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ASSESSMENT OF SOIL ORGANIC CARBON STOCK OF TEMPERATE CONIFEROUS FORESTS IN NORTHERN KASHMIR

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Abstract

Soil organic carbon (SOC) estimation in temperate forests of the Himalaya is important to estimate their contribution to regional, national and global carbon stocks. Physico chemical properties of soil were quantified to assess soil organic carbon density (SOC) and SOC CO_2 mitigation density at two soil depths (0-10 and 10-20 cms) under temperate forest in the Northern region of Kashmir Himalayas India. The results indicate that conductance, moisture content, organic carbon and organic matter were significantly higher while as pH and bulk density were lower at Gulmarg forest site. SOC % was ranging from 2.31± 0.96 at Gulmarg meadow site to 2.31 ± 0.26 in Gulmarg forest site. SOC stocks in these temperate forests were from 36.39 ±15.40 to 50.09 ± 15.51 Mg C ha^{-1}. The present study reveals that natural vegetation is the main contributor of soil quality as it maintained the soil organic carbon stock. In addition, organic matter is an important indicator of soil quality and environmental parameters such as soil moisture and soil biological activity change soil carbon sequestration potential in temperate forest ecosystems.

Key words: Soil organic carbon, CO_2 mitigation, Soil organic matter, Kashmir

Introduction

Forests play an important role in regional and global carbon cycles as they contain a large part of the carbon stored on land, in the form of both biomass and soil organic matter (SOM) and helps to control atmospheric carbon dioxide concentrations (Zhou et al., 2006). About two-thirds of terrestrial carbon is sequestered in the standing forests, forest understorey plants, leaf and forest debris, and in forest soils (Sedjo et al., 1998, IPCC, 2007). The long-term fate of carbon in forest ecosystems depends on whether it is stored in living biomass or soils. World soils contain an important pool of active carbon that plays a significant role in the global carbon cycle (Prentice et al., 2001). The global soil carbon pool is 3 times the size of atmospheric carbon and 3.8 times the size of biotic pools (Lal, 2001). In addition, residence time of soil carbon is longer than that of vegetation carbon. So, even a minute variation in soil carbon pool could have a major impact on global carbon budget (Medlyn et al., 2005). Hence, it is essential to study the mechanisms and variation in forest soil organic carbon and moreover, soil carbon sequestration has been suggested as a means of reducing the rate of increase of atmospheric carbon dioxide (Fang et al., 1996). Soil carbon stocks and the changes that occur in them are the result of climate, soil properties, litter quality and litter production by vegetation; the more productive the site, the more litter is fed into soil (Lal, 2005). Significant amounts of soil organic carbon occur in temperate forest ecosystems, both globally and regionally (Dar and Sundarapandian, 2013).

It has been estimated that about 44% of the total SOC stock of the global soils resides in forest ecosystem to a depth of 1 meter (Pan et al., 2011). Thus, more carbon exists in forests than entire atmosphere and roughly half of total carbon is found in soils and litter combined (FAO, 2006). Out of the total world forest carbon stock, temperate forest contributes 14 % (Pan et al., 2011). The dense forest vegetation in Himalayan zone covers nearly 19% of India and contains 33% of soil organic carbon reserves of the country (Bhattacharyya et al., 2008). In northern temperate forests soil carbon stocks is twice as that in vegetation (Schlesinger, 1997). Monitoring and assessing variation in soil organic carbon in forests need to be accounted for periodically at national and sub-national levels using standard methodologies. Assessment of soil organic carbon stock is important in drawing relation with climate and carbon dioxide balance (Olsson et al., 2009). Soil carbon sequestration is a natural, cost-effective, and environmentally friendly process (Lal, 2004).

India has already agreed under Bali action plan to all elements of REDD (Reducing emissions from deforestation and forest degradation) at Bali in COP 13. In view of huge data gaps for this region, soil organic carbon estimates in present study are significantly important for India. Furthermore, the result will contribute to understanding the role and importance of Gulmarg forest soil in climate change. In India, a great work has been done on soil carbon sequestration. However, no work has been reported on soil carbon sequestration in northern region of Kashmir Himalayas although few studies have been carried out on soil carbon sequestration in southern region of Kashmir Himalaya (Dar and Sundarapandian, 2013; Wani et al., 2013).

