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CARBON SEQUESTRATION IN THE SOILS UNDER CONIFEROUS AND BROAD LEAVED FORESTS IN UTTARAKHAND STATE OF INDIA

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Abstract: Recently, the greenhouse effect has been of great concern, and has led to scientists for quantitative estimation of SOC stock. Soil organic carbon stock studies in Indian Himalayan forests are very scanty. Therefore, this study was under taken to estimate the SOC stock in coniferous and well as in broad leaved forests of Uttarakhand. Soil sampling was done in entire Uttarakhand under all coniferous and broad leaved forests. All the thirteen districts were covered and soil samples collected from available forests covers within the district. Coniferous forests have higher SOC stock individually as compared to broad leaved forests as far as per ha basis is concern. On an average, organic carbon stock in the soils under coniferous forests was 79.21 t/ha while under broad leaved forests it was 71.06 t/ha. Over all, coniferous forests had 40.60 million tons of SOC stock while broad leaved forests contained 91.47 million tons of SOC stock in the state. Broad leaved forests have 125.35% higher total SOC stock as compared to conifers forests. It was due to the difference in the area occupied by both types of the forests in the state. Broad leaved forests occupied 13,10,503.32 ha area while conifers forests have only 5,24,180.86 ha area in entire Uttarakhand. Results of one - way ANOVA indicates that SOC stock between conifers and broad leaved forest were significantly different at 0.05 level (Variance ratio, F= 25.601; $p < 0.05$).
Keywords: Coniferous forest, Broad leaved forest, Carbon sequestration, Soil organic carbon, Mitigation potential.
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INTRODUCTION

Bulk of the carbon enters the ecosystem through the process of photosynthesis in the leaves. After litter fall, the detritus is decomposed and forms soil organic carbon by microbial process. The soil organic carbon is thus stored for a long time in the form of humic substances. This sequestered carbon finally act as Sinks in the forest land (Ramchandran *et al*., 2007). Tree growth serves as an important means to capture and store atmospheric carbon dioxide in vegetation, soils and biomass products (Makundi and Sathaye, 2004). Forest ecosystem contributes a lot of organic material to the soil in the form of leaves, twigs, branches, reproductive parts, fruits etc. and this contribution of plants to the soils varies in composition and differs from species to species. As much as two-thirds of the terrestrial carbon in forest ecosystems is contained in soils (Dixon *et al*., 1994). Strategies to increase the soil carbon stock include soil restoration and woodland regeneration, no-till farming, cover crops, nutrient management, manuring and sludge application, improved grazing, water conservation and harvesting, efficient irrigation, agroforestry practices, and growing energy crops on spare lands (Lal, 2004).

The Intergovernmental Panel on Climate Change (IPCC) identified creation and strengthening of carbon sinks in the soil as a clear option for increasing removal of CO_2 from the atmosphere and also identified SOC stock as one of five major carbon stocks for LULUCF sector. Knowledge of Soil Organic Carbon especially related to its amount and quality is essential to sustain the quality and productivity of soils. Study of organic carbon status in Indian soils was conducted by Jenny and Raychaudhuri (1960) for the first time by collected 500 soil samples from different cultivated fields and forests from the areas having different rainfall and temperature patterns. Gupta and Rao (1994) attempted to estimate organic carbon stock which was based on a hypothesis of enhancement of organic carbon level on certain unproductive soils. Recently, the greenhouse effect has been of great concern, and has led to scientists for quantitative estimation of SOC. Global warming and its effect on soils in terms of SOC management have led to several quantitative estimates for global Carbon content in the soils (Eswaran *et al*., 1993; Batjes, 1996; Velayutham *et al.,* 2000; Buringh, 1984; Kimble *et al*., 1990). Although, so far the soil organic carbon stock studies in Indian Himalayan forests are very scanty. Therefore, this study was under taken to estimate the SOC stock in coniferous and well as in broad leaved forests of Uttarakhand.

