Soil organic carbon variation under sub-tropical forest of Himachal Pradesh, India

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It is important to estimate soil organic carbon (SOC) content of natural forests for an understanding of the Himalayan ecosystem. In this study SOC concentration was evaluated at three different soil depths (0–10, 10–20 and 20–30 cm) under *Anogeissus latifolia* (site I) and *Pinus roxburghii* (site II) forest stands in Himachal Pradesh, India. SOC (%) in these forests ranged from 0.37% to 2.20% up to 30 cm soil depth and was higher at site I compared to site II. Tree density was also more at site I than site II. The present study shows that the tree species can influence SOC of the forest ecosystem, but other environmental parameters such as soil type, moisture and pH are also responsible for changes in the soil carbon sequestration potential. Carbon sequestration in the study area showed significant contribution in minimizing the increase in carbon dioxide in the atmosphere and improving soil quality.

Keywords: *Anogeissus latifolia*, carbon sequestration, *Pinus roxburghii*, soil organic carbon, sub-tropical forest.

IN recent years rapid anthropogenic activities such as human settlements, deforestation and infrastructure development have led to an adverse effect on our environment, causing a continuous increment in the amount of atmospheric carbon dioxide, and resulting in serious setbacks like global warming and climate change. Due to this, attention has shifted towards the study of distribution patterns of carbon and its storage across different ecosystems[1–3]. Forest ecosystem is one of the largest carbon sinks which stores significant amounts of carbon, thus signifying its value at both regional and global levels[4,5]. Forests act as sink and source for atmospheric carbon by processes like photosynthesis and decomposition[6]. Factors affecting the forest carbon content are type of vegetation, topography, climatic conditions and edaphic factors[4,7–10]. Forest management practices and anthropogenic disturbances also affect carbon storage content of the area[11]. Soil is a natural dynamic resource which plays a vital role in sustainability of different ecosystems and is also considered as the largest reservoir of organic carbon in terrestrial ecosystems[4,12]. Soil organic carbon (SOC) of the forest ecosystem is an essential part of the global carbon cycle and variation in its concentration not only affect the terrestrial ecosystem, but also the global carbon equilibrium[13].

SOC has become an important area of research because of its significance to mitigate climate change and its role in the global carbon cycle. A noticeable fluctuation in the SOC storage can be seen due to degradation of forests[4,6,7]. This also affects the microbial biomass of the soil and plays a critical role in nutrient cycling of the ecosystem. The vertical distribution of SOC along with soil depth has a strong association with soil properties[10,14]. Physico-chemical properties of the soil up to 1 m depth can be correlated with the amount of SOC[10]. Thus the relationship between physico-chemical characteristics of the soil and potential of the soil to store organic carbon is one of the key elements of soil carbon dynamics[11,13]. Maintenance and enhancement of SOC is beneficial not only for the quality and functioning of the soil, but also for stability of the ecosystem. Thus, it also acts as an indicator of soil fertility[6].

In this study SOC was estimated up to 0–30 cm soil depth because maximum amount of SOC is present in the topmost layer of the soil, which is double the amount of carbon present in the atmosphere[6,15]. Association of SOC with factors like temperature and precipitation is also more in the topmost layer of the soil[10].

The SOC concentration can cause significant change in the atmospheric concentration of carbon dioxide (CO_2) and contribute to mitigate climate change[6]. Hence, it becomes essential to study the mechanisms and changes in SOC in the forest ecosystem for a better understanding of the mitigation mechanism of climate change. The Himalaya is among the youngest mountain ranges on earth and consists mostly of sedimentary and metamorphic rocks[16] and therefore reflects the mitigation significantly.

It is important to understand the type of tree species and appropriate management strategies for forest restoration which affect carbon storage and soil physico-chemical properties. To study these factors we chose two forest stands – broadleaf (*Anogeissus latifolia*) and coniferous needle-shaped (*Pinus roxburghii*) in Himachal Pradesh (HP), India.

Materials and methods

Study area

The study area is situated at the foothills of the Himalaya in the southern part of HP. It lies between 31°12′30″–31°35′45″N lat. and 76°23′45″ and 76°55′40″E long. The

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study area is a hilly terrain with temperate to subtropical climate and altitude ranging from 350 to 1500 m. The region receives moderate to high rainfall with an average annual rainfall of about 1106.28 mm. The temperature ranges from 1.3°C to 40.7°C.

For the present study the two forest types, i.e. *A. latifolia* (broadleaf) and *P. roxburghii* (coniferous) were designated as site I and site II respectively. In each forest type seven plots of 0.04 ha each were selected for a detailed study of the region. The coniferous forest encountered frequent forest fires mainly during summer season, which was not the case with the broadleaf forests. Biotic disturbance such as collecting fuelwood, fodder and forage for livestock was common among both forest sites.

