

Soil Organic Carbon Stock Assessment in Two Temperate Forest Types of Western Himalaya of Jammu and Kashmir, India

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Abstract

Soil organic carbon (SOC) in the temperate forests of the Himalayas is important to estimate their contribution to regional, national and global carbon stocks. This information however is poor and fragmented in regards to the western Himalayas of India. No published information is available on SOC stock in this region. Carbon stocks were assessed at different soil depths (0-10, 10-20 and 20-30 cm) in *Pinus wallichiana* (PW) and *Abies pindrow* (AP) forest types in the western Kashmir Himalayas of India. SOC stocks in these temperate forests were relatively low ranging from 50.37 to 55.38 Mg C ha⁻¹ in the top 30 cm of soils. Significantly greater SOC stock was observed in PW forest type compared to AP forest type. Tree density, shrub density, shrub biomass, herb biomass, and forest floor litter were greater in the PW forest type as compared to AP forest type, which could be the reason for greater accumulation of organic carbon in soil. The present study revealed that tree species composition and its associated underground vegetation alter SOC accumulation in the moist temperate forest ecosystems. In addition, environmental parameters such as soil moisture and soil biological activity change soil carbon sequestration potential in moist temperate forest ecosystems.

Keywords: Soil organic carbon stock; Temperate forest; Kashmir Himalaya; *Pinus wallichiana*

Introduction

Soil organic carbon is considered to be one of the largest carbon reservoirs of the terrestrial ecosystems and also plays an important role in the global carbon cycle [1-3]. Forests act as one of the largest carbon sinks and helps to control atmospheric CO₂ concentrations [4]. Forest soil contains a globally significant amount of carbon (C), approximately half of earth's terrestrial carbon is in forests (1146×10¹⁵ g), and of this amount, about two-thirds is retained in soil pools [5]. Temperate forests ecosystems contain a significant amount of soil organic carbon (C), both globally [6] and regionally [7].

It has been estimated that present carbon stock in the world's forests is 861 ± 66 Pg C, of which 383 ± 30 Pg (44%) is in soil to a depth of 1 meter [8]. Temperate forests contribution to world forest carbon stock is 14 % (119 ± 6 Pg), [8]. Based on average global or regional soil carbon densities estimated in Indian forest soils, it has been calculated that our soil organic carbon pool ranges from 5.4 to 6.7 Pg [9,10], while Chhabra et al. [11] had estimated that the total soil organic pool in Indian forests in the top 50 cm and top 1 m soil depth were 4.13 and 6.81 Pg, respectively.

Soil organic carbon is normally estimated to a depth of 0-30 cm since most of it is present in the top layers and root activity is also concentrated in this horizon [12]. Thus the quantity of SOC in the 0-30 cm layer is about twice the amount of carbon in atmospheric carbon dioxide (CO₂) and three times that in global above ground vegetation [13]. It is estimated that the global stock of SOC to a depth of 30 cm is 684-724 Pg [1]. A small change in soil carbon results in a large change in atmospheric concentration [14,15]. It is essential to study the mechanisms and changes of forest SOC to better understand and mitigate climate change [16].

Mountainous cold-temperate areas have high SOC content but large spatial variability, due to variable climate and vegetation [17]. This spatial variability has made it difficult to predict the spatial distribution of SOC in forest soils [18]. Various studies have reported the influence of topography [19], climatic conditions [20], soil composition [21],

litter quality and its decomposition rate [22] and species composition or vegetation type [23] on the spatial distribution of SOC.

The Himalayas are among the youngest mountain ranges on the planet and consists mostly of sedimentary and metamorphic rocks. In India, the Himalaya occupies 16.2% of the total geographical area and spans over 12 states of the country. The Himalayas in India are categorized into Northern Himalaya, Western Himalaya, Central Himalaya and North-eastern Himalaya [24]. The geographical area of the state is 101387 sq.km and from which 20230 sq.km are under forest cover. Hence the present study was aimed to estimate the SOC stock assessment in two different forest types widely distributed in the Kashmir Himalayas. This study will provide a baseline soil carbon stock data, which helps to assess the plausibility of diverse published inventory data.