EXPERIMENTAL

This study was conducted in Uttarakhand which forms part of the western Himalaya. It is located between 28^{o} 43' – 31^{o} 27' N latitudes and 77^{o} 34' – 81^{o} 02' E longitudes. Important rivers like the Ganga and Yamuna rise from this state. Total forest area under the forest department is 24,414.80 km^2. As the input of organic matter is largely from the aboveground litter, forest soil organic matter tends to concentrate in the upper soil horizons, with roughly half of the soil organic carbon of the top 100 cm of mineral soil being held in the upper 30 cm layer. The carbon held in the upper profile is often chemically the most decomposable, and the most directly exposed to natural and anthropogenic disturbances (IPCC, 2003). This layer is readily depleted by anthropogenic disturbances such as land use changes and cultivation. Therefore, soil organic carbon stock was estimated up to the depth of 30 cm for this study. Topsoil is very sensitive to human disturbance under the changing climate. Estimates of topsoil soil organic carbon (SOC) stock may be crucial for understanding soil carbon dynamics under human land uses and soil potential of mitigating the increasing atmospheric CO_2 by soil C sequestration (Song *et al*., 2005). Soil sampling was done in entire Uttarakhand under all coniferous forests (spreaded on an area of 5,24,180.86 ha) and broad leaved forest (spreaded on an area of 13,10,503.32 ha). All the districts were covered and soil samples collected from available forests covers within each district. A total of 3022 soil samples were collected from coniferous and broad leaved forests for this study. These samples were collected for estimation of soil organic carbon, bulk density and coarse fragments. Statistically, two stage sampling was done in which first stage unit *i.e.* Forest Ranges were selected randomly (minimum three Forest Ranges or 50 % of total Forest Ranges in each Forest Division, whichever is higher, were selected randomly) and second stage unit *i.e.* soils, for this sites were selected systematically and sampling points selected randomly. In each Forest Range, sampling sites were selected in all coniferous forest covers *viz*. Spruce / fir (*Abies pindrow* and *Picea smithiana*), Deodar (*Cedrus deodara*), Kail (*Pinus wallichiana)* and Chir (*Pinus roxburghii)* and broad leaved *viz*. Quercus (*Quercus leucotrichophora*), Sal (*Shorea robusta)* and miscellaneous species, available there in. SOC stock was estimated to compute the total SOC stock in these forests in Uttarakhand on an area of 18,34,684.18 ha under these both types of forest. Details of the samples collected are given in Table 1. Latitude, Longitude and altitude of each sampling site were recorded by GPS. Forest floor litter of an area of 0.5m x 0.5 m, at each sampling point was removed and a pit of 30 cm wide, 30 cm deep and 50 cm in length was dug out. Soil from 0 to 30 cm depth, from three sides of the pit, scraped with the help of Kurpee and this soil mixed thoroughly. Kept the soil in a polythene bag and tightly closed with thread with proper labelling. In the laboratory, samples were air dried and after drying the samples, grind it and sieve it through 100 mesh sieve (2 mm sieve). This sieved sample used for soil organic carbon estimation.

Table. 1 Details of the sites under Coniferous and Broadleaved forests of Uttarakhand

S.No.	Vegetation Cover	Altitude (m)	Area Covered (Districts)	No. of samples Collected
Coniferous Forests				
1.	Deodar	1226 - 2618	Tehri Garhwal, Uttarkashi, Chamoli, Dehara Dun, .Nainital Champawat, Almora,Pauri Garhwal, Bageshwer, Pithoragarh *(23 Forest Ranges of 15 Forest Divisions were covered to collect the soil samples)*	343
2.	Chir	802 - 2184	Nainital, Uttarkashi, Tehri Garhwal, Pauri Garhwal, Rudrapryag, Chamoli, Dehra Dun, Pithoragarh, Champawat, Almora, Bageshwer *(48 Forest Ranges of 24 Forest Divisions were covered to collect the soil samples)*	904
3.	Silver Fir and Spruce	2314 - 3135	Utterkashi, Chamoli, Rudrapryag, Tehri Garhwal, Dehra Dun *(5 Forest Ranges of 5 Forest Divisions were covered to collect the soil samples)*	63
4.	Kail	1783 - 2383	Tehri, Dehra Dun, Champawat, Pithoragarh *(6 Forest Ranges of 4 Forest Divisions were covered to collect the soil samples)*	49
Total Samples collected from Coniferous forests				**1359**
Broad Leaved Forests				
1.	Miscellaneous	261 - 2175	Dehra Dun, Haridwar, Nainital, Tehri Garhwal, Uttarkashi, Pauri Garhwal, Rudrapryag, Chamoli, Champawat, Almora, Pithoragarh, Bageshwer *(51 Forest Ranges of 24 Forest Divisions were covered to collect the soil samples)*	651
2.	Sal	213 - 1421	Dehra Dun, Nainital, Champawat, Haridwar, Tehri Garhwal, Pithoragarh, Pauri Garhwal, Almora *(30 Forest Ranges of 14 Forest Divisions were covered to collect the soil samples)*	434
3.	Quercus	1383 - 3050	Dehra Dun, Tehri Garhwal, Nainital, Uttarkashi, Chamoli, Champawat, Almora, Pauri Garhwal, Bageshwer, Rudrapryag, Pithoragarh *(30 Forest Ranges of 18 Forest Divisions were covered to collect the soil samples)*	578
Total samples collected from Broad leaved forests				**1663**