The present study endeavors to figure out soil carbon sequestration potential of Gulmarg forest of northern Kashmir Himalaya and the objectives of this study was 1) to quantify soil physical properties and chemical properties (pH, Electrical conductivity, bulk density, moisture percentage, soil organic carbon percentage, and soil organic matter).2) To evaluate variability in soil organic carbon (SOC) density and subsequently SOC CO_2 mitigation potential among forest strata.

Materials and Methods

Study Site

The study area is located in district Baramullah, 52 km from Srinagar, the summer capital of Jammu & Kashmir. It lies on the northern side of Pir Panjal forest situated in forest compartment number 0047 of Kashmir Himalaya at an altitude of about 2684 m, lying within geographical co-ordinates of $34^{O}03^{'}51.6$" N latitude and $74^{O}23$'2.1" E longitude. The area is mountainous with dense coniferous forests. The climate of Gulmarg may be described as Sub-Mediterranean type in conformity with that of Kashmir valley and has an annual precipitation of 660-1674 mm. The climate has moderate summers through June to August and severely cold winters from December to February with temperatures ranging from 20 to 30 ^{0}C in summer and 0 to -10 ^{0}C in winter. The region receives moderate to high snow fall from December to February. For the present study two forest sites i.e., Gulmarg forest site and Drung forest site and one meadow site i.e., Gulmarg meadow site were selected. Drung forest site is situated at an altitude of about 2664 m, lying within geographical co-ordinates of $34^{O}02^{'}51.6$" N latitude and $74^{O}23$'2.1" E longitude. It is a forested area dominated by *Pinus* *willichiana* and *Picea simithiana*.The area is having less human interference. Gulmarg meadow site is located at an altitude of 2684m between coordinates $34^0$02'51.6" N and $74^0$23'06.1" E. The herbaceous vegetation is under the impact of grazing and anthropogenic activities due to the heavy tourist flow with increasing number of horse hires leading to the negative impact on soil and vegetation. Gulmarg forest site is located at an altitude of 2783 m within geographical co-ordinates of $34^0$04'28.0" N latitude and $74^0$10'47.0" E longitude. The site is abundantly covered by forests dominated by *Pinus willichiana*, *Abies pindroo* and *Picea simithiana* with an understory of shrubs and herbaceous vegetation like *Cynodon dactylon, Trifolium pratense, Poa pratensis, Plantigo lanceolata, Taraxacum officinale, Plantigo major, Medicago denticulate, Dryopteris sp.*, etc. The site is well protected and is free human interference.

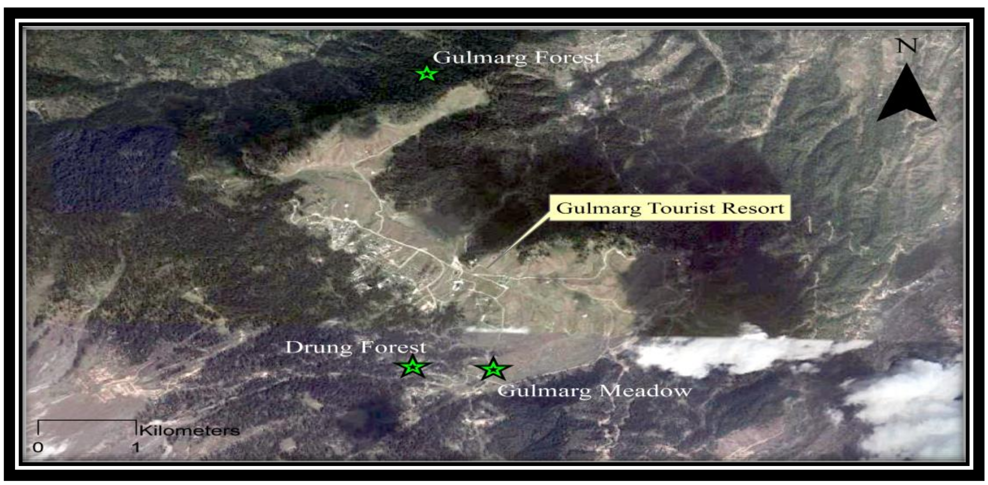

Fig. 1: Map of study area showing study sites.