Materials and methods

Study area

The study area is situated in western part of the Kashmir Himalaya, Pahalgam, Anantnag, one of the southern-most districts of Jammu & Kashmir state, India. The area is totally mountainous with dense coniferous forests. The climate of the area is moist temperate type. The region receives moderate to high snow fall from December to February. Average annual precipitation was 1289 mm (including snow) and Mean temperature ranged -4°C to 30°C (Figure 1). The study area

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lies in between the geographical coordinates of 33° 45' 01" to 34° 15' 35"N latitude and 74° 02' 00" to 75° 32' 29" E longitude (Figure 2). This area comes under the Lidder forest division. This forest division has a total forest area of approximately 894 Sq.Km. For the present study two different forest types were selected i.e., *Pinus wallichiana* (PW) and *Abies pindrow* (AP). In each forest type 10 plots of 1 ha each were selected for the detailed study.

Soil sampling and laboratory analysis

Soil samples were collected at 0 to 10, 10 to 20 and 20 to 30 cm from each forest plot with the help of soil core sampler in the month of October 2012. Soil samples from ten randomly selected points in each sample plot were collected and mixed together to form a composite soil sample in each plot, from which five replicate samples were brought to the laboratory for organic carbon estimation. Before analysis soil samples were sieved through a 2 mm sieve. For organic carbon estimation Walkley and Black's method [25] was used, which is a widely used procedure [26] for organic carbon estimation. In Walkley and Black methods about 60-86% of SOC is oxidized, therefore a standard correction factor of 1.32 was used to obtain the corrected SOC values [27].

For bulk density in each sample plot six aggregated undisturbed soil cores were taken by soil corer having 5 cm internal diameter. When

taking cores for measurements of bulk density, extra care was taken to avoid any loss of soil from the samples. The soil samples were weighed immediately and transported to the laboratory where they were oven dried at $105 \pm 5^\circ\text{C}$ for 72 h and again weighed. In the soils containing coarse rocky fragments, the coarse fragments were separated by sieve and weighed. The bulk density of the mineral soil core was calculated with the help of the following formula described by Pearson et al. [26].

$$\text{Bulk density (g / m}^3\text{)} = \frac{\text{Oven dry mass (g / m}^3\text{)}}{\text{Core volume (m}^3\text{)} - (\text{Mass of coares fragments (g)} / 2.65(\text{g / cm}^3))}$$

Where 2.65 was taken as constant for the density of rock fragments (g/cm^3)

Soil carbon stock was then calculated for each soil layer based on the thickness of the soil layer, its bulk density and carbon concentration. The total carbon content of 30 cm depth was finally estimated by summing all layers [26].

$$\text{SOC (Mg ha}^{-1}\text{)} = [(\text{soil bulk density (gm}^{-3}\text{)} \times \text{soil depth (cm)} \times \text{C})] \times 100$$

The forest floor standing crop litter in soil surface was collected using a 1x1 m wooden frame from twenty quadrates in each plot, weighed *in situ* and then taken the representative samples in triplicate to laboratory and were kept in oven for 48 hr and dry weight were measured.

In each forest type three replicate plots of 1 ha each were selected for harvest of understory vegetation (Herbs & shrubs), where the biomass of shrubs and herbs were directly estimated through a harvest method [28]. Fresh weight of both herbs and shrubs were measured *in situ* species wise and then taken the representative samples in triplicate to laboratory and were kept in an oven for 48 hrs at 65°C and weighed until two subsequent values were constant.

Soil moisture (%) was measured at three different depths (0-10, 10-20 and 20-30 cm) by gravimetric method. Soil pH (1:2.5 ratio of soil: water) was measured with dynamic digital pH meter.

Statistical analysis

The variation in SOC stock among different forest types (PW and AP) and soil depths (0-10, 10-20, 20-30 cm) were examined with analysis of variance (ANOVAs). The correlation between SOC percent and 9 variables (soil pH, soil moisture, tree density, tree basal area, shrub density, shrub biomass, herb biomass, forest floor standing crop litter) was examined followed by linear regression analyses by using Past software.

Results

Characteristic features of the study sites

Tree and shrub density was greater in the PW forest type compared to AP forest type (Table 1). Shrub biomass was greater in the PW forest compared to AP forest type, and herb biomass was greater in the AP compared to PW forest type. The forest floor standing crop litter, soil moisture, soil pH and soil respiration were significantly greater in the PW forest compared to AP forest type.

Bulk density of two different forests types is given in Figure 3. A significant ($P < 0.001$ in PW and AP) trend of increasing bulk density was observed with increased soil depths in both the forest types (PW & AP). Similarly bulk density of soil showed a significant variation ($P < 0.001$ in 0-10 cm; $P < 0.05$ in 10-20 cm and 0-30 cm) among both forest types except bottom layer (20-30 cm).