The diverse nature of soils introduces uncertainty into the estimation of soil organic carbon (SOC) storage. Laboratory analyses indicate carbon concentration in soils, but the soil layer thickness, bulk density, and percent of fragments >2 mm must be known in order to estimate SOC storage. Ideally, measurements of SOC concentration are performed on the same soil samples used to determine bulk density and percent of fragments >2 mm (Schwager and Mikhailova, 2002). Soil organic carbon (SOC) constitutes usually a small portion of soil, but they are one of the most important components of ecosystems. Bulk density value is necessary to convert organic carbon (OC) content per unit area (Sakin, 2012). Soil organic carbon was estimated by the standard Walkley and Black (1934) method. Bulk density of every site was estimated by standard core method (Wilde *et al*., 1964). All the methods used in this study are in accordance to Ravindranath and Ostwald (2008). Amount of coarse fragments were estimated in the sample collected from different forests and deducted from the soil weight to get an accurate soil weight per ha basis for soil organic carbon stock estimation. The mitigation potential of the soils under different forest covers was estimated for the soils with respect to the species having minimum SOC stock by assuming 1 (Jha *et al*., 2001). The data for SOC stock was calculated by using the equation as suggested by IPCC Good Practice Guidance for LULUCF (IPCC, 2003).

Equation for SOC Calculation:

$$SOC = \sum_{Horizon=1}^{Horizon=n} SOC_{horizon} = \sum_{Horizon=1}^{Horizon=n} ([SOC] * \text{Bulk density} * \text{depth} * (1 - C\ frag) * 10)_{horizon}$$

Where SOC = Representative soil organic carbon content for the forest type and soil of interest, in tonnes C/ha.

$SOC_{horizon}$ = soil organic carbon content for a constituent soil horizon, in tonnes C/ha

[SOC] = concentration of SOC in a given soil mass obtained from analysis, as g C /kg soil

Bulk density = soil mass per sample unit volume in tones soil/m^3 (equivalent to mg/m^3)

Depth = horizon depth or thickness of soil layer, m

C Fragments = % volume of coarse fragments / 100, dimensionless

RESULT AND DISCUSSION

Coniferous forests have higher SOC stock individually as compared to broad leaved forests as far as per ha basis is concern. Organic carbon stock in the soils under coniferous forests was 79.21 t/ha while under broad leaved forests it was 71.06 t/ha. Over all coniferous forests occupied 5,24,180.86 ha area in Uttarakhand and hence, had 40.60 million tons of SOC stock (Table 2) while broad leaved forests had 13,10,503.32 ha area and contained 91.47 million tons of total SOC stock.

Table. 2 SOC Stock under Coniferous and Broad leaved Forests in Uttarakhand (up to 30 cm)

S. No	Vegetation Cover	SOC Stock (t/ha)	Area (ha)	SOC Stock (m tons)	SE	M P	Confidence Interval (t/ha) (α= 0.05)	
							Lower bound	Upper bound
Under Coniferous Forests								
1.	Silver fir and Spruce	140.76[a] ± 36.3880	92464.84	13.02	5.42	2.30	129.82	151.68
2.	Deodar	118.09[b] ± 36.6573	18783.35	2.22	2.36	1.93	113.43	122.74
3.	Kail	67.66[c] ± 27.4467	18548.83	1.26	4.63	1.11	58.23	77.08
4.	Chir	61.10[c] ± 25.4641	394383.84	24.10	1.00	1.00	59.14	63.06
	Average	79.21 ± 40.3722	-	-	1.29	-	76.66	81.75
	Total		**5,24,180.86**	**40.60**				
Under Broad Leaved Forests								
1.	Quercus	96.44[a] ± 35.8570	383088.12	36.95	1.75	1.65	93.00	99.88
2.	Miscellaneous	58.95[b] ± 29.9835	614361.00	36.22	1.27	1.01	56.44	61.44
3.	Sal	58.45[b] ± 26.1011	313054.20	18.30	1.48	1.01	55.53	61.36
Average		71.06 ±35.8253	-	-	0.99	-	69.10	73.02
Total			**13,10,503.32**	**91.47**				

Same alphabets represent statistically at par group
± Standard Deviation; SE - Standard Error; M P - Mitigation Potential; m tones – Million tons

