon stock in turn.

Key words: Shiwalik, carbon stockpile, anthropogenic, carbon sinks, soil organic carbon.

INTRODUCTION

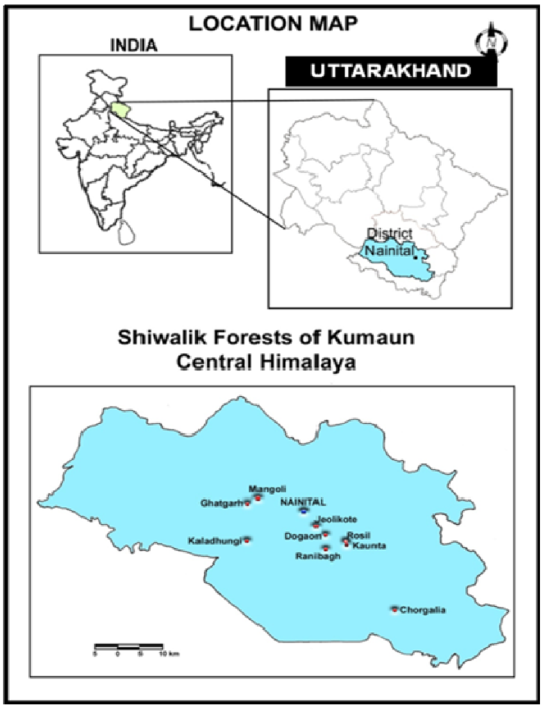
Soils are largest carbon reservoirs in the terrestrial carbon cycle. With dense forest vegetation Indian Himalayan zone covers a fifth part of the country and stores one third part of country's soil organic carbon (SOC) reservoirs. However, the details of altitudinal distribution of these carbon stockpiles, which are vulnerable to forest management and climate change impacts are not well known. Worldwide, the first 30 cm of soil holds 1500 pg carbon (Batjes 1996) and for India, it is 9 pg (Bhattacharya *et al.* 2000). It plays a key role in global carbon budget and greenhouse effect (Jha *et al.* 2003). Forest soils are one of the major carbon sinks on earth, because of their higher organic matter (Dey 2005). First estimate of organic carbon stockpile in Indian soils was 24.3 pg (1pg = 10^{15} g) based on 48 soil samples (Gupta and Rao 1994). Soils can act as sinks or as a source for carbon in the atmosphere depending on the changes occurred to soil organic matter (SOM). SOM can also increase or decrease depending on numerous factors including climate, vegetation type, nutrient availability, disturbance, land use, management practice, etc (Six and Jastrow 2002, Baker 2007). The release of nutrients from decomposed litter is a fundamental process in the internal biogeochemical cycle of an ecosystem and decomposers recycle a large amount of carbon that was bounded in the plant or tree to the atmosphere (Sevgi and Tecimen 2008).

Himalayan zone with dense forest vegetation covers nearly 19% of India and contains 33% of total SOC reserves of the country (Bhattacharya *et al.* 2008). Forest management may be useful technique to increase soil carbon status that affects carbon dynamics directly or indirectly. Through ecological and physiological changes, trees improve soil productivity which depends upon the quantity and quality of litter reaching to the soil surface with its decomposition rate and nutrient release (Meentemeyer and Berg 1986).

Current global stock of SOC is estimated to be 1,500-1,550 pg (Lal 2004). The greenhouse effect has been of great concern in last decade, and has led to several studies on the quality, kind, distribution and behavior of SOC (Batjes 1996, Velayutham *et al.* 2000). Global warming and its effect on soils in terms of SOC management have led to several quantitative estimates for global C content in the soils (Batjes 1996, Velayutham *et al.* 2000). So far the soil organic carbon stock studies in Indian Himalayan forests in relation to altitudinal gradient are not available.

MATERIALS AND METHODS

The study area is located between 29° 17' 39" N to 29° 30' 40" N and 79° 9' 13" E to 79° 26' 24" E, between 400-2000 m a.s.l. in Shiwalik mountain ranges of Kumaun Himalaya in Uttarakhand State of India. In this zone, three sites were selected for each forest type i.e., Sal (*Shorea robusta*) forest at an altitude of 400-700 m; Pine forest (*Pinus roxburghii*) at an altitude of 700-1300 m and Oak (*Quercus leuchotrichophora*) forest with an altitude of 1300-2000 m a.s.l. in lower, middle and higher elevations, respectively.



Sampling was done by nestled plot technique. In each site, a plot of 10×20 m size was laid and six sampling points were selected in each plot by the standard method. These samples were collected at each sampling point at three depths (0-10, 10-20 and 20-30 cm). A total of 81 soil samples (27 from each site) were collected by digging soil pits using soil auger. Samples were air dried and sieved before analysis. SOC for various depths was determined by partial oxidation method (Walky and Black 1934). Samples from each depth were analyzed to express the total SOC stock data in 0-10, 10-20 and 20-30 cm. Weighed mean average values were considered. Total SOC stock was estimated by multiplying the values of SOC g kg^{-1} by a factor of 8 million based in the assumption that a layer of soil 30 cm deep covering an area of one ha weighs 8 million kg (Dey 2005).

