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Carbon Management Index and Soil Organic Carbon Pools of Different Landuse in Uttarakhand, Western Himalaya

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Abstract

Himalayan soils are young, unstable and prone to erosion due to its terrain, climate responsive conditions and human activities. Thus, a research was conducted to assess the dynamics of total organic carbon, particulate organic carbon, labile and non-labile carbon, lability index and carbon management index among three distinct landuse at various soil depth in north himalayan region. Mixed forest have considerably more total organic carbon (43.0 g/kg), particulate organic carbon (5.45 g/kg) followed by agricultural total organic carbon (29.58 g/kg), particulate organic carbon (3.51 g/kg) and tea garden total organic carbon (21.96 g/kg), particulate organic carbon (2.42 g/kg). There is a greater accumulation of all the indices and carbon pools at the surface layer in all landuse system. Mixed forest have higher lability index (0.77) and carbon management index (67.76) value indicating better soil health and quality. Therefore mixed forest is considered as the best landuse system in mitigating climate change through carbon storage. This study provides key details for conservation framing and reducing land deterioration in mountainous regions.

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Introduction

The net global carbon dioxide (CO_2) emissions significantly increased to 43.1 billion tonnes by 31.10 from 2010 to 2019. This increased CO_2 concentration in the atmosphere exacerbates climate change[1] ultimately causing a major ecological concern in the form of land deterioration. Agriculture contributes a massive 24% of total world CO_2 emissions due to intense farming, forestry, land-use changes and poor farming management.[2] Therefore, it is important to establish strategies for minimizing carbon output and storing it in the environment. Soil organic carbon proves beneficial in determining soil quality assessment.[3] Soil carbon dynamics is essential as it regulates carbon cycle, thus considered as largest sink of organic carbon in the terrestrial ecosystem. Soil profile in the top 1m stored nearly 1200 to 1600 Pg global SOC, out of which Indian soil contains

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approximately 9 Pg C, with 33% of total SOC in the Himalayan region.[4] Although, SOC changes significantly and depends on soil characteristics, seasonality, and topography.

Due to modification in vegetation cover and coping strategies, landuse/land cover type has a tremendous repercussion on carbon fluxes via the input and output rate of soil biological materials.[5] Organic carbon is a continuum, thus categorized into different functional pools: Labile (active) and Non-labile (passive) pool, passive pool is sensitive due to its high turnover rate.[6] However, non-labile pool is more persistent and forms organic compounds.[7] Consequently, labile SOC is considered better for evaluating landuse changes, whereas non-labile SOC contributes to total carbon stocks.[8] Cooler climatic areas have more organic as well as labile carbon because of slower mineralization rate. However, elevated soil temperatures and more soil erosion problem lowers the organic carbon level in hot and semi-moderate mountain ranges of India in contrary with moderate soils around the world.[9] Furthermore, optimum management strategies for balancing SOC level requires to validate and put into practice, specifically in regions having naturally poor soil fertility.[10]

Knowledge about SOC and CMI of varied landuse systems in hilly areas is essential for conserving productivity and reducing environmental impacts. To date, there is still a lack of study from north western himalayan region that are important in terms of carbon storage and also maintains soil-plant-atmosphere equilibrium. Thus, this study investigate SOC dynamics and CMI at the ecosystem level and also check how various indices fluctuates depth wise among varied landuse pattern.

Methodology

Features of the Study Area

Three distinct and contrasting landuse were identified from Champawat, Uttarakhand, India. Champawat comprises of sub–temperate climate and lies between 29°20'09.97" N and 80°05'27.70" E at a height of roughly 1615 meters above average sea level. All the site characteristics were elucidated in Table 1.