Among coniferous, maximum SOC stock was under sliver fir and spruce forests (140.76 t/ha) followed by deodar (118.09 t/ha), kail (67.66 t/ha) and the least SOC stock was under chir forests (61.10 t/ha). Mitigation potential was worked out with reference to chir as it had the lowest SOC stock and observed that it varied from 1.00 to 2.30 which indicate that soil supported by silver fir and spruce can sequester more than double SOC as compared to chir. Standard error varied from 1.00 to 5.42 between coniferous forests and 1.27 to 1.75

between broad leaved forests which indicates lesser variations in the data. Higher SOC stock under sliver fir and spruce and deodar forests may be because of high accumulation of litter which is a common phenomenon in these forests. SOC associated with the soil of high altitudes is higher than at lower altitudes. This may be low temperature conditions coupled with good hydrated environment which support fir- spruce and oak at higher altitude. Soil organic carbon is the most important part of the soil organic fractions which is functional in almost all the biochemical activities in these forests. Increasing rainfall which favours luxurious plant growth and low temperature which slows down the rate of organic matter decomposition are the factors responsible for accumulation of higher amounts of organic matter at higher altitudes reported by Minhas and Bora (1982). Soil carbon density generally increases with increasing precipitation, and there is an increase in soil carbon with decreasing temperature for any particular level of precipitation (Post *et al.,* 1982). Temperate climate favour organic carbon accumulation in soils (Arrouays *et al.,* 2001; Jones *et al.,* 2005) and a major concern for such regions is the change that may take place in the large SOC stocks as temperatures rise. Negi and Gupta (2010) studied the soil organic stock in Giri catchment (HP) and reported that higher organic carbon stock (93.47 t/ha) was in the soils under Kail + Silver fir and Spruce forests as compared to soil organic carbon store under miscellaneous forests (57.66 t/ha) and under Sal forests (47.29 t/ha). Among the broad leaved forests, maximum organic carbon stock in soils was under quercus forests (94.44 t/ha) followed by miscellaneous (58.95 t/ha) and the least was under sal (58.45 t/ha). Conifer forests have 11.47% higher soil organic carbon stock per ha basis as compared to broad leaved forests. Hart and Perry (1999) reported that high-elevation old-growth forest soils had higher carbon and nitrogen storage than their low-elevation analogues primarily because low temperatures limit net carbon and nitrogen mineralization rates at higher elevation. The soil carbon sequestration is a truly win-win strategy. It restores degraded soils, enhances biomass production, purifies surface and ground waters, and reduces the rate of enrichment of atmospheric CO_2 by offsetting emissions due to fossil fuel (Lal, 2004).

When total SOC stock was worked out in Uttarakhand state, broad leaved forests have higher soil organic carbon stock *i.e.* 91.47 million tons as compared to conifers forests which had 40.60 million tons. Broad leaved forests have 125.35% higher SOC stock as compared to coniferous forests. It was due to the difference in the area occupied by both types of the forests in the state. Broad leaved forests occupied 13,10,503.32 ha area while conifers forests have smaller area, only 5,24,180.86 ha in entire Uttarakhand (Anon., 2010). Total contribution of SOC stock indicates that natural conifers have only 31% of total SOC stock while broad leaved forests have 69% share of total SOC stock (Figure 1) in Uttarakhand.

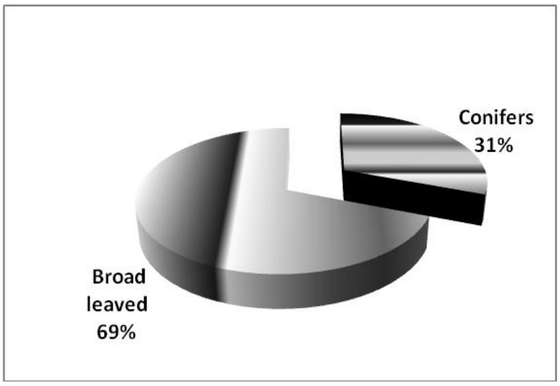
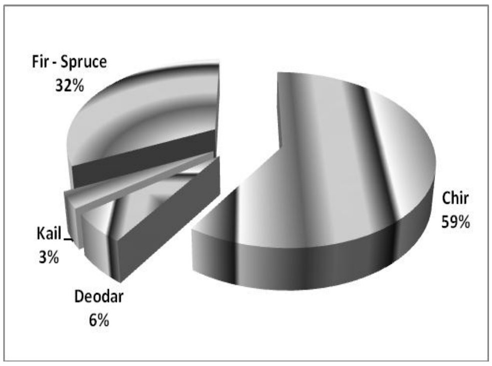
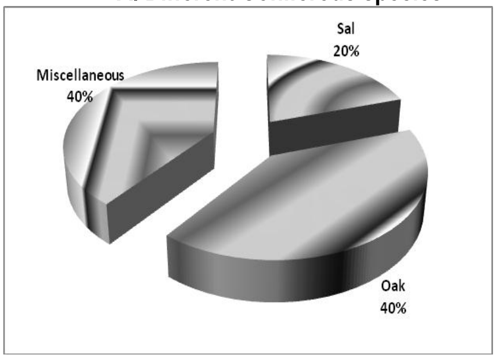


