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# SEQUESTERED ORGANIC CARBON POOL IN THE FOREST SOILS OF UTTARAKHAND STATE, INDIA

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**Abstract:** Forest soils are one of the major sinks of carbon as they normally contain higher organic carbon in comparison to the soils of agricultural lands, grasslands and plantation areas. A study was conducted in Uttarakhand state of India to estimate the SOC pool under different forest covers. Due to wide variations in climate, soil types, topography and altitude, the forest species vary from broad leaved to conifers and from deciduous to evergreen. SOC pool under *Abies pindrow & Picea smithiana* forests was the maximum (140.76 t $ha^{-1}$) followed by *Cedrus deodara* (118.09 t $ha^{-1}$), *Quercus leucotrichophora* (96.44 t $ha^{-1}$), *Pinus wallichiana* (67.66 t $ha^{-1}$), *Pinus roxburghii* (61.10 t $ha^{-1}$), Miscellaneous forests (58.95 t $ha^{-1}$) and the minimum SOC pool was under *Shorea robusta* forests (58.45 t $ha^{-1}$). SOC pool, under planted forests (plantation on the area under control of the State Forests department) was also estimated and data revealed that maximum SOC pool was under *Cypress cashmeriana* plantations (66.32 t $ha^{-1}$) followed by *Eucalyptus spp.* (42.73 t $ha^{-1}$), *Acacia catechu* (41.67 t $ha^{-1}$), *Tectona grandis* (40.71 t $ha^{-1}$) and *Dalbergia sissoo* plantations (32.96 t $ha^{-1}$). However, the SOC was minimum in the barren land (27.73 t $ha^{-1}$). Total SOC pool in 24,414.80 $km^2$ forest area of Uttarakhand state was 149.73 million tones. Out of this pool 132.05 million tons was in the natural forests, 15.01 million tons in unproductive barren lands and 2.67 million tons in the planted forests. The Garhwal zone contained maximum i.e. 65.43 mt (43.69 %) of the total SOC pool, followed by 47.13 m t (31.48 %) in the National Parks and Sanctuaries and 37.17 m t (24.83 %) in the Kumaon zone of the Uttarakhand state. Findings of this study on this important aspect of climate change will serve as benchmark for the future investigations to ascertain the changes in SOC pool over a period of time and to take mitigation measures if required.

**Keywords:** Soil Organic Carbon Pool; Natural Forests; Plantation Forests; Mitigation, Potential; Uttarakhand.

## Introduction

The scientific community has been aware of the role of soil in emission and sequestration of GHGs but an in-depth quantitative understanding of this complex process has only been developed in the past two decades. Soil studies related to this field increased

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after the International Conference on Soils and the Green House Effect held in Netherlands in 1989. Planners across the globe are attempting to formulate plans for reducing the level of atmospheric $CO_2$ either by reducing emissions or by taking $CO_2$ out from the atmosphere.

The soil represents the largest depository for fixing carbon within all ecosystems [1]. Forest soils are one of the major carbon sinks on earth, because of their higher organic matter content [2]. About 40% of the total SOC stock of the global soils resides in the forest ecosystem [3]. Soil carbon has much longer residence mean time than the carbon in the vegetation that the soil supports. Storage of organic carbon in this long residence time, pool is referred to as 'carbon sequestration'. The concern about increasing atmospheric $CO_2$ and its role in future global climate change has lead soil scientists to quantify soil organic carbon content (also referred as stocks or storage) [4]. Accurate quantification of soil organic carbon store is necessary for detection and prediction of changes in response to changing global climate**.**

The Himalayan zones, with dense forest vegetation, cover nearly 19% of India and contain 33% of SOC reserves of the country [5]. Uttarakhand state that forms part of the western Himalaya represents forest ecosystems ranging from tropical to alpine vegetation [6]. This study was conducted in Uttarakhand, to estimate SOC pool under different forests covers by extensive field data collection. The results of this study have provided comprehensive estimates of the SOC pool under different forests covers. Information generated from this study can be used as a benchmark for future studies to estimate the changes in SOC pool in these land uses in order to take up mitigating measures if necessary.