Table 1: Soil attributes of varied landuse

Landuse type	Location	Soil pH range	Soil textural class	Description	Management practices
Mixed forest	Laluwapani, 29°20'13.11"N and 80°05'20. 88"E.	5.2-5.5	Fine loamy soil	Natural vegetation dominated by Oak and Pine tree species.	Anthropogenic disturbances for the purpose of collecting fuel wood and other non-timber forest products.
Agricultural land	Madli, 29° 20'40.64"N and 80°06'16. 19"E.	7.2-7.8	Coarse and fine loamy soil	Field with organic manures growing wheat, maize, potatoes and cowpea.	Weeding and harvesting of above ground biomass regularly.
Tea garden	Dudh pokhara, 29°18'36.66"N and 80°08'04. 15"E.	6.2-6.5	Fine loamy soil	Field under tea plantation.	Weeding and periodic harvesting of above ground biomass.

Soil Sampling and Analysis

5 independent samples (30 cm ×30 cm × 30 cm) were drawn to collect soil samples from various soil strata 0–15 and 15–30 cm during March – September. Different plant detritus and stones were separated manually. The fractions of soil were homogenized, crushed, sieved and kept in air tight bags at an ambient temperature for further analysis.

Soil Organic Carbon Fractions

Both the carbon fractions were analyzed via wet oxidation diffusion method[11] and labile carbon was also analysed.[12]

Carbon management index (CMI)

All-important indices were calculated using formula.[13] Furthermore, any changes occurring in carbon fraction influences CMI and CPI. The index is calculated as described:

Carbon Management Index (CMI) = CPI ×LI ×100

Carbon Pool Index (CPI) = Total Carbon of soil sample (mg/g) / Total Carbon of reference soil (mg/g)

Lability Index (LI) = Lability of Carbon in soil sample / Lability of Carbon in reference soil

Lability of C (L) = Carbon fraction oxidized by $KMnO_4$ / Carbon remaining unoxidized by $KMnO_4$

Statistical Analysis

Correlation coefficient (Pearson's) method was applied between various carbon fraction, LI and CMI. Results of different landuse including soil strata on SOC, LI along with CMI was compared by ANOVA. Microsoft Excel and SPSS window version 22 were used.

Results

Mixed forest recorded the highest TOC in both surface and sub-surface layer which was markedly distinct ($P < 0.05$) in comparison to all other, apparently due to significant supply of leaf litter and root biomass from the native vegetation. However, tea garden recorded the lowest because of frequent soil disturbance and is presented in Fig.1 and Table 2. All landuse system exhibit higher POC value at 0-15 cm depth, indeed mixed forest recorded the highest value (Table 2 & Fig. 2). Although, least POC was observed in tea garden because of constant soil utilization, thus diminishing stability of organic matter. Labile (LC) and non-labile carbon (NLC) proportion witnessed a significant decrease with increasing depth in different systems. Labile pools are easily altered by various management practices and significant value of labile carbon in mixed forest occurs due to long term supply of readily decomposable plant debris all through the year.

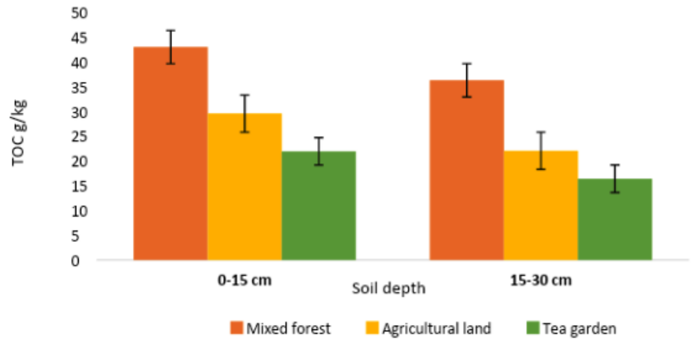

Fig. 1. Total organic carbon (TOC) under different land use type.