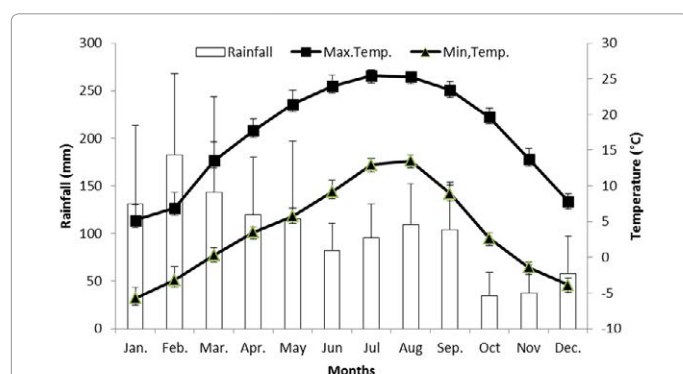


Figure 1: Mean monthly maximum and minimum temperature and rainfall pattern (2002-2012) of the two study sites in temperate forests of western Himalaya, J&K, India.

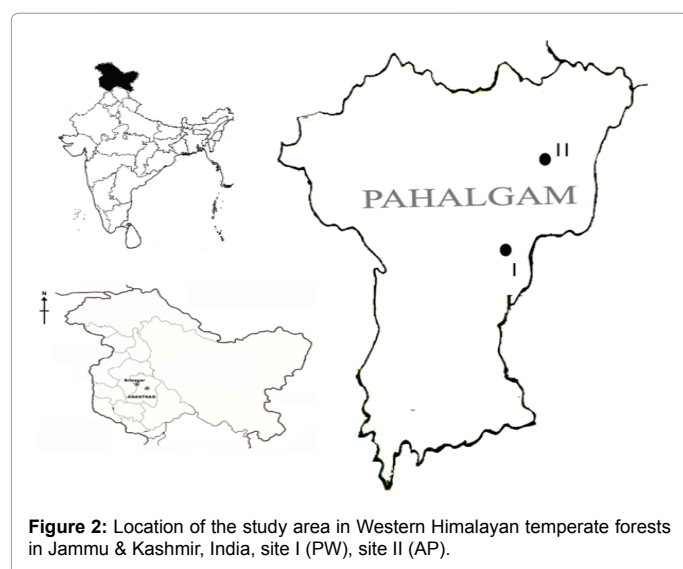


Figure 2: Location of the study area in Western Himalayan temperate forests in Jammu & Kashmir, India, site I (PW), site II (AP).

Criteria	<i>Pinus wallichiana</i> (PW)	<i>Abies pindrow</i> (AP)	Sig.
Latitude & Longitude	N34°00'51.9 E075°18'40.6	N34°02'16.8 E075°20'35.1	
Elevation (m.a.s.l)	1800-2450	2000-2550	
Tree density (No./ha ⁻¹)	245 ± 16.5	232 ± 12	NS
Tree Basal area (m ² /ha ⁻¹)	55.38 ± 4.25	54.11 ± 2.63	NS
Shrub density (No./ha ⁻¹)	87349 ± 21964	15547 ± 2501	***
Shrub Biomass (g/m ²)	887.32 ± 590.43	330.67 ± 118.65	NS
Herb Biomass (g/m ²)	49.17 ± 25.83	50.43 ± 0.85	NS
Forest floor litter (g/m ²)	466.5 ± 15.39	194.1 ± 2.99	***
Soil Moisture (%)			
0-10 cm	59.38 ± 16.4	36.9 ± 6	**
10-20 cm	41.62 ± 17.7	26.6 ± 1.9	*
20-30 cm	26.7 ± 8.6	20.6 ± 2.9	NS
Soil pH	6.13 ± 0.07	6.06 ± 0.12	*

*** P<0.001; ** P<0.01; * P<0.05; NS = Not significant; Mean ± SD, Sig= Significance

Table 1: Characteristics of experimental sites in temperate forests of Kashmir Himalaya at Pahalgam, Jammu & Kashmir, India.