Soil sampling and laboratory analysis

Soil samples were collected at 0–10, 10–20 and 20–30 cm depth respectively, from each forest plot during 2017. Soil samples were randomly collected from each selected plot during different seasons and mixed together to form a composite soil sample for each site. Three replicate samples from this were analysed in the laboratory for physico-chemical properties and organic carbon. Soil samples were also sieved through a 2 mm sieve before analysis. For estimation of bulk density, extra care was taken to avoid any loss of soil from the samples. The soil samples were weighed and kept in an oven to dry. Bulk density of the soil was calculated according to Wilde *et al.*[17]. Soil moisture (%) was estimated at three different soil depths (0–10, 10–20 and 20–30 cm) using gravimetric method respectively. Soil pH and electrical conductivity (EC) (1 : 2.5 ratio of soil and water) were measured using a digital pH meter and digital EC meter respectively. Soil texture was determined according to Brady and Weil[18]. For the estimation of organic carbon, the Walkley and Black method[19] was employed, which is widely used for the estimation of SOC. Soil organic matter (SOM) was analysed using the conventional factor of Waxman and Stevens[20]. Soil available nitrogen was estimated using a nitrogen analyser[21].

Statistical analysis

The variation in SOC concentration among different soil depths (0–10, 10–20, 20–30 cm) was examined using analysis of variance (ANOVA). The correlation technique was also used to establish the relationship between SOC and other soil variables like pH, EC, moisture, bulk density, SOM and nitrogen.

Results

Tree density was more in the broadleaf forest type than coniferous forest type. The textural class of soil was silty clay loam and it had slightly acidic to neutral characteristics (6.43–6.99) in site I. On the other hand, in site II soil was silty clay in texture and slightly neutral (6.84–6.94) in reaction. Bulk density increased with increasing soil depth at both sites. Bulk density and soil moisture were high in site II compared to site I (broadleaf). EC was high in site I followed by site II (Table 1).

Soil bulk density fluctuates under different forest types and can be influenced by increasing soil depth under forest-floor horizons. SOM content can be considered as the main factor which affected the bulk density[22]. An increase in bulk density of the soil was observed with increase in soil depth in both forest types (Figure 1). SOC had a significantly negative correlation with soil bulk density soil[23]. However, moisture, pH, EC, SOM and available nitrogen showed a positive correlation with SOC (Table 2). SOC concentration and soil bulk density are the main factors used to determine SOC stock and soil depth[22].

Under subtropical conditions during summer season maximum temperature can reach up to 42°C, which causes oxidation and thus a decrease in SOC concentration[15,24]. According to Turner *et al.*[25] SOC concentration was lowest in the dry season. SOC concentration in different soil depths, viz. the topmost layer (0–10 cm) and lower layers (10–20 cm and 20–30 cm) differed significantly due to various factors. The SOC concentration in the broadleaf forest stand at different soil depths was high (1.03–2.20%, 0.58–1.13% and 0.37–0.43% at 0–10, 10–20 and 20–30 cm respectively), whereas in the coniferous forest stand it was low (0.98–1.26%, 0.55–0.798% and 0.38–0.523% at 0–10, 10–20 and 20–30 cm respectively; Figure 2). At lower soil depth (20–30 cm), SOC concentration in both

Table 1. Characteristics of the study sites

Criterion	Site I	Site II
Dominant species of forest area	*Anogeissus latifolia*	*Pinus roxburghii*
Occurrence of forest fires	Occasional	Frequent
No. of plots	Seven	Seven
Tree density (no./ha)	799.75	710.5
Soil texture	Silty clay loam	Silty clay
Sand (%)	34.33 ± 1.51	26.65 ± 1.55
Silt (%)	28.69 ± 0.97	27.29 ± 3.26
Clay (%)	36.97 ± 2.11	46.06 ± 1.83
Soil bulk density (g cm^{-3})	1.09 ± 0.10	1.17 ± 0.08
Soil moisture (%)	4.66 ± 0.29	8.42 ± 0.21
Soil pH		
0–10 cm	6.99 ± 0.22	6.84 ± 0.16
10–20 cm	6.71 ± 0.33	6.84 ± 0.23
20–30 cm	6.43 ± 0.3	6.94 ± 0.1
Soil EC		
0–10 cm	265 ± 99.01	174.33 ± 25.9
10–20 cm	215.11 ± 10.77	99.22 ± 7.4
20–30 cm	147.56 ± 38.86	112.34 ± 37.02
Soil organic carbon (SOC; %)	0.88 ± 0.31	0.77 ± 0.24
Soil organic matter (SOM; %)	1.52 ± 0.54	1.32 ± 0.41
Nitrogen (mg/kg)	56.35 ± 4.65	42.86 ± 5.43

forest stands was nearly equal. However, in the topmost soil layer, SOC concentration was higher in the broadleaf forest stand than the coniferous forest stand.