Soil Sample Collection

The collection of soil samples was carried out during 2013 from randomly selected points in each sample site on seasonal basis by using AMS soil core sampler. Top organic matter was removed manually and soil samples were taken from the depths 0-10 cm and 10-20 cm in three replications from study sites. The collected samples were stored in polythene bags and then transferred to laboratory for analysis. The soil samples were air dried and then grounded using pestle and mortar and sieved through 0.5mm mesh sized sieve. Powdered samples thus prepared were stored in well labeled bags for subsequent analysis.

Soil Analysis

pH and electrical conductivity (EC) of the soil samples was determined in 1:2 soil water suspension with pH meter Eutech PH 700 and electric-conductivity meter Eutech CON 700 respectively by adopting procedure (Gliessman, 2000).

Percent moisture content for the fresh composite soil samples was determined on oven dry weight basis as per (Michael, 1984). The percentage moisture content was determined by using the following formula:

$$\text{Moisture \%} = \frac{\text{Wt. of fresh soil} - \text{Wt. of oven dry soil}}{\text{Wt. of oven dry soil}} \times 100$$

Bulk density of the soil samples was analyzed by following the method of (Gupta, 2004) and was calculated by the formula:

$$\text{Bulk Density } (g/cm^3) = \frac{\text{Dry weight of soil sample (g)}}{\text{Volume occupied by the same soil sample } (cm^3)} \times 100$$

For organic carbon estimation, a widely used procedure (Pearson et al., 2005) i.e., rapid titration Walkley and Black's method (Walkley, 1947) was used. Since, it is assumed that organic carbon recovery by this method is only 77%, the values obtained are multiplied by a correction factor of 1.32 in order to obtain corrected soil organic carbon values (De Vos et al., 2007). Assuming that organic matter contains 58% organic carbon, the organic matter was determined from organic carbon by multiplying the values of organic carbon with Van Bemmelen factor of 1.724. Soil organic matter 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 & Weil, 1999).

SOC density and SOC CO_2 mitigation

Based on the results obtained on Bulk density and SOC% from samples by the laboratory analysis, SOC density (Mg ha^{-1}) for different soil depths was calculated as (Brown, 2004, IPCC, 2006).

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

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

Statistical analysis

The data obtained for all the physical and chemical properties, SOC density and SOC CO_2 mitigation density between two forest sites (DFS and GFS) was subjected to statistical analysis using one way ANOVA. Standard deviation and Standard error were computed for all the sites. Soil property values that differed at $p \leq 0.05$ were considered significant. The statistical analysis was performed by using statistical package (Graph Pad Prism, 2006).

Results and Discussion

Soil physical and chemical properties

Soil pH

Soil pH values differed significantly ($p<0.01$) at various study sites in the current study with highest for Gulmarg meadow site (6.87±0.11) and lowest for Gulmarg forest site (6.10±0.27) as given in Table 1.The lower pH under forest may be attributed to presence of high organic matter in addition to decomposition of litter (vegetation, leaves, twigs, animal wastes), supported by significant correlation ($r=0.71$) between organic matter and pH. The pH of the soils under forest sites was slightly acidic which is the typical of coniferous soils and is favourable range for nutrient availability (De Vries et al., 1995). However, increase in pH in Gulmarg meadow site during the present study could be attributed absence of fresh conifer litter due to absence of tree cover and increase in base cations. Within the two depths, pH increased with the increase in depth, which may be attributed to the corresponding decrease in organic matter with depth. pH values of (6.64± 0.39) were reported for soils of temperate coniferous forests in southern region of Kashmir Himalaya (Wani et al., 2013), which is in harmony with present study. Another study conducted in coniferous forests of Tangmarg J &

K reported a pH value of 6.33 ± 0.05 for dense forest site and 6.45 ± 0.14 for deforested site (Jehangir et al., 2012).