RESULTS

Soil organic carbon (SOC) at different depths in oak forest, pine forest and sal forest is given in Table 1. A decreasing trend in soil organic carbon

(SOC) was observed with increased soil depths in all the sites except site-2 of *Pinus roxburghii* forest, where OC was highest on surface layer and lowest in middle. In site-1 of *Quercus leuchotrichophora* forest, level of soil organic carbon was higher (16.7±1.2 to 19.4±6.49 kg^{-1}) in upper layer, dropping with depth. Same trend was for sites 2 and 3 where the SOC values also decreased with increasing depths (14.4±0.9 to 19.2±4.5 and 16.0±4.3 to 18.7±0.89 kg^{-1}), respectively. Same pattern was observed in *Shorea robusta* forest (Table 1). Maximum carbon stock was found in *Quercus leucotricophora* forest soils (Table 2). Higher percent of soil organic carbon in *Quercus leucotricophora* forest may be due to dense canopy and higher input of decomposed forest floor litter and seeds, as a resultant of maximum carbon stock. In *Quercus leucotricophora* forest, dense forest leads to higher accumulation of soil organic carbon compared to conifers. In *Pinus roxburghii* forest, the amount of organic carbon was low which resulted in less storage of carbon stock. It was observed higher in *Shorea robusta* as compared to *Quercus leucotricophora* forest.

In *Quercus leucotricophora* forest soils, maximum carbon stock was estimated in site-1 (193.6 t C ha^{-1}) and minimum in site-3 (166.4 t C ha^{-1}). Similar kind of observations were found for *Pinus roxburghii* forest soils (Table 2), where the highest carbon was present in site-1 (146.4 t C ha^{-1}) followed by site-2 (139.2 t C ha^{-1}) and site-3 (137.6 t C ha^{-1}). In *Shorea robusta* forest, it was maximum in site-1 (159.2 t C ha^{-1}), while minimum in site-3 (141.6 t C ha^{-1}) with the increasing soil depth. While comparing SOC stock values of different sites in all three forests, the carbon stock tended to decrease with increasing altitudes and depth class. A characteristic decline in the vegetation layer was observed across altitudinal strata and among sites. Altitude has a significant effect on species richness which declines with even a 100 m increase in altitude. It results in less accumulation of litter and low input of organic carbon in the soils. In *Quercus leuchotrichophora* and *Pinus roxburghii* forests, SOC was higher in the upper layer, dropping with an increase in depth for all the sites (Table 1). Higher amount of soil organic carbon on surface layer may be due to rapid decomposition of forest floor litter having favourable environmental conditions.

Table 1. Soil organic carbon (±SD) values at different soil depths in *Q. leuchotrichophora, P. roxburghii* and *Shorea robusta* forests.

Site	Soil depth (cm.)	SOC (g kg^{-1}) (Q. *leuchotrichophora*)	SOC (g kg^{-1}) (*P. roxburghii*)	SOC (g kg^{-1}) (*S. robusta*)
S1	0-10	18.7 ± 5.5	25.6 ± 1.6	21.4 ± 1.9
	10-20	19.4 ± 6.4	24.9 ± 2.8	19.6 ± 3.4
	20-30	16.7 ± 1.2	22.2 ± 3.1	18.7 ± 3.2
S2	0-10	19.2 ± 4.5	22.7 ± 0.9	19.7 ± 0.8
	10-20	18.6 ± 3.1	18.5 ± 1.2	18.3 ± 3.4
	20-30	14.4 ± 0.9	21.2 ± 2.4	16.2 ± 1.2
S3	0-10	18.7 ± 0.8	23.5 ± 2.1	19.9 ± 2.6
	10-20	16.8 ± 0.6	22.1 ± 4.8	17.4 ± 6.8
	20-30	16.0 ± 4.3	17.8 ± 2.0	15.8 ± 2.2

Table 2. Soil organic carbon stock (upto 30 cm depth) in Oak (*Quercus leuchotrichophora*), Pine (*Pinus roxburghii*) and Sal (*Shorea robusta*) forests.

Site	Altitudinal range (m)	SOC ($g\ kg^{-1}$)	Carbon stock ($t\ C\ ha^{-1}$)
Quercus leuchotrichophora			
S1	1300-1500	24.2 ± 1.2	193.6
S2	1500-1700	21.3 ± 0.8	170.4
S3	1700-2000	20.8 ± 3.1	166.4
Pinus roxburghii			
S1	700-900	18.3 ± 0.22	146.4
S2	900-1100	17.4 ± 0.29	139.2
S3	1100-1300	17.2 ± 0.40	137.6
Shorea robusta			
S1	400-500	19.9 ± 1.4	159.2
S2	500-600	18.1 ± 0.8	144.8
S3	600-700	17.7 ± 1.2	141.6

Maximum and minimum values of carbon stock were 193.6 t C ha^{-1} (site-1) and 166.4 t C ha^{-1} (Site-3), respectively for *Quercus leuchotrichophora* forest. It was observed same for *Pinus roxburghii* forests (Table 2), whereas the highest and lowest values of carbon stock were 146.4 t C ha^{-1} (site-1) and 137.6 t C ha^{-1} (site-3), respectively. For *Shorea robusta* forest, pattern was as similar as Oak and Pine forest (Table 2).

