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ORIGINAL ARTICLE

Estimating soil carbon storage and mitigation under temperate coniferous forests in the southern region of Kashmir Himalayas

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Abstract Soil physical and chemical properties were quantified to assess soil organic carbon (SOC) density (t ha^{-1}) and SOC CO2 mitigation (t ha^{-1}) under six forest strata *Cedrus deodara* (closed) (S1), *Cedrus deodara* (open) (S2), *Abies pindrow-Picea smithiana* (closed) (S3), *Abies pindrow-Picea smithiana* (open) (S4), *Pinus wallichiana* (closed) (S5) and *Pinus wallichiana* (open) (S6) in the southern region of Kashmir Himalayas India. Lowest average bulk density (D_b) of 0.95 was found same in S3 (σ±0.07) and S5 (σ±0.09) and highest D_b (1.08) was observed in S2 (σ±0.05). A relatively higher coarse fraction was observed in all the six strata ranging from 19.23 (SD±4.66) in S3 to 29.37 (σ±6.12) in S6. Soil pH ranged from 6.09 (σ± 0.64) in S4 to 6.97 (σ±0.53) in S2. The region under biotic interference has observed significant deforestation and degradation in the past two decades leading to lower SOC% values compared to other studies in the adjoining regions of Indian Himalayas and temperate coniferous forests in general. SOC% values were observed to range from 1.03 (σ±0.22) in S2 to 2.25 (σ±0.23) in S3. SOC density ranged between 25.11 (σ±5.41) t ha^{-1} in S2 and 51.93 (σ±5.24) t ha^{-1} in S3. SOC CO2 mitigation density was found highest 190.59 (σ±19.23) t ha^{-1} in S3 and lowest 92.16 (σ±19.86) t ha^{-1} in S2. A significant variation was observed in SOC density within strata. SOC density values in closed strata in general exceed to those in open strata. Primary results indicate that the average SOC stock for all the strata is low due to continuous biotic pressure in the last two decades making it a potential region for SOC buildup under plus options of REDD + (Reducing emissions from deforestation and forest degradation) which includes conservation, sustainable management of forests and enhancement of forest carbon (C) stocks.

Keywords Soil organic carbon · CO_2 mitigation · Coniferous forests · Himalayas · Kashmir

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1 Introduction

Forests have assumed special importance after it was realized that managed forests could help reduce the atmospheric carbon (C) (FAO 2010) by trapping it in various pools of C (IPCC 2007) viz. above ground biomass, below ground biomass, soil, litter and deadwood. Among these pools soil assumes second but prominent role after biomass C in mitigating climate change (IPCC 2003, 2006). Forest loss accounts for a significant share of the global greenhouse gas emissions estimated between 12 % (Van der Werf et al. 2009) and 17 % (IPCC 2007). However estimates of soil organic carbon (SOC) at global level are uncertain and range from (1,500–2,000) Pg (Post et al. 1982; Eswaran et al. 1993; Batjes 1996; IPCC 2000). The world's forests store large quantities of C, with an estimated C of 330 Gt in live and dead above and below-ground vegetation, and 660 Gt in mineral soil plus organic (O) horizon (IPCC 1995; Watson et al. 1996). Soil has been recognized as one of the important C pools exceeding biomass C in almost all ecosystems by a factor of two to ten (Sombroek et al. 1993). SOC is seen as one of the recognized options to mitigate atmospheric CO_2 (IPCC 2000; Lal and Kimble 2000) and the role of SOC in greenhouse effect has been recognized in particular (Bouwman 1990; Lal et al. 1998; Lal 2004). Forest SOC account losses or gains need to be accounted for periodically at national and sub-national levels using standard methodologies to monitor and estimate changes. Assessment of SOC stock is important in drawing relation with climate and carbon dioxide balance (Olsson et al. 2009).

Soil C monitoring system will enable developing countries to improve reporting in national communications to be submitted every 4 years to the United Nations Framework Convention on Climate Change (UNFCCC). India has already agreed under Bali Action Plan to all the elements of REDD + (Reducing emissions from deforestation and forest degradation, + sign denoting the role of conservation, sustainable management of forests and enhancement of forest C stocks) in 13th meeting of the Conference of parties (COP 13) at Bali. In this context SOC estimates in the present study are significantly important for India in view of huge data gaps for this region which pose a great challenge to collect information on C forestry. Very little data is available regarding (SOC) density in southern region of Kashmir Himalayas India although some works on SOC% estimation have been carried out as a part of soil physical and chemical properties (Bhat and Wani 2003; Hussain and Pandit 2008; Jehangir et al. 2012). The state of Jammu and Kashmir has a recorded forest area of 20,230 km^2 covering 9.1 % of its geographical area (FSI 2011). These forests are predominantly coniferous with some mixed composition in few places (Champion and Seth 1968; Joshi et al. 2001).