ANOVA indicates that significant difference in SOC concentration can be observed in case of different soil depths ($P < 0.01$). A significantly positive correlation of SOC with soil moisture, pH, EC, SOM and nitrogen showed that all these factors together are responsible for variability in the SOC concentration (Table 2). On the other hand, soil bulk density showed negative correlation with SOC concentration, which is one of the factors, responsible for changes in SOC concentration along with SOM[23,25]. The type of land use within a particular climatic condition also significantly influences SOC concentration at different soil depths[15].

Discussion

A few studies have been carried out in the Himalayan region to assess the SOC concentration. A study was carried out in Western Himalaya, which reported 0.90% (0–30 cm) and 0.57% (30–100 cm) SOC concentration in subtropical forests[15]. Joshi and Negi[13] reported 0.46–1.64% SOC concentration in a pine forest during rainy and winter season in Uttarakhand, India. Kumar *et al.*[26] reported 0.48–0.68% SOC under *A. latifolia* forest and 0.47% under *Pinus* forest in Garhwal Himalaya, India. Aryl *et al.*[8] reported that SOC was higher in the mixed forest areas than in pine-dominated forest in Lalitpur district, Nepal. Liu *et al.*[27] suggested that SOC accumulation in the forest ecosystem can be altered not only by the tree species, but also by vegetation composition and age of the forest stand. In addition, environmental parameters such as soil moisture and SOM can alter the soil carbon storage potential of the forest ecosystem.

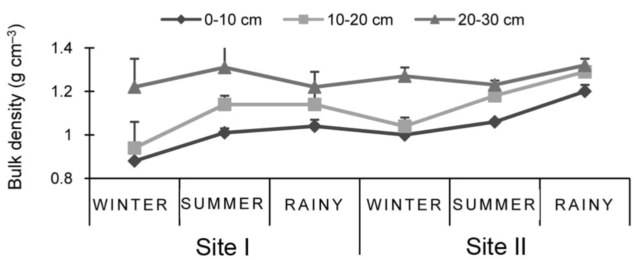

Figure 1. Variation in soil bulk density (g cm^{-3}) in the experimental sites.

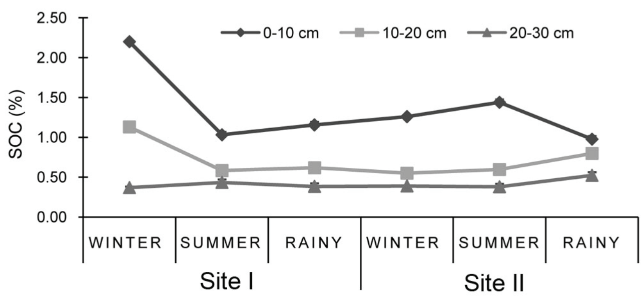

Figure 2. Variation in soil organic carbon (SOC) in the experimental sites.

Pant and Tiwari[28] analysed SOC under three forests of *P. roxburghii* and reported values of 0.69−1.30% and 0.63–1.10% at 0–10 cm and 10–20 cm soil depth respectively.

SOC content at 0–30 cm depth in two different forest types (broadleaf and coniferous) of the study area ranged from 0.37% to 2.20%. However, comparison is difficult with reference to SOC concentration, because it shows variation due to complex and integrated interactions of climate, altitude, slope, soil type, soil sample depth and management of tree species or type of vegetation[4,14].

Effect of tree species on SOC concentration

The type of tree species had an influence on soil properties and SOC concentration. Hence SOC depends on the composition of tree species, and in most circumstances, the soil carbon sequestration potential cannot be established without analysing the characteristics of vegetation as well. Although tree species showed less variability, they had an effect on SOC concentration[22]. The litter components of coniferous forest were difficult to decompose due to which there was an increase in litter storage in this forest, due to which thickness of forest floor increased and more material was found on the topmost layer[22]. In broadleaf forest stand, there are more biological activities and more humification in the topmost layer. However, the roots of *P. roxburghii* are shallow compared to other tree species and accumulate more SOC under the topmost layer[11]. The high SOC content in the coniferous forest stand in this study may be attributed to the dynamic nature of the fine roots of *P. roxburghii* trees. Schulp *et al.*[22] observed higher carbon content in coniferous forest stand than broadleaf forest stand at 10–20 cm soil depth. In the present study, SOC concentration in the broadleaf and conifer forest stands was nearly equal at 20–30 cm soil depth.