All the indices helped to evaluate the importance and amount of soil. Overall, a little difference in lability index was reported under mixed forest at 2 distinct soil strata (Table 2 & Fig. 3). Mixed forest showed maximum carbon pool index (0.88) followed by agricultural (0.59) then tea garden (0.47) in 0-15 cm depth. Highest CMI value (67.76) of mixed forest at surface layer indicates that the forest ecosystem of western Himalaya are sustainable to maintain soil organic carbon (Fig. 4). Incorporation of external carbon inputs to agricultural soil, a significant CMI value was also recorded at both the soil depth i.e. 41.89 and 31.36 respectively. The least CMI value was observed in tea garden (21.62 and 15.75) at successive soil depths probably because of erosive problems and inadequate management practice. Table 3 represents significant positive correlation among distinct carbon components studied.

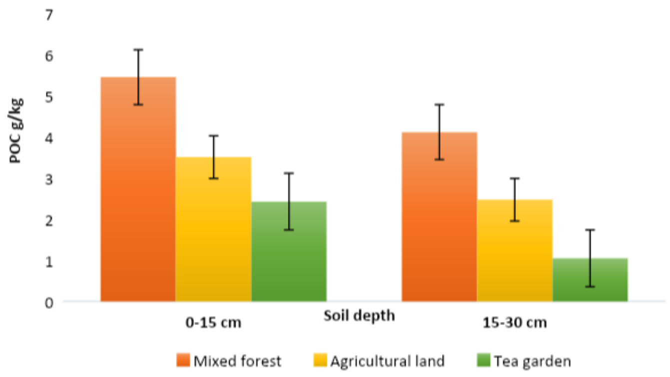

Fig. 2: Particulate organic carbon (POC) under varied land use type

Table 2: Values of different carbon fractions of 3 landuse system at varying soil depth.

Landuse type	TOC	POC	LC	NLC	LI	CPI	CMI
			DEPTH (0-15 Cm)				
Mixed Forest	43.0a	5.45a	3.12a	13.5b	0.77a	0.88a	67.76a
Agricultural Land	29.58b	3.51b	2.60b	14.24a	0.71b	0.59b	41.89b
Tea Garden	21.96c	2.42c	1.42c	11.81c	0.46c	0.47c	21.62c
			DEPTH (15-30 Cm)				
Mixed Forest	36.3a	4.12a	2.93a	13.1a	0.76a	0.77a	58.52a
Agricultural Land	22.08b	2.47b	1.95b	11.7b	0.64b	0.49b	31.36b
Tea Garden	16.42c	1.05c	1.01c	10.1a	0.45c	0.35c	15.75c

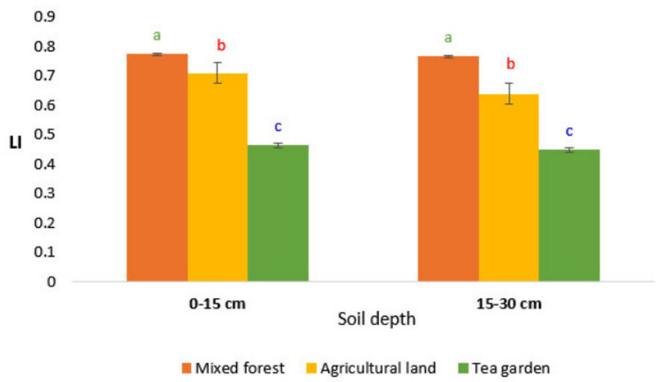

Fig. 3: Lability Index of different land use type.