The objective of this study was: 1) to quantify soil physical properties (coarse fraction, bulk density, particle density), soil chemical properties (pH, Electrical conductivity and SOC %) and SOC density within (O) horizon (0–30 cm) under different forest strata based on species and density. 2) to evaluate variability in SOC density and subsequently SOC CO_2 mitigation potential among forest strata.

2 Materials and methods

2.1 Study site

Geographically the area under investigation lies approximately between 33° 21′ 57.6″ to 34° 15′ 25.2″ north latitude and 74° 52′ 58.8″ to 75° 32′ 20.4″ east longitude (Fig. 1). The area occupies southern portion of Kashmir valley and chiefly lies in Anantnag, Pulwama and Kulgam districts of Jammu and Kashmir India. It is bounded on the east and south by the mighty Pir Panjal mountain range separating it from the districts of Doda, Kishtwar and Ramban. It is bounded by district Shopian and Srinagar in the west and north respectively.

The study area experiences temperate climate with an average temperature of around 13^o C and has an annual precipitation of 660–1,400 mm. The main forest types confined to the study area include 12/C_1 Lower western Himalayan temperate forest, 13/C_3 West Himalayan dry temperate deciduous forest, 15/C_1 West Himalayan sub alpine Fir forest, 15C_2 Deciduous alpine scrub and 15C_3 Alpine pastures (Champion and Seth 1968).

2.2 Pilot study

A reconnaissance survey was carried out to collect preliminary information regarding the study area. The forests of both the divisions are predominantly coniferous with sprinkled broad leaved species. The conifers mainly comprise of *Pinus wallichiana*, *Abies pindow*, *Picea smithiana* and *Cedrus deodara*. Some associations of *Taxus baccata* and traces of *Juniperus recurva* are found locally. Conifers generally conform to distribution based on

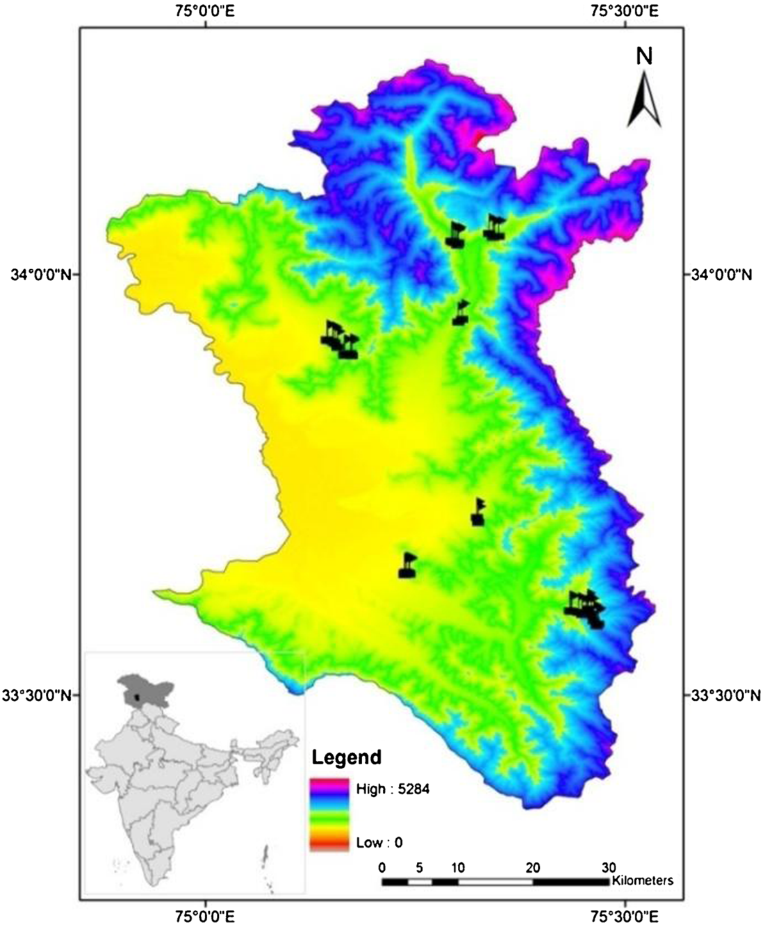

Fig. 1 Location of sample plots within study area in southern region of Kashmir Himalayas India