DISCUSSION

Soil organic carbon (SOC) represents a major carbon pool within the biosphere (Grace *et al.* 2006). Climate-shift in temperature and precipitation has a major role on decomposition and accumulated SOC within an ecosystem and released into environment. Cycling rate of carbon at various depths and pools across different vegetational cover is still not clear. As soil depth increases, steep fall in SOC content was found as an indication of higher biological activity or anthropogenic disturbance associated with top layers. Observations justify the higher concentration values of SOC in the top soil with previous reporting by various authors (Wang *et al.* 2004, Alamgir and Amin 2008).

Higher accumulation of soil organic carbon was found in broad leaved vegetation as compared to coniferous which is in accordance with Markus *et al.* (2007). Added litter (Lal 1989) and the proliferated root system of the growing plants probably prejudiced the carbon storage in the soil, suggesting a positive correlation of SOC with the quantity of litter fall (Singh 2005). Present study suggests that, the coarse and fine woody debris are substantial forest ecosystem carbon stock. It indicates the region of highest carbon stock with cool summer, while lower carbon in arid desert/steppes or temperate humid regions.

A study of Jha *et al.* (2001) recorded the following levels of organic carbon stored in some Indian soils; 41.2, 120.4, 13.2 and 18.0 t C ha^{-1} in the Red soil, Laterite soil, Saline soil and Black soil, respectively. All these measurements were lower than the present observations. Another study showed national average content of soil organic carbon stored in *Quercus leuchotrichophora* forest soil is almost similar to the national average and expresses the excellent ability of these forests to stock and sequester organic carbon. However, the total amount of organic carbon stored in *Pinus roxburghii* forest soils was lower than the national average.

While comparing soil organic carbon stock in all the forests with each other, the carbon stock tended to decrease with increasing altitudes. A soil carbon study in Kathmandu valley of Nepal and Shiwalik ranges of Uttarakhand state of India in *Pinus roxburghii* forest along altitudinal gradient at an elevational range between 1200 to 2000 m reported that the higher altitude soil was found to be much more exhausted of C than the lower altitude soil (Sah and Brumme 2003, Jina *et al.* 2009). The decreasing trend of C might be attributed to the lower mineralization rate and net nitrification rate at the higher altitude. Earlier studies of Himalayan forests indicate a characteristic decline in vegetation across the altitudinal strata and among sites (Bohra *et al.* 2010). Decrease in species richness in high elevation could be due to eco-physiological constraints, low temperature and productivity (Korner 1998). Altitude had a significant effect on species richness, which declines with even a 100 m increase in altitude. Species composition too is significantly affected by altitude (Hardy *et al.* 2001). Altitude is often employed to study the effects of climatic variables on SOM dynamics (Lemenih and Itanna 2004). Changes in climate along altitudinal gradients influence the composition and productivity of vegetation and consequently after the quantity and turnover of SOM (Quideau *et al.* 2001). Altitude also influences SOM by controlling soil water balance, soil erosion and geologic deposition processes (Tan *et al.* 2004). A study was carried out to check the balance between carbon input (organic matter production) and output (decomposition, methanogenesis, etc.) and resulting storage of carbon depends on the topography and geographical position of the wetland, hydrological regime, type of plant percent, temperature and moisture of soil and soil pH and morphology (Adhikari *et al.* 2009). According to Schlesinger (1997), there is a strong relation between climate and soil carbon pools where organic carbon content decreases with increasing temperatures, because decomposition rates doubles with every 10^oC increase in temperature.

A study of Western Ghats of Southern India shows the decline of soil organic carbon from 110.2 t C ha^{-1} to 82.6 t C ha^{-1} at increasing upto 1400 m. Characteristic decline in vegetation with increasing altitude results in less accumulation of litter and low input of organic carbon in soils. Similar findings were also reported by Bohra *et al.* (2011) in the Shiwalik region of Kumaun Himalayas that, the number of trees per hectare decreases with increasing elevation. The increasing tendency of carbon density with decreasing altitude may be better stabilization of SOC at lower altitudes. It is a proven fact that forest ecosystems are the best way to sequester carbon, however, considering the huge human population in developing countries like India, much of the land can not be spread for increase in forest cover. In such circumstances at lower elevations, the management of vast areas of Himalayan forests can be regarded as major sinks of mitigating atmospheric carbon dioxide.

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