Figure 1. Contribution of SOC by Coniferous and Broad Leaved forests

Among conifers, maximum share was occupied by chir (59.37%), followed by silver fir and spruce (32.07%), deodar (5.47%) and the least share was occupied by kail (3.09%) (Figure 2A). As far as area under these conifers are concern, maximum area was covered by chir (3,94,383.84 ha) followed by silver fir and spruce *i.e.* 92,464.84 ha, deodar 18,783.35 ha while kail was having the least area (18,548.83 ha) in Uttarakhand (Anon, 2010). Among the broad leaved forests, maximum share of SOC stock was attained by oak forests (40.39%) followed by miscellaneous forests (39.60%) and the least was occupied by sal (20.01%) (Figure 2B). Area under miscellaneous forests was higher (6,14,361.00 ha) as compared to quercus forests (3,83,088.12 ha) but SOC stock under quercus forests was much higher (96.44 t/ha) in comparison to miscellaneous (58.95 t/ha), therefore, over all share of SOC stock of both the forests was similar. Sal forests have the least area as well as SOC stock among broad leaved forests; hence have the least share of SOC stock.



A. Different Coniferous species



B. Different Broad leaved species

Figure 2. Percent share of SOC occupied by different species

Results of one - way ANOVA indicates that SOC stock between conifers and broad leaved forest were significantly different at 0.05 level (Variance ratio, F= 25.601; p< 0.05). When organic carbon stock in the soils under individual species of broad leaved and conifers were tested, results of one way ANOVA indicated that it was significantly different at 0.05 level (Variance ratio, F=214.857; p<0.05). SOC stock under fir/spruce was significantly different from the SOC stock under quercus, miscellaneous and sal. SOC stock under deodar was also significantly different from the SOC stock under quercus, miscellaneous and sal. SOC stock under quercus was statistically significant different from the SOC stock under kail and chir (Table 3). Statistically, 95% confidence interval for mean of coniferous forests (actual mean, 79.21 t/ha) and broad leaved forests (actual mean, 71.06 t/ha) were very narrow *i.e.* 76.66 to 81.75 t/ha for coniferous forests and 69.10 to 73.02 t/ha for broad leaved forests, which justified the finding of this study. The soil carbon stocks increased mainly because litter fall from living trees increased while the other sources of soil carbon, *i.e.* the residues of harvests and natural disturbances, varied less. This litter fall was also the largest source of soil carbon accounting for 70-80% of the total. The soil carbon stocks in these forests could thus be most effectively controlled by forest management actions, such as the choices of harvest regimes or tree species, which especially affect the litter production of living trees (Liski, *et al.,* 2002).

Table 3. Statistically significant mean differences on the basis of CD (LSD)

S. No.	Vegetation	Mean Difference	p value
1.	Fir / Spruce vs Quercus	44.3112*	0.000
2.	Fir / Spruce vs Miscellaneous	81.8072*	0.000
3.	Fir / Spruce vs Sal	82.3036*	0.000
4.	Deodar vs Quercus	21.6462*	0.000
5.	Deodar vs Miscellaneous	59.1422*	0.000
6.	Deodar vs Sal	59.6386*	0.000
7.	Kail vs Quercus	28.7848*	0.000
8.	Chir vs Quercus	35.3397*	0.000

** Mean difference is significant at the 0.05 level*

CONCLUSION

Organic carbon stock in the soils under coniferous forests was higher (79.21 t/ha) as compared to broad leaved forests (71.06 t/ha). As the area under broad leaved was higher (13,10,503.32 ha) in Uttarakhand state in comparison to coniferous forest (5,24,180.86 ha), therefore, overall SOC stock was higher (91.47 million tons) under broad leaved forests as compared to coniferous forests (40.60

million tons). SOC stock between conifers and broad leaved forest was statistically significantly different. Total contribution of SOC stock indicates that natural conifers have 31% of total SOC stock while broad leaved forests have 69% share of total SOC stock in Uttarakhand under these two types of the forests.

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