altitudinal zonation. *Cedrus deodara* as a purer crop or an associate of *Pinus wallichiana* is poorly represented in the region mostly on easy slopes at an elevation range of (1,830–2,424) mamsl. *Pinus wallichiana* is a light demander and generally found at lower elevations (1,700–2,400) mamsl and generally predominates in southern aspects. *Abies pindrow* mainly occupies higher elevations (2,153–3,380) mamsl and extends to alpine zone where it gives way to alpine scrub. *Cedrus deodara* grows well on well drained, light and loamy soils. *Pinus wallichiana* thrives well on stiff and clayey soils while as *Abies pindrow* and *Picea smithiana* prefer shallow soils on upper hills. The undergrowth found in *Cedrus deodara* type strata includes *Parrotiopsis jacquemontiana, Viburnum foetens, Cotoneaster spp., Indigofera spp., Desmodium spp., Berbaris spp., Viola odorata, Frageria vesca, Taraxacum spp., Thymus spp.,* and *Oryzopsis spp.* The undergrowth encountered *Pinus walllichiana* includes *Parrotiopsis jacquemontiana, Viburnum foetens, Cotoneaster spp., Indigofera spp., Rubus spp., Berbaris spp., Frageria spp., Plantago spp., Taraxacum spp., Verbascum spp.* and *Oryzopsis spp.* The third type species strata *Abies pindrow-Picea smithiana* had some common and unique undergrowth viz. *Viburnum spp., Sambucus ebulus, Skimmia laureola, Podophylum hexandrum, Parrotiopsis jacquemontiana, Viola odorata, Frageria vesca., Polygonum spp., Rumex spp., Anemone spp., Phytolacca spp., Aralia spp., Actaea spp.* and *Atropa spp.*

Based on results of pilot study a scheme of classification was developed and stratified random sampling design was adopted. The investigation sites were covered under five forest ranges with a significant variation in species, elevation and soil giving rise to different physical features (Table 1). The density classes were based on (FSI 2005) as Open Forest (10 to 40 %) and Closed Forest (>40 %). The forest area was divided into the following six strata based on species and density: *Cedrus deodara* (closed) (S1), *Cedrus deodara* (open) (S2), *Abies pindrow-Picea smithiana* (closed) (S3), *Abies pindrow-Picea smithiana* (open) (S4), *Pinus wallichiana* (closed) (S5) *and Pinus wallichiana* (open) (S6). Within these strata simple random sampling was adopted for actual ground measurements. Sample size (n) was obtained using the formula given by Chacko (1965) and n was worked out to be 42. All the 42 quadrates of 0.1 ha were laid randomly in the proposed strata for collection of soil samples.

$$n = \frac{t^2 \times CV^2}{(SE\%)^2}$$

Where, n = number of sample plots, CV = coefficient of variation, SE% = standard error percentage (10 %) and t = statistical value at 95 % significance level.

Table 1 Physical features of the study area covered under sampling sites in southern region of Kashmir Himalayas India

Forest division	Forest range	Compartments covered	Elevation (m)	Slope (Degrees)	Forest strata
Anantnag	Duksum	17, 16A, 14A, 15A , 19	2358–2933	3.63–49.42	S3 and S4
	Kokernag	9,10,110	1752–1862	7.27–26.30	S5 and S6
	Kuthar	72,73	1825–2054	20.37–30.42	S1, S2, S5 and S6
Lidder	Pahalgam	17 AC, 19 AC, 39, 40,29	2025–2656	22.32–34.72	S3, S4, S5 and S6
	Tral	Wildlife, 38,39,44	1906–2290	9.10–36.96	S1, S2, S5 and S6

2.3 Soil sample collection

Soil samples were collected using standard methodology (Ravindranath and Ostwald 2008). Three random points (replications) were chosen in a way that altitudinal gradient is well represented within the sample quadrant. Top organic matter was removed from each location and samples scraped from (O) horizon (0–30 cm). The soil was thoroughly mixed and gravels were removed. The samples were kept in a properly labeled air tight polythene bag. Diameter at breast height (DBH) (>10 cm) was measured with tree caliper, tree height with Ravi multimeter and crown density with spherical crown densiometer. Additionally slope, altitude, aspect and density were also recorded. The position of quadrates was recorded using hand held global positioning system (GPS) unit.

2.4 Soil properties

A portion of soil from each sample was ground and passed through 100 mm mesh. 1 g of soil from each sample was taken for estimation of SOC by Walkley and Black (1934). This rapid titration method works on the principle that organic matter (OM) in the soil gets oxidized by potassium dichromate ($K_2Cr_2O_7$) and concentrated sulphuric acid (H_2SO_4) utilizing the heat of dilution of H_2SO_4. The excess H_2SO_4 not reduced by the organic matter of the soil is determined by back titration with standard ferrous sulphate ($FeSO_4.7H_2O$) or ferrous ammonium sulphate [$FeSO_4$. $(NH_4)_2$ SO_4 $6H_2O$].

$$\begin{aligned} &K_2Cr_2O_7 + 4H_2SO_4 \rightarrow K_2SO_4 + Cr_2(SO_4)_3 + 4H_2O + 3O \\ &C(OC) + 2O \rightarrow CO_2 \\ &FeSO_4 + H_2SO_4 + O \rightarrow Fe_2(SO_4)_3 + H_2O \end{aligned}$$