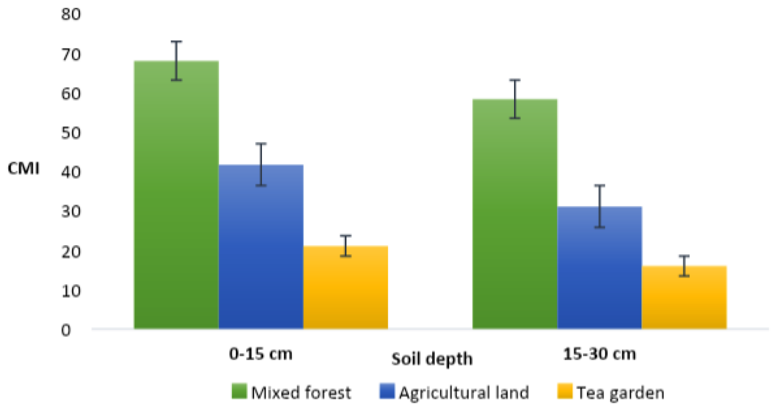

Fig. 4: Carbon Management Index of different landuse type.

Table 3: Correlation coefficient (Pearson's) among various soil organic carbon fractions at various soil depth.

	TOC	POC	LC	NLC	LI	CMI
DEPTH (0-15 Cm)						
TOC	1					
POC	0.99**	1				
LC	0.93**	0.92**	1			
NLC	0.55	0.54	0.82**	1		
LI	0.89**	0.89**	0.99**	0.87**	1	
CMI	0.99**	0.99**	0.95**	0.63	0.93**	1
DEPTH (15-30 Cm)						
TOC	1					
POC	0.96**	1				
LC	0.97**	0.99**	1			
NLC	0.96**	0.99**	0.99**	1		
LI	0.88**	0.97**	0.96**	0.98**	1	
CMI	0.99**	0.97**	0.98**	0.97**	0.91**	
	1					

** Correlation is significant at 0.01 level

Discussion

Native vegetation shows maximum TOC and tends to decrease depth wise.[14] Also, several factors significantly affects the carbon dynamics of any system.[15] This study documented higher TOC in mixed forest that further effectively enhances the soil carbon storage. Our findings go in line with the study that higher density of roots of forest ecosystem leads to greater buildup of soil C.[16] Although, reduced TOC occurred due to higher disturbance and erosive problems.[17] Our data reported high POC value under mixed forest. Similar results were found in central Himalayan region.[18] On the other hand, various landuse recorded low POC because it does not form organocomplexes with minerals[19] Active or labile carbon responds rapidly to any environmental changes thus considered as early or sensitive indicator of soil quality.[20] Indeed soil macro and mesofaunal activities stimulated labile carbon and furthermore releases CO_2 on rapid oxidation.[21] Data confirmed high labile carbon under mixed forest in the surface layer. These findings affirms that higher percentage of labile carbon makes it easier to obtain mineralizable and quickly hydrolysable carbon.[22,23]

Higher CMI and LI value reflects rehabilitation while lower value indicates degradation and depletion of C compounds.[24] Moreover, landuse with higher CMI proves effective for C sequestration and our study reported higher CMI in mixed forest. Furthermore, higher CMI value under bamboo plantation was also reported.[25] Also, lowest CMI value in soil stratum (0-20 cm) indicates that intensive soil management practices results in soil quality decline. CMI is a sensitive and helpful index for evaluating soil organic carbon dynamics over varied landuse.[26]

Conclusion

Study concludes that mixed forest, as compared to other landuse system accelerates the SOC fraction and stores maximum carbon component in the pedosphere. CMI along with all other carbon components was documented highest in mixed forest soil, thus considered the best management strategy for maintaining soil health and ensuring long-term fertility in the western Himalaya. Additionally, sustaining and re - establishing natural (mixed forest) ecosystem will strengthen soil condition and durability. Furthermore, CMI values of any landuse helps in prediction of soil erosion phenomenon, which is informative and useful for sloping land planning and potentially used to check runoff and land degradation challenges in hilly ecosystems. The outcomes of the present study provides a new dimension to landuse and conservation planning, agricultural area diversification, periodic replenishment of soil nutrients in the cultivated land and appropriate soil management strategies that could be useful for government and policy makers for sustainable use of Himalayan ecosystems.

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Conflict of Interest

The authors declares no conflict of interest.

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