Electrical conductivity

Electrical conductivity is relative measure of the total quantity of ions in the soil sample. The results indicated the variation in soil electrical conductivity values across all the study sites with highest 211.00±33.84 for Gulmarg forest site and lowest 141.33±19.20 for Gulmarg meadow site. The lower electrical values exhibited by Gulmarg meadow site may be attributed to the lesser release of ions from mineral weathering under different temperature and moisture regimes (Kaushal et al., 1997). Within the two depths, the electric conductivity decreases with increase in depth which may be related to leaching of nutrients from surface soils, consequently increasing their concentration in lower soil layer. Accumulation of soluble salts in mountainous region is unlikely because of the climatic conditions of the region e.g. heavy rainfall. Electric conductivity values of (218.63± 41.71 µS/cm) were reported for soils of temperate coniferous forests in southern region of Kashmir Himalaya (Wani et al., 2013), which is in harmony with present study. Another study conducted in coniferous forests of Tangmarg J & K reported Electric conductivity value of 139± 10 µS/cm for dense forest site and 196 ± 67 µS/cm for deforested site (Jehangir et al., 2012).

Table 1. Soil characteristics in temperate coniferous forests, Northern Kashmir Himalayas

Parameters studied	Drung Forest Site		Gulmarg Meadow Site		Gulmarg Forest Site		ANOVA	
	Mean± S.D.	±S.E.	Mean± S.D.	±S.E.	Mean± S.D.	±S.E.	P-value	Sign.
pH **0 – 10 cm** **10 – 20 cm**	6.60±0.16 6.76±0.12	0.09 0.07	6.76±0.10 6.87±0.11	0.05 0.06	6.10±0.27 6.56±0.12	0.5 0.07	0.0012	**
Conductivity (µS/cm) **0 – 10 cm** **10 – 20 cm**	186.33±18.23 167.33±19.00	10.53 10.97	171.00±22.33 141.33±19.20	12.90 11.22	211.00±33.84 194.66±28.37	19.54 16.38	0.05	ns

Moisture content (%) **0 – 10 cm** **10 – 20 cm**	23.03±2.37 19.81±3.06	1.37 1.76	21.5±1.37 16.39±1.89	0.79 1.09	31.03±4.79 26.36±5.27	2.76 3.04	0.0034	**
Bulk density (g/cm^3) **0 – 10 cm** **10 – 20 cm**	1.25±0.47 1.35±0.43	0.27 0.25	1.11±0.26 1.56±0.38	0.15 0.22	1.11±0.26 1.43±0.18	0.15 0.10	0.72	ns
Organic carbon (%) **0 – 10 cm** **10 – 20 cm**	3.44±0.44 2.86±0.22	0.25 0.12	3.34±0.40 2.31±0.96	0.23 0.55	3.97±0.26 3.06±0.62	0.15 0.36	0.04	*
Organic Matter (%) **0 – 10 cm** **10 – 20 cm**	5.92±0.77 4.93±0.38	0.44 0.22	5.72±0.74 3.98±1.65	0.43 0.95	6.84±0.45 5.28±1.08	0.25 0.62	0.04	*

*** P<0.001; ** P<0.01; * P< 0.05; ns = not significant; Mean ± SD, Sig= Significance

Table 2. Mean SOC and SOC CO_2 mitigation density in temperate coniferous forests, Northern Kashmir Himalayas.