Amount of coarse fragments per sample was weighed and deducted from the respective samples to get correct weight bulk density *(D_b)* and particle density *(D_p)*. D_b and D_p were estimated using standard core method (Wilde et al. 1964) and were calculated using the formula:

$$D_b = \frac{mass\ of\ dry\ soil(g)}{volume\ of\ solids\ \&\ pore\,spaces\,(cm)^{-3}}$$

$$D_p = \frac{mass\ of\ dry\ soil(g)}{volume\ of\ solids\ (cm)^{-3}}$$

pH and electrical conductivity (EC) of the soil samples was determined in 1:2 soil water suspension with pH meter and EC meter respectively. Soil texture for each sample was estimated from 50 g of soil, previously dried, ground and sieved through a 2 mm sieve by hydrometer method using (Jennson ASTM: soil hydrometer 152 H: Temp 68 deg F per litre Bouyoucos scale) all in accordance with (Gupta 2009). Soil particles less than 2 mm include sand, silt and clay which form 100 %. Once the two fractions were determined the percentage of third was automatically fixed and finally texture was determined using the (United States Department of Agriculture) USDA textural classification chart.

2.5 SOC density and SOC CO_2 mitigation

Based on the results obtained on CF, B_d and SOC% from samples, SOC density (t ha^{-1}) for (O) horizon (0–30 cm) was calculated by using the following equation as suggested by IPCC Good

Practice Guidance (IPCC 2006) for Land use, Land-use Change and Forestry (LULUCF).

$$SOC = \sum_{\text{Horizon 1}}^{\text{Horizon n}} SOC\,\text{horizon} = \sum_{\text{Horizon 1}}^{\text{Horizon n}} \{(SOC) * \text{Bulk density} * \text{depth} * (1 - C\ \text{frag}) * 100)\}\text{horizon}$$

Where, SOC = Representative soil organic carbon content for the forest type and soil of interest, tonnes (t) C ha^{-1}, SOC = Soil organic carbon content for a constituent soil horizon, , t C ha^{-1}, (SOC) = Concentration of SOC in a given soil mass obtained from analysis, g C (kg soil)$^{-1}$, Bulk Density = Soil mass per sample volume, tonnes soil m^{-3} (equivalent to Mg m^{-3}), Depth = Horizon depth or thickness of soil layer, m, C fragments = % volume of coarse fragments/100.

The SOC density calculated for each stratum was converted to SOC CO_2 mitigation after multiplication by with a factor of 3.67 (C equivalent of CO_2). The values obtained demonstrated the amount of CO_2 mitigated by soil under each stratum.

2.6 Statistical analysis

The data obtained for all the physical and chemical properties, SOC density and SOC CO_2 mitigation density was subjected to statistical analysis using one way ANOVA (Analysis of variance) as per procedure suggested by Gomez and Gomez (1984). Standard deviation (±σ) and Standard error (±SE) were computed for all the strata (Tables 2 and 3). The strata exhibited significance at 5 % level of probability and hence critical difference (CD) was calculated between various strata.

3 Results

3.1 Soil physical and chemical properties

3.1.1 Coarse fraction (CF)

Highest coarse fraction >2 mm masses were separated and SOC was determined on soil masses <2 mm assuming that the fraction of SOC in coarse fraction with fast turnover rate doesn't contribute to SOC significantly (Schrumpf et al. 2011). Highest CF was observed in S6 with 29.37 % (σ±6.12) and lowest value was found in S3 with 19.23 (σ±4.66) as shown in Table 4.

Table 2 Soil organic carbon (SOC) density (t ha^{-1}) under different forest strata in the southern region of Kashmir Himalayas India

Forest strata	Mean	± σ	± SE
S1	40.07	8.10	3.06
S2	25.11	5.41	2.05
S3	51.93	5.24	1.98
S4	43.39	2.14	0.81
S5	49.77	6.35	2.40
S6	28.18	6.51	2.46
Mean	39.74	5.63	2.13
CD (0.05)	6.73	–	–

Table 3 Soil CO_2 mitigation density (t ha^{-1}) under different forest strata in the southern region of Kashmir Himalayas India

Forest strata	Mean	± σ	± SE
S1	147.05	29.72	11.23
S2	92.16	19.86	7.51
S3	190.59	19.23	7.27
S4	159.23	7.85	2.97
S5	182.66	23.32	8.81
S6	103.40	23.88	9.03
Mean	145.85	20.64	7.80
CD (0.05)	24.71		

3.1.2 Bulk density (D_b) and particle density (D_p)

The relation between SOC and D_b is frequently used to estimate C pools (Post et al. 1982). Lowest average D_b of 0.95 g cm^{-3} was found same in S3 (σ±0.07) and S5 (σ±0.09) and highest 1.08 g cm^{-3} in S2 (σ±0.05). SE for all the strata varied from 0.02 to 0.03 (Table 4). The highest D_p 2.68 g cm^{-3} (σ±0.17) was observed for S3 and lowest 2.36 g cm^{-3} (σ±0.14) for S2. A correlation plotted between D_b and D_b showed a negative relation ($r=-0.74$) and R^2 was found to be 0.54 (Fig. 2).