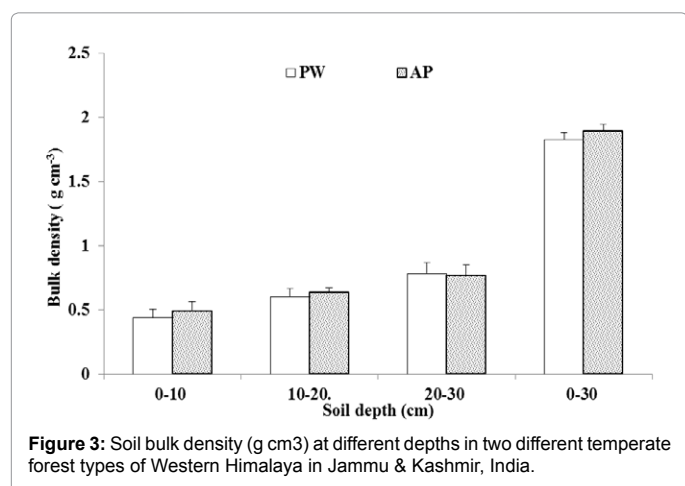


Figure 3: Soil bulk density (g cm³) at different depths in two different temperate forest types of Western Himalaya in Jammu & Kashmir, India.

SOC stock

The mean range of SOC stock in temperate forest ecosystems of Kashmir Himalaya at Pahalgam was 50.37 Mg C ha⁻¹ to 55.38 Mg C ha⁻¹ in 0-30 cm depth (Figure 4). SOC has showed a significant (P<0.001) decreasing trend with increased soil depth in both forest types (PW & AP). The mean range of SOC stock in different soil depths was 25.3 to 30.5 Mg C ha⁻¹ at 0-10 cm, 11.79 to 17 Mg C ha⁻¹ at 10-20 cm and 9.87 to 12.9 Mg C ha⁻¹ at 20-30 cm.

The test of ANOVA indicates that there is a significant (P<0.001) difference of SOC among both the forest types in 0-30 cm depth. A similar trend was observed in case of all the three layer depths (P<0.0001 in 20-30 cm; P<0.001 in 0-10 cm and 10-20 cm). SOC in 0-30 cm depth was significantly greater in PW forest compared to AP forest type. A similar trend was observed in case of middle and bottom layer (10-20 and 20-30 cm). However SOC in upper surface layer (0-10 cm) was significantly greater in PW forest type than AP forest type.

Soil moisture, shrub density, tree density, forest floor litter and soil respiration showed significant positive correlation with SOC (Table 2). In addition to that soil pH and shrub biomass also showed positive relationship with SOC. However, soil bulk density and tree basal area showed negative correlation with SOC while herb biomass showed very weak negative relationship with SOC.

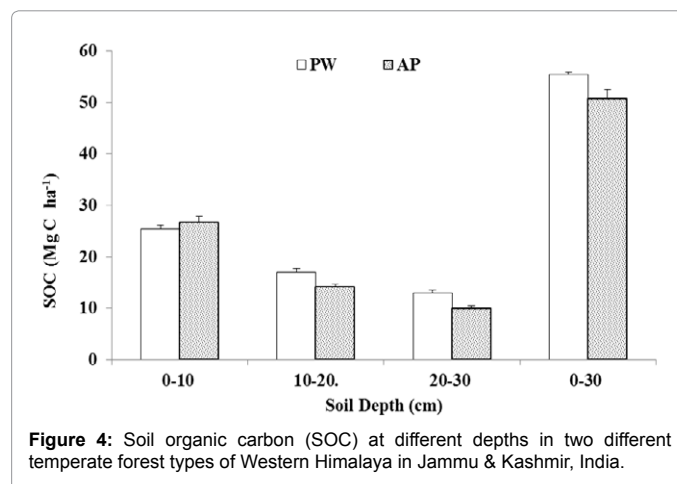


Figure 4: Soil organic carbon (SOC) at different depths in two different temperate forest types of Western Himalaya in Jammu & Kashmir, India.

Predictor	0-30 cm
Soil bulk density	-0.40
Soil moisture	0.89
Soil pH	0.31
Herb biomass	-0.06
Shrub biomass	0.56
Shrub density	0.86
Tree density	0.70
Basal area	-0.33
Forest floor litter	0.94
Soil respiration	0.84

Table 2: Correlations (R values) between soil organic carbon (%), and above ground vegetation properties and soil properties in temperate forests of Kashmir Himalaya, India.

Discussion

The SOC stock decreased with increasing soil depth observed in the present study is in agreement with earlier studies [21,29]. The higher organic carbon content may be due to rapid decomposition of forest litter in a favourable environment. A steep fall in the SOC as depth increases is an indication of higher biological activity associated with upper soil layer [29]. The trend of decreasing SOC with increasing depth may be due to the increased proportion of slower cycling of SOC pools at depth [21].