Parameters studied	**Drung Forest Site**		**Gulmarg Meadow Site**		**Gulmarg Forest Site**		**ANOVA**	
	Mean± S.D.	**±S.E.**	**Mean± S.D.**	**±S.E.**	**Mean± S.D.**	**±S.E.**	**P-value**	**Sign.**
SOC **0 – 10 cm** **10 – 20 cm**	42.35±14.36 38.90±13.56	8.28 7.83	47.30±10.51 34.82±14.12	6.06 8.15	43.99±10.41 43.66±8.61	6.01 4.97	0.85	***
SOC CO_2M.D **0 – 10 cm** **10 – 20 cm**	155.4±52.68 142.7±49.80	30.42 28.75	173.0±38.57 127.8±51.81	22.27 29.91	161.6±38.08 160.2±31.62	21.99 18.26		

*** P<0.001; ** P<0.01; * P< 0.05; ns = not significant; Mean ± SD, Sig= Significance

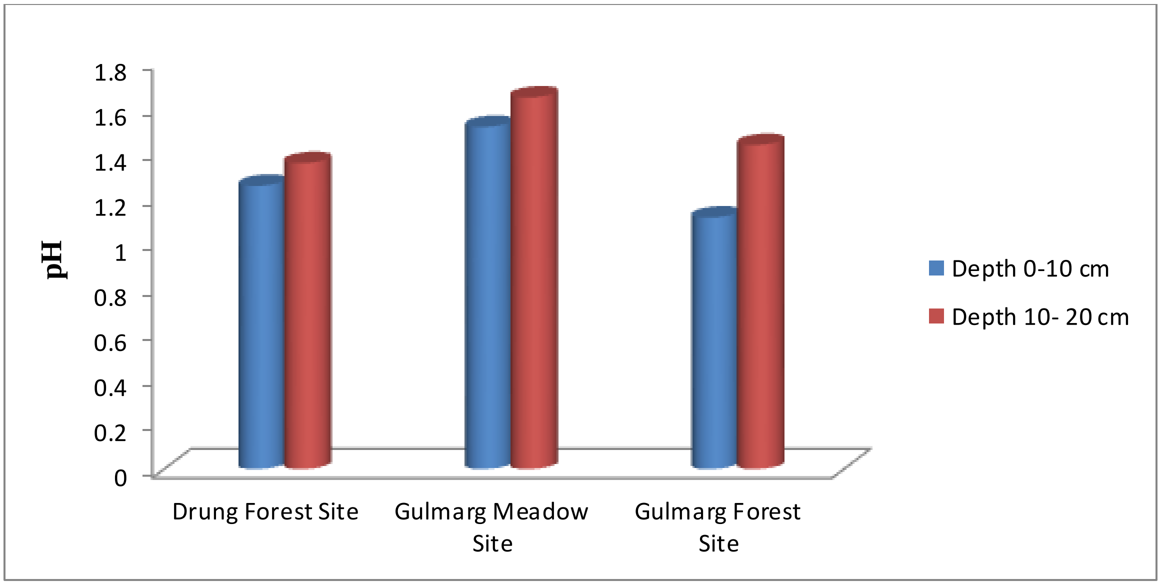

Fig. 2: Soil pHfrom two depths under temperate coniferous forests in Northern region of Kashmir Himalaya.