3.1.3 Electrical conductivity (EC) and soil pH

EC is the direct measure of soluble salt concentration in the soil sample. These salts may be acidic, neutral or basic and the excess of such salts creates high osmotic pressure and preventing absorption of moisture and nutrients and thus affecting plant growth (Gupta 2009). In the present study EC differed significantly ($p<0.05$) (Table 5) among the strata with highest 262.59 (σ±52.76) μS/cm for S5 and lowest 191.56 (σ±41.65) μS cm^{-1} for S4 as shown in Table 4. Soil pH differed significantly ($p<0.05$) among various strata in the current study with highest value for S2 6.97 (σ±0.53) and lowest 6.09 (σ±0.64) for S4 as given in Table 4.

3.1.4 Soil organic carbon percent (SOC %)

The OC content is commonly used to characterize the amount of SOM. OM=1.724 * %OC. SOM is defined as the summation of plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and well-decomposed substances (Brady and Weil 1999). In the present study SOC% values ranged from 1.03 (σ±0.22) in S2 to 2.25 (σ±0.23) in S3 as given in Table 4. A negative correlation ($R^2=0.57$) was observed between SOC (mg g^{-1}) and B_d (g cc^{-1}) (Fig. 3).

3.1.5 Soil texture

On the basis of various proportions of sand, silt and clay in samples from different strata, texture of sandy loam was observed for soils under all the three type strata *Cedrus deodara, Pinus wallichiana and Abies pindrow-Picea smithiana* using soil texture triangle. The percentage of sand, silt and clay were estimated for soils under species was found to be

Table 4 Soil physical and chemical properties under different forest strata in the southern region of Kashmir Himalayas

Forest strata	B_d (g cm^{-3})			B_p (g cm^{-3})			CF (%)			EC (μS cm^{-1})			pH			SOC (%)		
	Mean	± σ	±SE	Mean	± σ	±SE	Mean	± σ	±SE	Mean	± σ	±SE	Mean	± σ	±SE	Mean	± σ	±SE
S1	1.05	0.07	0.03	2.49	0.15	0.06	19.34	6.46	2.44	232.79	37.24	14.08	6.69	0.50	0.19	1.58	0.32	0.12
S2	1.08	0.05	0.02	2.36	0.14	0.05	24.82	6.51	2.46	197.17	29.14	11.01	6.97	0.53	0.20	1.03	0.22	0.08
S3	0.95	0.07	0.02	2.68	0.17	0.06	19.23	4.66	1.76	198.91	14.75	5.58	6.44	0.10	0.04	2.25	0.23	0.09
S4	0.97	0.06	0.02	2.55	0.12	0.04	25.81	4.20	1.59	191.56	41.65	15.74	6.09	0.64	0.24	2.00	0.10	0.04
S5	0.95	0.09	0.03	2.59	0.19	0.07	24.01	4.01	1.52	262.59	52.76	19.94	6.90	0.47	0.18	2.20	0.28	0.11
S6	1.06	0.05	0.02	2.45	0.12	0.04	29.37	6.12	2.31	228.79	32.72	12.37	6.73	0.13	0.05	1.24	0.29	0.11
Mean strata	1.01	0.07	0.02	2.52	0.15	0.06	23.76	5.33	2.01	218.63	34.71	13.12	6.64	0.39	0.15	1.72	0.24	0.09
CD (0.05)	0.08	–	–	0.16	–	–	5.93			41.71	–	–	0.506	–	–	0.284	–	–

Where CD (0.05) = Critical difference at 5 % level of significance

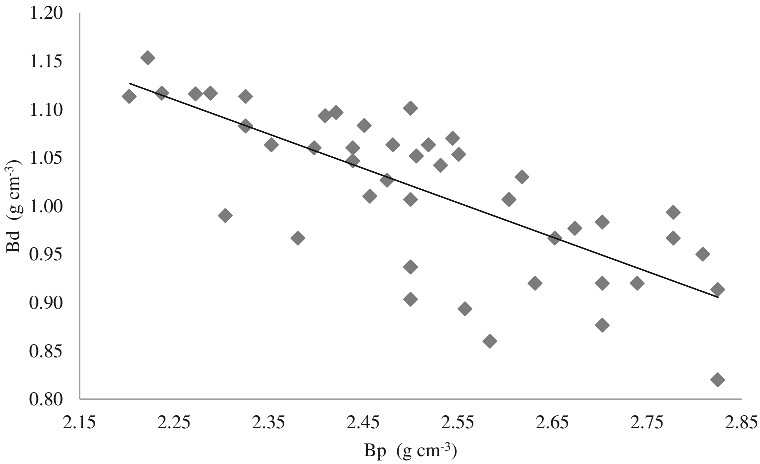

Fig. 2 Correlation between particle density *Bp* (g cm^{-3}) and bulk density *Bd* (g cm^{-3}) of soil in the southern region of Kashmir Himalayas India based on 42 sample observations under different type -density forest strata