## Material and Methods

Uttarakhand state of India, which forms a part of the western Himalayas, was taken up as study area. It is located between 177 m and 7909 m altitude and is stretched 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 $km^2$. Soil sampling was carried out in the entire forest area of Uttarakhand state and a total of 3148 soil samples were collected for the estimation of soil organic carbon, bulk density and coarse fragments. Two-stage statistically sound sampling design was adopted in which first stage unit was forest ranges and the second was soil. Three forest ranges or 50 % of total forest ranges in each forest division, whichever was higher, were selected randomly. For second stage unit of soils, the sites were selected systematically and sampling points were selected

randomly. As per the land record (Uttarakhand Forest Statistics 2009–2010), forest land in Uttarakhand supports natural forests of Spruce / fir (*Abies pindrow & Picea smithiana*), Deodar (*Cedrus deodara*), Quercus (*Quercus leucotrichophora*), Kail (*Pinus wallichiana)*, Chir (*Pinus roxburghii)*, Sal (*Shorea robusta)* and Miscellaneous species. The plantation of *Cypress cashmeriana, Eucalyptus spp.*, *Acacia catechu, Tectona grandis* and *Dalbergia sissoo* were also found on forests land. Therefore, besides the natural forests, soil samples were also collected from the different sites under planted forests as well as barren lands and the total SOC pool was computed in Uttarakhand forest lands covering an area of 24,414.80 $km^2$.

Soil organic carbon was estimated by the standard Walkley & Black [7] method and the bulk density by standard core method [8]. All the methods used in this study are in accordance to Ravindranath and Ostwald [9]. 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 on hectare basis for SOC pool estimation. The data for SOC pool was calculated by using the equation as suggested by IPCC Good Practice Guidance for LULUCF [10].

The most prudent approach to study SOC, however, would be on a unit area basis for a specified depth interval which requires information on the spatial distribution of soil types, SOC and bulk density of soils. It would thus provide a better understanding of the terrestrial reservoir of SOC far beyond the general objectives of C sequestration in soils and the detrimental effects of global warming [11]. SOC is concentrated in the upper 12 inches of the soil. Thus it is readily depleted by anthropogenic (human-induced) disturbances such as land-use changes and cultivation [12, 13]. The soil organic carbon pool therefore, was estimated up to the depth of 30 cm in this study.

## Results and Discussion

### SOC Pool under Natural Forests

SOC pool under Fir & Spruce forests was maximum *i.e.* 140.76 t $ha^{-1}$ (CI 129.82 – 151.68) followed by Deodar forests 118.09 t $ha^{-1}$ (CI 113.43 – 122.74), Quercus forests 96.44 t $ha^{-1}$ (CI 93.00 – 99.88), Kail forests 67.66 t $ha^{-1}$ (CI 58.23 – 77.08), Chir forests 61.10 t $ha^{-1}$ (CI 59.14 – 63.06), Miscellaneous forests 58.95 t $ha^{-1}$ (CI 56.44 – 61.44) and the minimum SOC pool was found under Sal forests 58.45 t $ha^{-1}$ (CI 55.63 – 61.36). SOC pool under Chir, Sal and Miscellaneous was statistically at par and therefore placed as subset ‘e’ at

α = 0.05. The SOC pool under Chir forest was statistically at par with Kail, Sal and Miscellaneous and therefore placed as subset 'de'. The amount of SOC under other forests differed significantly and therefore placed under different subsets from 'a' to 'd' (Table 1).