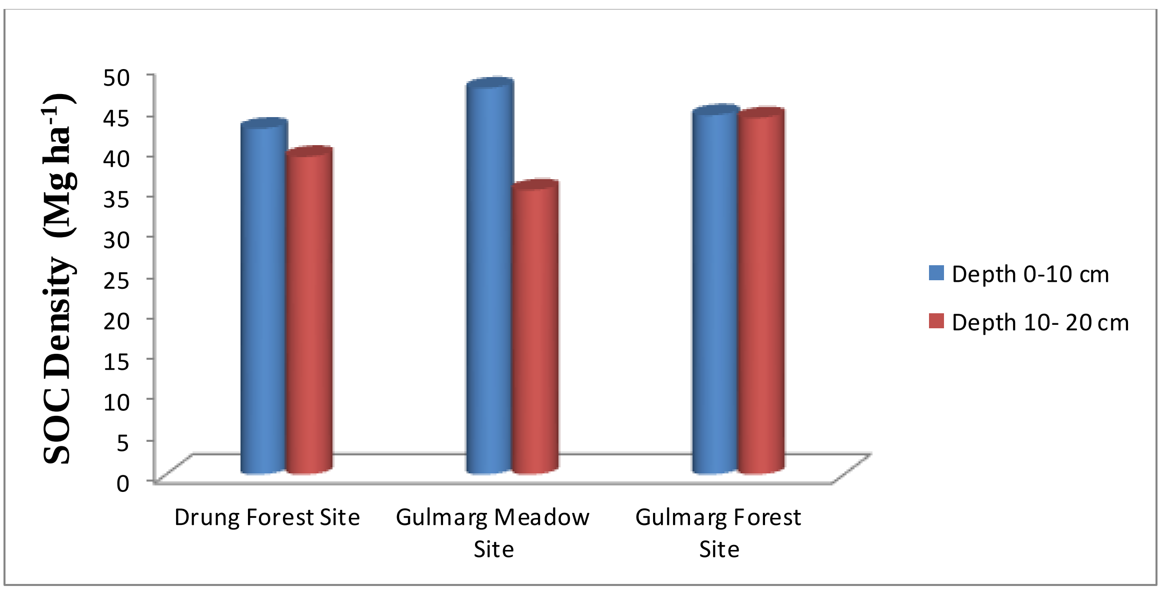

Fig. 3: Soil organic carbon densityfrom two depths under temperate coniferous forests in Northern region of Kashmir Himalaya.

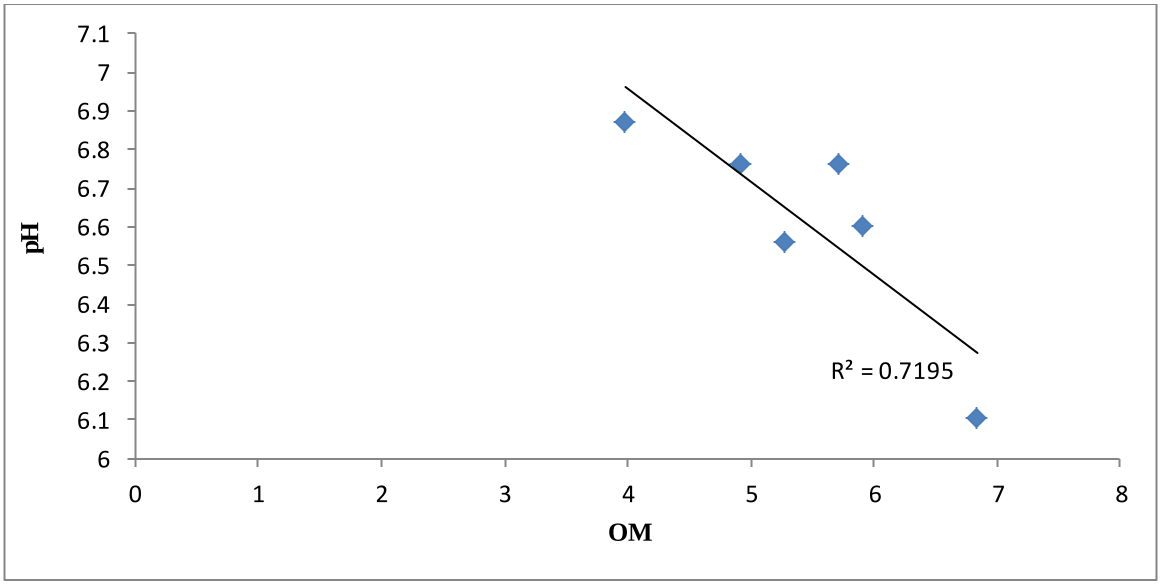

Fig. 4: Correlation between pH and organic matter of soils collected from temperate coniferous forests in Northern region of Kashmir Himalaya.