Table 5 Analysis of variance (ANOVA) for soil physical and chemical properties under different forest strata in the southern region of Kashmir Himalayas

Soil property	Source of variation	SS	df	MS	F	P-value	F crit	CD
Bulk density (B_d) (g cm^{-3})	Between strata	0.12	5.00	0.02	5.27	0.001	2.48	0.07
	Within strata	0.16	36.00	0.00				
	Total	0.28	41.00					
Particle density (B_d) (g cm^{-3})	Between strata	0.43	5.00	0.09	3.88	0.006	2.48	0.16
	Within strata	0.80	36.00	0.02				
	Total	1.23	41.00					
Coarse fraction (CF) (%)	Between strata	538.22	5.00	107.64	3.65	0.009	2.48	5.93
	Within strata	1062.11	36.00	29.50				
	Total	1600.34	41.00					
Soil organic carbon (SOC) (%)	Between strata	9.20	5.00	1.84	29.67	7.990E–12	2.48	0.28
	Within strata	2.23	36.00	0.06				
	Total	11.44	41.00					
Electrical conductivity (EC) (μS cm^{-1})	Between strata	26724.23	5.00	5344.85	3.99	0.006	2.48	41.71
	Within strata	48256.33	36.00	1340.45				
	Total	74980.55	41.00					
Soil pH	Between strata	3.73	5.00	0.75	3.78	0.007	2.48	0.51
	Within strata	7.10	36.00	0.20				
	Total	10.84	41.00					
Soil organic carbon (SOC) density (t ha^{-1})	Between strata	4272.73	5.00	854.55	24.46	1.168E–10		
	Within strata	1257.66	36.00	34.93			2.48	6.73
	Total	5530.38	41.00					

Where *SS* Sum of squares; *df* degress of freedom; *MS* Mean sum of squares; *F* Variance; *P* Probability; *CD* Critical difference

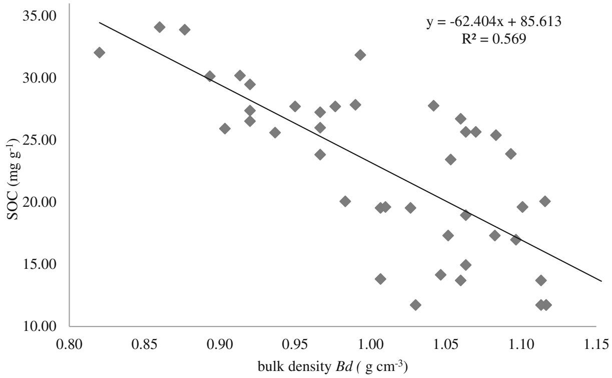

Fig. 3 Correlation between bulk density *Bd* (g cm^{-3}) and soil organic carbon (SOC%) of soil in the southern region of Kashmir Himalayas India based on 42 sample observations under different type -density forest strata

(58.33, 33.33 and 8.33) *Cedrus deodara*, (71.25, 22.08 and 6.67) *Abies pindrow-Picea smithiana* and (8.75, 27.08 and 64.17) *Pinus wallichiana*.

3.2 SOC and SOC CO_2 mitigation density

SOC density is determined by SOC%, B_d, and CF in the soil as per IPCC equation (IPCC 2006). The SOC pool is the balance between C input from aboveground litterfall and below ground rhizo-deposition, and release by decomposition (Jandl et al. 2007). In the present study highest SOC density in (O) horizon (0–30 cm) 51.93 t ha^{-1} (σ±5.24) was observed for S3 and the least value 25.11 t ha^{-1} (σ±5.41) for S2 as shown in Table 2.

CO_2 mitigation density values estimated on the basis of SOC density for different strata (Tables 3 and 4) were found significantly different ($p<0.05$). The analysis revealed highest CO_2 mitigation density of 190.59 t ha^{-1} (σ±19.23) for S3 and lowest value of 92.16 t ha^{-1} (σ±19.86) for S2. There was a significant difference ($p<0.05$) (Table 5) between all the estimated values of SOC and SOC CO_2 mitigation density.

4 Analysis and discussion

4.1 Soil physical and chemical properties

4.1.1 Coarse fraction (CF)

The average course fraction in this study was found to be 23.76 % which is comparatively more than the values in a similar study by (Gupta and Sharma 2011). Coarse fraction of 14 % was reported in coniferous plantation forests in northern Taiwan (Tsai et al. 2009). The varying values of SOC density within different strata is related to varying proportion of coarse fragments (Liski and Westman 1997; IPCC 2003).

4.1.2 Bulk density (D_b)

D_b in the present study was observed to be in conformity with other studies on C estimation. D_b of 0.73 g cm^{-3} was observed for plantation forests soils in Taiwan (Tsai et al. 2009) and

0.77 g cm^{-3} for dense forests in King County Washington United States of America (USA) (Porder and Lipson 2012). The present study demonstrates that SOC density varies significantly ($p<0.05$) within forest types and density classes. The estimate of standard error for soil properties, SOC density and soil CO_2 mitigation density of samples was found to be within allowable limits. A correlation of −0.75 ($R^2=0.57$) found between B_d and SOC density shows that with the increase in SOC there is an increase in the stabilization of aggregates which reduces B_d. This is in agreement with other studies (Drew 1973; Bonini and Alves 2010; Sakin 2012).