**Table 1.** Soil Organic Carbon Pool under Natural Forests in Uttarakhand (Upto 30 cm)

| Sl. No. | Vegetation Cover | SOC Pool (t/ha)* | Area (ha) | SOC Pool (million tons) | SE | Confidence Interval (t ha$^{-1}$) (□= 0.05) | |
|---|---|---|---|---|---|---|---|
| | | | | | | Lower bound | Upper bound |
| 1 | Silver fir & Spruce | 140.76$^{a}$ ± 36.3880 | 92464.84 | 13.02 | 5.42 | 129.82 | 151.68 |
| 2 | Deodar | 118.09$^{b}$ ± 36.6573 | 18783.35 | 2.22 | 2.36 | 113.43 | 122.74 |
| 3 | Quercus | 96.44$^{c}$ ± 35.8570 | 383088.12 | 36.95 | 1.75 | 93.00 | 99.88 |
| 4 | Kail | 67.66$^{d}$ ± 27.4467 | 18548.83 | 1.26 | 4.63 | 58.23 | 77.08 |
| 5 | Chir | 61.10$^{de}$ ± 25.4641 | 394383.84 | 24.10 | 1.00 | 59.14 | 63.06 |
| 6. | Miscellaneous forests | 58.95$^{e}$ ± 29.9835 | 614361.00 | 36.22 | 1.27 | 56.44 | 61.44 |
| 7. | Sal | 58.45$^{e}$ ± 26.1011 | 313054.2 | 18.30 | 1.48 | 55.53 | 61.36 |

**Same alphabets represent statistically at par group*
*± Standard Deviation; SE - Standard Error*

SOC pool under Fir & Spruce forests was 19.19 % higher as compared to Deodar forests while it was 45.95 % higher as compared to Quercus forests. It was more than 108.03 to 140.80 % higher than the SOC pool under Kail, Chir, Miscellaneous and Sal forests. SOC pool under Deodar forests was 22.45 % higher as compared to Quercus forests and 74.53 % higher in comparison to Kail forests however, it was 93.27 %, 100.70 % and 102.04 % higher

as compared to Chir, Miscellaneous and Sal forests respectively. SOC pool under Quercus forests was 42.54 % higher as compared to Kail forests while it was 57.84 %, 63.90 % and 65.00 % higher in comparison to Chir, Miscellaneous and Sal forests respectively. SOC pool under Kail forests was 10.74 %, 14.99 % and 15.76 % higher as compared to Chir, Miscellaneous and Sal forests respectively. SOC pool in the soils under Chir, Miscellaneous and Sal forests had marginal differences. However, it was 3.84 % and 4.53 % higher in Chir as compared to Miscellaneous and Sal forests.

Results of one-way ANOVA indicated that SOC pool amongst the natural forests was significantly different at 0.05 level (Variance ratio, $F = 214.857$; $p < 0.05$). SOC pool under Fir & Spruce and Deodar forests was significantly different from the SOC pool under all other natural forests *viz.* Quercus, Kail, Chir, Miscellaneous forests and Sal. SOC pool under Quercus forests was also statistically significantly different from the SOC pool under all other forests covers. However, SOC pools in the soils under Kail, Chir, Miscellaneous and Sal forests were not significantly different between each other (Table 2).

**Table 2.** Statistical Mean Differences on the Basis of CD (LSD)

| Sl No. | Vegetation | Mean Difference | p value |
|---|---|---|---|
| 1 | Fir / Spruce Vs Deodar | 22.6650* | 0.000 |
| 2 | Fir / Spruce Vs Quercus | 44.3112* | 0.000 |
| 3 | Fir / Spruce Vs Kail | 73.0960* | 0.000 |
| 4 | Fir / Spruce Vs Chir | 79.6510* | 0.000 |
| 5 | Fir / Spruce Vs Misc. | 81.8072* | 0.000 |
| 6 | Fir / Spruce Vs Sal | 82.3037* | 0.000 |
| 7 | Deodar Vs Quercus | 21.6465* | 0.000 |
| 8 | Deodar Vs Kail | 50.4310* | 0.000 |
| 9 | Deodar Vs Chir | 56.9850* | 0.000 |
| 10 | Deodar Vs Misc. | 59.1422* | 0.000 |
| 11 | Deodar Vs Sal | 59.6387* | 0.000 |
| 12 | Quercus Vs Kail | 28.7848* | 0.000 |
| 13 | Quercus Vs Chir | 35.3398* | 0.000 |
| 14 | Quercus Vs Misc | 37.4960* | 0.000 |
| 15 | Quercus Vs Sal | 37.9924* | 0.000 |

* *Mean difference is significant at the 0.05 level*

Mitigation potential was worked out for the soils under each forest cover with respect to Sal forests which contained the minimum SOC pool among all the forest covers. Maximum mitigation potential was of Fir & Spruce (2.41) followed by Deodar forests (2.02). It indicated that soils under Fir & Spruce and Deodar forests can hold double organic carbon as compared to Sal forests. Quercus forests had mitigation potential 1.65 which means that these forests can store one and half time more soil organic carbon than Sal forests. Mitigation potential of Kail (1.16), Chir (1.04) and Miscellaneous (1.01) forests was not significant since the variations in SOC were marginal.