Moisture content

The moisture content varied significantly ($p < 0.01$)at various study sites with lowest for Gulmarg meadow site (16.39±1.89) and highest for Gulmarg forest site (31.03±4.79) as given in Table 1.The high moisture content can be related to the high forest density. This is due to the fact that both the forest and litter covers have conserving effect on soil moisture. The shady conditions that prevail in the forest floor due to canopy cover and overlying litter covers slows down evaporation and transpiration and thus results in the less loss of moisture (Palviainen et al.,2004). Moisture content in the present study was observed to be in conformity with other studies. Moisture content value of 14.2±1.9% for dense forest site and 16.3±1.1% for deforested site were reported for soils of coniferous forests of Tangmarg, J & K (Jehangir et al., 2012).

Bulk density

Bulk density values differed across all the study sites with lowest1.11±0.26 for Gulmarg forest site and highest1.42±0.34for Gulmarg meadow site. Higher values of bulk density in Gulmarg Meadow site may be attributed to reduction in organic matter decomposition due to increase in temperature and humidity following deforestation and cultivation (Haji Abbasi, 1997). Lower values of bulk density may be due to presence of high organic matter content at

Drung forest site and Gulmarg forest site because organic matter had a significant effect on the bulk density of soils (Handayani et al, 2012). Within the two depths, bulk density increased with the increase in depth, which may be attributed to the corresponding decrease in organic matter with depth and mixing with mineral material in the profile (Schulp, 2008). Bulk density in the present study was observed to be in conformity with other studies on carbon estimation. Bulk density of 1.01±0.08 g cm^{-3}were reported for soils of temperate coniferous forests in southern region of Kashmir Himalaya (Wani et al., 2013) and 1.04±0.02 g $cm^{-3}$for dense forest site and 1.14±0.02 g cm^{-3} for deforested site in coniferous forests of Tangmarg, J & K (Jehangir et al., 2012).

Soil organic carbon percent (SOC %)

Soil organic carbon, being the largest terrestrial carbon pool, plays a very important role in the carbon balance of global terrestrial ecosystem (Chhabra and Dadhwal, 2005). In the forest ecosystems, the balance between the litter input and the soil heterotrophic respiration determines soil carbon (Lu and Cheng, 2008). Moreover, in case of extensive grazing, animal excretion also leads to the entry of carbon into the SOC pool (Bol et al., 2004). The Soil organic carbon values varied significantly ($p < 0.05$) from 2.31±0.96 %for Gulmarg meadow site and 3.97±0.26 for Gulmarg forest site (Fig. 2). The present values are well within the range as reported for other temperate forests in the western Himalayas (Raina et al., 2001). Higher carbon content may be due to higher plant density resulting in higher amount of litter addition. Within the two depths, the SOC decreased with the increase in depth, which may be attributed to accumulation of decomposed forest litter and dead and decayed logs over the floor. Soil organic carbon values of (1.72±0.284%) were reported for soils of temperate coniferous forests in southern region of Kashmir Himalaya (wani et al; 2013), which is in harmony with present study.

Soil organic matter

Soil organic matter is of great significance as it acts as a store house of plant nutrients besides having a profoundal impact on soil physico- chemical properties. The soil organic matter of Drung forest, Gulmarg meadow and Gulmarg forest varied significantly ($p < 0.05$) from 3.98±1.65 to 6.84±0.45 % (Table 1). Within the two depths, OM decreased with depth depicting that it was not only the location/site which significantly affected the level of OM, but soil depth also had a significant effect on OM distribution. Gupta and Singh (1990) have also reported higher and different organic matter contents in the soils where better tree density and canopy coverage were maintained. The observed decrease in soil organic matter for Gulmarg meadow site can be attributed to increased organic matter oxidation and decreased quantity of plant residues (Post and Kwon, 2000). The highest soil OC content for Gulmarg forest site and Drung forest site may be attributed to addition of fresh conifer litter from tree canopy which may have resulted in slow decomposition and thus high accumulation of OM at these sites. Soil organic matter in the present study was observed to be in conformity with other studies. Soil organic matter of 5.26 ± 1.01 % and 7.42 ± 1.45 % were reported for soils of dense forest site and deforested site in coniferous forests of Tangmarg, J & K (Jehangir et al., 2012).