4.1.3 Electrical conductivity (EC) and pH

EC values of 161.33 μS cm^{-1} and 169.00 μS cm^{-1} in (O) horizon (0–10 cm) were observed under *Pinus wallichiana* and 137.33 μS cm^{-1} and 134.67 μS cm^{-1} under *Cedrus deodara* in Kashmir Himalayas (Hussain and Pandit 2008). EC values of 139 μS cm^{-1} and 136 μS cm^{-1} were reported by Jehangir et al. (2012) in (O) horizon under coniferous forest for dense and deforested sites respectively in Tangmarg Jammu and Kashmir. pH values of 6.12 and 6.95 (0–10 cm) and 6.21 and 7.36 (10–20 cm) in (O) horizon were reported for *Pinus wallichiana* and *Cedrus deodara* forests respectively in Kashmir Himalayas by Hussain and Pandit (2008) which is in harmony with the average estimate in the present study 6.64 (σ±0.39). Another study conducted in coniferous forests of Tangmarg Jammu and Kashmir reported a pH value of 6.33 for dense forest site and 6.45 for deforested site (Jehangir et al. 2012). pH ranged from 5.9 to 6.10 for Pinus communities and 5.8–6.1 for Cedrus communities in Qalagai hills, district Swat, Khyber Pakhtunkhwa Pakistan (Ilyas et al. 2012).

4.1.4 Texture

USDA textural classification chart indicated a sandy loam texture for all the three type strata. Other studies suggest sandy loam texture under *Pinus spp.* and silt loam under *Cedrus spp.* (Ilyas et al. 2012). Texture affects B_d with changing soil moisture (Hopkins et al. 2009; Schrumpf et al. 2011) and thus influences SOC density. Volume in clay loam texture reduced by 6–31 % when dried to wilting point (Hopkins et al. 2009). Different soil components show different shrinking properties under variable moisture conditions which affect B_d and hence SOC density.

4.1.5 SOC%

Type stratum *Abies pindrow-Picea smithiana* in general exhibited higher values for SOC density due to higher SOC% which may be due to the presence of mature girth classes compared to other type strata. Results of many works conducted earlier are in agreement with the present study with a little but explainable variation. SOC% values of 6.4 (σ±0.78) in forests and 3.8 (σ±0.29) in house woodlots was recorded in King County Washington USA (Porder and Lipson 2012). SOM% values of 14.1 and 9.9 were observed under *Pinus wallichiana* and *Cedrus deodara* respectively in (O) horizon (0–10 cm) and 6.1 and 5.1 (10–20 cm) (Hussain and Pandit 2008). In another study SOC% values of 3.05 and 4.32 were observed under dense and degraded forest sites with corresponding SOM % values of 5.26 and 7.45 respectively (Jehangir et al. 2012). SOC% in (O) horizon (0–30 cm) varied from 1.8 to 3.5 under *Pinus wallichaina*, 1.4 to 1.97 under *Abies Pindrow* and 1.4 to 3.1 under *Cedrus deodara* in forested sites of northern Kashmir (Bhat and Wani 2003). SOC% in (O) horizon (0–20 cm) varied from 1.8 to 1.96 at three different sites in Garhwal Himalayas (Sheikh et al. 2009). SOC% of 5.01–6.13 in (O) horizon (0–15 cm) was reported under *Pinus spp.* and 6.13 to 6.2 under *Cedrus spp.* (Ilyas et al. 2012). The SOC% variation observed in these studies may be due to change in selection of depth in (O) horizon varying from (0–15), (0–30) and (0–60). However a depth of (0–30 cm) has been taken in this study because SOC tends to concentrate in the upper 30 cm within (O) horizon (IPCC 2003). A study conducted by Kaur (2007) also reported similar results for SOC% under different coniferous strata ranging from 1.36 to 3.56.

4.1.6 SOC and SOC CO_2 mitigation density

Mean SOC density 39.73 t ha^{-1} (σ±5.63) in the present study was lower than the corresponding values in (O) horizon of soils under temperate forests in other part of the globe. Several studies on SOC density report 480 t ha^{-1} in coniferous plantation soils in northern Taiwan (Tsai et al. 2009), 280 t ha^{-1} in Swedish podzol soils (Olsson et al. 2009), 350 t ha^{-1} in podzol soils in Denmark (Vejre et al. 2003), 500 t ha^{-1} in mineral forest soils in Norway (De Wit and Kvindesland 1999), 190 t ha^{-1} in mineral forest soils in Finland (Liski and Westman 1995, 1997) and 640 t ha^{-1} in 3.8 % in forests and house wood lots respectively in King County Washington USA (Porder and Lipson 2012). However some studies have reported much lower SOC densities. Hunt et al. (2010) reported SOC density of 13–34 t ha^{-1} in managed conifer forests from L, F and H horizons. SOC density in disturbed boreal coniferous forests was reported to be 6–69 t ha^{-1} under *Pinus mariana* aged 20 years (Wang et al. 2003), 10–13 t ha^{-1} for soils under *Pinus banksiana* aged 30 years (Nalder and Wein 1999) and 12–13 t ha^{-1} for soils under *Pinus banksiana* aged 36–52 years (Rothstein et al. 2004).