In case of coniferous forest stand, mycorrhizal association along with the root system provide additional favourable conditions for SOC potential of the area. The higher organic carbon content under both broadleaf and conifer forest types is an indicator of sufficient amount of forest litter in the study area. The high content of SOC in the topmost layer can also be related to the high rate of decomposition caused by favourable environmental conditions[23].

The decreasing trend of SOC along the vertical distribution is due to more biological activities prevalent in the topmost soil layer and decreasing along with increasing soil depth[10,14,23]. The decrease in SOC in topsoil (0–30 cm)

Table 2. Correlation (*R* values) between SOC (%) and soil properties in the two study sites

	SOC	Bulk density	Moisture	pH	EC	SOM	Nitrogen
SOC	1.000						
Bulk density	–0.922	1.000					
Moisture	0.024	0.254	1.000				
pH	0.544	–0.419	0.479	1.000			
EC	0.685	–0.842	–0.604	0.122	1.000		
SOM	1.000	–0.922	0.024	0.544	0.685	1.000	
Nitrogen	0.796	–0.867	–0.542	0.017	0.884	0.796	1.000

was high in subtropical forests compared to alpine forests[15]. Thus change in the SOC concentration in soil layer (mainly at 0–30 cm and up to 1 m) changes the atmospheric concentration of carbon dioxide[15,22]. The present study reveals that SOC content under different soil depths varied significantly, but did not change significantly for different seasons.

Higher SOC content was recorded in broadleaf forest type compared to coniferous forest type. This may be due to adequate tree density with optimum litter fall and these conditions help stabilize the amount of SOC present in coniferous forest. So, the amount of SOC does not differ significantly within these different forest stands and SOC concentration also does not vary significantly during different seasons. The high SOC in the study region with adequate tree density, resulted into enough litter input and organic matter accumulation, which ultimately led to greater storage of carbon in the study area, especially under coniferous forest stand[22].

The decomposed organic component under these forest stands was trapped by clay particles. The clay content of the soil was higher under coniferous stand compared to broadleaf forest stand, which was favourable for high SOC concentration as suggested by some studies[10,15]. Hence, clay mineral is a leading factor for SOC storage in the study area[29]. Also, physico-chemical properties are common predictors that can be used to influence SOC concentration.

Many studies evidently proved that SOC content was higher in broadleaf forest compared to coniferous forest[14,26]. Although some studies also suggested that SOC stock was significantly higher in coniferous forest stand compared to broadleaf forest stand. This may be due to the fact that coniferous trees live much longer and have high basal area[8].

The study area is a hilly terrain, due to which soil erosion is a major problem. This probably lowers the carbon sequestration potential of the soil. Some of the other problems encountered were removal of litter with run-off and difficulty in regular cycling of organic residues. An inverse relationship between slope factor and SOC was observed by Singh *et al.*[15].

Regeneration of degraded forests through plantations can enhance the area under forests, thus improving the SOC content of the area which further enhances the sustainability of the forest ecosystem. On comparison we found that SOC was higher in case of broadleaf forest stand, but the relationship between SOC concentration and the coniferous forest stand was also relatively well established. These could be the reasons for increased SOC content in the *Pinus* forest type as well as distribution in the soil profile in forests of the study area.

If there is a small increase in SOC content which is not beneficial for climate mitigation, it will likely help improve the soil properties and functioning. A large increase in SOC content is likely to show positive influence on soil properties and functioning[6].

The storage of SOC in the topmost layer is more susceptible to variation compared to other soil layer. So, protection of the top layer of soil under these forests is necessary[13,30]. The change in SOC content was significantly different for various soil depths in both the forest sites, as reported in previous studies[23]. A sharp reduction in nutrient concentration could be seen along with increase in soil depth. This is due to leaching effect, because the nutrient accumulation zone in mountain forest soils is not well established[13].

Many studies suggest that a particular type of vegetation has the potential to influence SOC concentration, but this factor alone cannot be considered to influence the soil carbon storage potential. There is a complex biological interaction of climate, soil type, slope, vegetation type, tree species, litter, organic detritus and type of forest management[4,14]. In the case of plantations, species composition along with age of plantation and precipitation had a significant influence on soil carbon[31].

Conclusion

The tree species can play an essential role in the storage of carbon, deep in the soil, but this alone does not influence SOC content. In fact, it is affected by factors like soil moisture, bulk density, pH and EC. Therefore, physico-chemical properties of the soil are helpful in describing the soil carbon storage potential. The present study highlights the importance of optimum growth and productivity in the subtropical forests. Thus, natural ecosystems can be considered as potential sinks for carbon. Therefore, management of forests may help sequester atmospheric carbon into the soils and balance the sink–source relationship.

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