SOC AND SOC CO_2 Mitigation density

The forest soil carbon stocks were calculated by multiplying the soil carbon concentration by the measured soil bulk density of each forest site (Brown, 2004). The Soil organic carbon stock values varied from 34.82±14.20 Mg ha^{-1}to47.30±10.51 Mg $ha^{-1}$for three study sites (Table 2). Within the two depths, the SOC decreased with the increase in depth. Variation in total SOC stock is attributed to SOC concentration and spatial variation of soil bulk density (Li et al., 2010). Coniferous litter contains acidic tissues of various tree species, which slows down the rate of decomposition leading to more SOC accumulation in the forest floor through microbial inhibition as suggested by Berg (2000). 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 (Thuille, 2006). In addition, conifers have shallower rooting systems and tend to accumulate more organic carbon in the forest floor (Jindal et al, 2007) and with the increase in depth soil microbes become active. These could be the reasons for the variation of SOC among the forest types as well as the distribution in the soil profile in temperate forests of the Kashmir Himalaya. SOC density values of 39.74 ± 5.63 Mg ha^{-1} were reported for soils of temperate coniferous forests in southern region of Kashmir Himalaya (Wani et al., 2013), which is in harmony with present study. Another study conducted in temperate forests of Western Himalaya of J & K, India reported a mean SOC density value of 50.37 Mg C ha^{-1} to 55.38 Mg C ha^{-1} in 0-30 cm (Dar and Sundarapandian, 2013). SOC stock values obtained in the present study is well within the range of montane temperate forests of India (Chhabra and Dadhwal, 2003).The SOC stock obtained in the present study was lower than the SOC density of 480t ha^{-1} reported in coniferous plantation soils in Northern Taiwan (Tsai et al., 2009) and 62.7-88.7 Mg C ha^{-1}reported in temperate mixed old growth forests of China (Zhu et al., 2010). Lower range of SOC stock recorded in the present study may be due to higher altitude and its related environmental variables as discussed above.

SOC Mitigation density is calculated by multiplying a factor of 3.67 (carbon equivalent of CO_2) to soil organic carbon (SOC) density. CO_2 mitigation density values estimated on the basis of SOC density for different strata (Table 2).The SOC Mitigation density of Drung forest Site, Gulmarg meadow Site and Gulmarg forest Site varied s from 127.8±51.81 Mg ha^{-1} to 173.0±38.57 Mg ha^{-1}.SOC Mitigation density values of 70.16-210.72 Mg ha^{-1} were reported for soils of temperate coniferous forests in southern region of Kashmir Himalaya (Wani et al., 2013), which is in harmony with present study. Significant difference ($p < 0.001$) occurred between all the estimated values of SOC and SOC CO_2 mitigation density.

Conclusion

Soil properties determined for different study sites showed that with few exceptions, values were higher in the increasing order Gulmarg meadow, Drung forest and Gulmarg forest. The increase in the observed soil properties is due to the presence of permanent plant cover resulting in the input of bulk organic substrate. A positive correlation of OM with pH indicates that organic matter is an important indicator of soil quality. The results of this study indicate that the soil of Gulmarg forest of Kashmir Himalaya has high carbon stock capacity and soil organic carbon density is influenced by physico chemical properties of soil. Variation in soil organic carbon density acts as an indicator of site quality. The storage of higher carbon in forest soil emphasizes the importance of maintaining or managing forests as such areas can be regarded as major sinks of mitigating atmospheric carbon dioxide. It is high time to confer that emphasis should also be given to soil in addition to trees to sequester more carbon from the atmosphere and to ascertain forests a more effective sink of carbon. The future prospects of this study will help to fill the knowledge gap of carbon stocks of temperate coniferous forests and the data obtained are increasing the total pool of data values that can be used as input parameters in and for validating, simulation models both for local use and for extrapolation of other areas with similar conditions.

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