The observed values of SOC density in the Indian subcontinent for *Cedrus deodara* and mixed conifers (Negi and Gupta 2010) for *Cedrus deodara* and *Pinus wallichiana* (Gupta 2011) in Garhwal Himalayan region of India were found in conformity with the present study. *Abies pindrown-Picea smithiana* stratum at various places in the study area comprise of old and over mature trees which have comparatively less litter fall than vigorously growing trees (Ram 1986; Singh 1999), so the presence of over mature girth classes reduces litter fall and hence doesn't allow SOC density reach very high values in *Abies pindrow-Picea smithiana*. The SOC increases from young age stands to mature stands (Chen and Shrestha 2012). Tchimbakala and Makosso (2008) also reported increase in SOC density with age of *Terminalia superba* plantation. Kaul et al. (2010) also reported increase in average SOC stock of forest vegetation upto a certain age. Similar results for SOC density were obtained in a country level estimate for Himalayan dry temperate forests (36.19 t ha^{-1}) and Himalayan moist temperate forests (71.58 t ha^{-1}) (Kishwan et al. 2009). Similarly SOC stock in the *Picea smithiana* plots exceeded than *Pinus wallichiana* plots by 20 % (Stendahl et al. 2010). The estimated SOC% and SOC density was comparatively lower than similar studies in other regions (Gupta 2011; Kishwan et al. 2009).

5 Conclusion

The results of this study suggest that factors such as quality and density of vegetation, soil physical and chemical properties influence SOC density (Post et al. 1982; Burke et al. 1989; Schimel et al. 1994; Homann et al. 1995; Kulmatiski et al. 2004; Tan et al. 2004). The varying values of SOC density within different strata also reflect site quality (Stendahl et al. 2010) and coarse fraction (Liski and Westman 1997; IPCC 2003). The continuous biotic pressure on these forests has led to removal of biomass and decline in its productivity. This removal of biomass has resulted in SOM deficiencies (Morris 1997; Carlyle and Nambiar 2001). The other factors which could be decisive and can be taken up for further research in this region include nitrogen deposition, mean annual temperature (MAT), mean annual precipitation (MAP) and latitude (Post et al. 1982; Harrison et al. 1995; Jobbágy and Jackson 2000; Zhou et al. 2003; Olsson et al. 2009). In this study the uncertainties in SOC estimates could have occurred for not taking all the factors into consideration. As a step ahead it is suggested to repeat the inventories with increased number of soil samples to evaluate the relation between SOC and all the factors.

The Indian forest management system committed to REDD + need to focus on forest SOC as one of the strongest and long term CO_2 mitigation options. Most of the coniferous forests in Indian Himalayas being managed under protection system strictly discourage harvesting of green timber, so disturbance due to harvesting is unlikely seen as a threat to SOC stock compared to forests managed under clear felling system (Davidson and Ackerman 1993; Paustian et al. 1998; Phillips et al. 1998; Miller et al. 2004). Illicit felling, fuel wood extraction and unmanaged grazing are seen as the immediate factors responsible for the depleted SOC status in the southern region of Himalayas. Strong legislation needs to be put in force with some physical interventions viz. fencing, soil engineering structures and plantation programs involving local community through the state forest department. These interventions can be taken under Green India Mission, a climate change initiative by India on REDD + approach (MoEF 2013). The soil monitoring system needs to be strengthened and integrated with the existing biomass C monitoring at regional and local level to address uncertainty and improve reporting of SOC in communications required to be sent to UNFCCC after every 4 years.

Strategies to replenish forest SOC includes immediate protection of degraded forest sites to allow natural growth where regeneration is promising and planting trees where natural regeneration is poor. Landslide prone areas inside forests need to be stabilized through physical interventions to prevent loss of soil and water. Wastelands within legal forest boundaries having huge potential to fix SOC should be afforested with right choice of species for long term storage of C. Forest nurseries presently not adequate in the area should be increased for production of quality planting stock to meet the requirements of afforestation. Illicit felling, a growing menace is required to be managed with strong legislation to achieve zero deforestation in the region. Pilot projects primarily aimed at C enhancement in forests should be undertaken in the region to demonstrate how strategically managed forests can play a role in minimizing green house gas emission and contribute to climate change mitigation.

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