The SOC stock at 0-30 cm depth in two different forest types (AP & PW) of Kashmir Himalaya was ranged in between 50.4-55.4 Mg ha⁻¹ which is closer to SOC stock reported in the Himalayan temperate forests [30-32]. The SOC value obtained in the present study is well within the range of montane temperate forests of India [11] and other parts of the globe. However, comparison is very difficult because of variation in soil type and soil sample depths.

The SOC stock obtained in the present study was lower than the range of 93.7-220.1 Mg C ha⁻¹ reported by Zhang and Wang [33] in temperate forest and 62.7-88.7 Mg C ha⁻¹ reported by Zhu et al. [34] in temperate mixed old growth forests of China. The higher range of SOC value reported in Chinese temperate forests was due to lower altitude (400 m.a.s.l). However, low range of SOC stock recorded in the present study may be due to higher altitude and its related environmental variables (Table 1).

The SOC stock is influenced by complex interactions of climate, soil type, altitude, slope, management and tree species or vegetation types

[3]. The carbon stock at 0-30 cm was significantly ($P < 0.001$) different in different vegetation types. For example, greater SOC stock was recorded in the PW forest type compared to AP forest type. Similarly, forest types significantly altering SOC stock in temperate forests was reported by several authors [17,31,35]. These differences have been attributed to the fact that tree species could potentially influence the SOC stabilization in several ways [31] such as input and chemistry of organic detritus carbon from different tree species can alter SOC stock [36].

Tree species could potentially cause a bridging effect between SOC and clay particles via their influence on cation chemistry, thereby reducing C decomposition [37]. In addition to that low soil pH resulting from the inputs of acidic tissues of various tree species may enhance SOC accumulation through microbial inhibition [38]. Tree species could also differ in their influence over the physical protection of SOC in to aggregates via fine root and mycorrhizal hyphae [39]. SOC quality is affected by tree species as some species produce more litter, roots and understory vegetation than others, and thus differences in net primary production between tree species eventually influence SOC stock [40]. The greater accumulation of organic carbon in the soil of the PW forest in the present study could have been due to the greater tree density, shrub density, shrub biomass, herb biomass, forest floor litter, and soil respiration.

Bulk density differed between the forest floor horizons. The soil organic matter (SOM) content was the main factor in explaining forest floor bulk density [23]. At greater depths in the forest floor, there is more mixing with mineral material in the profile. This leads to a higher bulk density [23]. SOC stock in a given depth is mainly determined by SOC concentration and bulk density. Soil bulk density can be quite variable in different forest types as reported earlier by Yimer et al. [41].

Total SOC stock variation could be attributed to SOC concentration or simply due to the spatial variation of soil bulk density as reported by Li et al. [17]. Coniferous litter contains more lignin, which slows down the rate of decomposition leading to more litter accumulation in the forest floor and formation of acidic compounds as suggested by Berg [42]. In these acidic soils, soil fauna are less active, decreasing the amount of humus mixing through mineral soil and leaving more materials in the forest floor [43]. In addition, conifers have shallower rooting systems and tend to accumulate more organic carbon in the forest floor [44]. These could be the reasons for the variation of SOC and SOM among the forest types as well as the distribution in the soil profile in moist temperate forests of the Kashmir Himalaya.

SOC (%) in 0-30 cm soil depth showed a significant positive correlation with above ground vegetation properties and soil properties. Similarly, a positive correlation was observed between SOC and tree density in temperate forest [29]. The lower SOC in areas with lower tree density and basal area might be due to wider spacing between the individuals, resulting in lower litter input and less accumulation in turn yielding less storage of carbon stock in this temperate forest as suggested by Sheikh et al. [29]. Similarly, a positive relationship with soil moisture and litter fall with SOC stock was observed in scot pine ecosystem [35]. Litter inputs through litter fall, litter quality, root turn over and soil chemistry are the key factors to alter SOC [31].

The present study revealed SOC stocks under different vegetation types did not differ at any specific depth but did differ statistically across all depths (0-30 cm) and SOC stocks were almost different for different forest. On the other hand, vegetation properties were consistently and closely related with SOC in both the two forest types. Hence, aboveground vegetation properties are common predictors that

can be used to estimate the SOC stock in complex mountainous forests across different spatial scales.

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