**SOC Pool under Plantation Forests and Barren Lands**

SOC pool, under plantation forests was estimated and the data revealed that maximum SOC pool was in the soils under Cypress *i.e.* 66.32 t $ha^{-1}$ (CI 58.05 – 74.58) followed by Eucalyptus 42.73 t $ha^{-1}$ (CI 35.65 – 49.80), Khair 41.67 t $ha^{-1}$ (CI 35.71 – 47.71), Teak 40.71 t $ha^{-1}$ (CI 33.89 – 47.51) and Shisham 32.96 t $ha^{-1}$ (CI 22.63 – 43.28). The barren land contained only 27.73 t $ha^{-1}$ (CI 22.62 – 32.82). Subset for $\alpha = 0.05$ indicates that the SOC pool under Shisham was statistically at par with Eucalyptus, Khair and Teak and unproductive barren lands, therefore, can be placed with both the 'a' and 'b' groups (Table 3). However, cypress plantation forests stands alone 'a', Eucalyptus, Khair and Teak stand together in subset 'b', while barren lands stand separately as 'c'.

**Table 3.** Soil Organic Carbon Pool under Planted Forests in Uttarakhand (up to 30 cm)

| Sl. No. | Vegetation Cover | SOC Pool (t $ha^{-1}$) | Area (ha) | SOC Pool (million tons) | SE | Confidence interval (t $ha^{-1}$) ($\alpha$= 0.05) | |
|---|---|---|---|---|---|---|---|
| | | | | | | Lower bound | Upper bound |
| 1 | Cypress | $66.32^{a}$ ± 23.3113 | 2965.11 | 0.20 | 4.06 | 58.05 | 74.58 |
| 2 | Eucalyptus | $42.73^{b}$ ± 21.8284 | 24411.73 | 0.91 | 3.50 | 35.65 | 49.80 |
| 3 | Khair | $41.67^{b}$ ± 19.8178 | 5796.61 | 0.24 | 2.95 | 35.71 | 47.61 |
| 4 | Teak | $40.71^{b}$ ± 28.5734 | 20209.16 | 0.82 | 3.42 | 33.89 | 47.51 |
| 5 | Shisham | $32.96^{bc}$ | 15114.19 | 0.50 | 4.98 | 22.63 | 43.28 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | ± 23.8708 | | | | | |
| 6. | Unproductive Barren Land | 27.73[c] ± 23.8708 | 541299.43 | 15.01 | 2.53 | 22.62 | 32.84 |

*Same alphabets represent statistically at par group*
*± Standard Deviation; SE – Standard Error*

SOC pool under Cypress plantation forests was 55.21 % higher as compared to Eucalyptus forests and 139 % higher as compared to barren land. SOC pool under Eucalyptus was marginally (2.54 % and 4.96 %) higher as compared to Khair and Teak respectively, while it was 54.09 % higher as compared to barren land. SOC pool under Khair was marginally (2.36 %) higher in comparison to the SOC pool under Teak and 26.43 % and 50.27 % higher as compared to Shisham and e barren land respectively. The SOC pool, under barren land was higher *i.e.* 15.01 million tons as compared to that of planted forests because the area under barren lands was larger.

Results of one-way ANOVA indicates that SOC pool between the planted forests was significantly different at 0.05 level (Variance ratio, $F = 11.357$; $p < 0.05$). SOC pool under Cypress planted forests was significantly different from the SOC pool under all other planted forests *viz.* Eucalyptus, Khair, Shisham, Teak and barren lands. SOC pool in the soils under Eucalyptus planted forests was significantly different from the SOC pool under barren lands (Table 4).

**Table 4:** Statistical Mean Differences on the Basis of CD (LSD)

| Sl No. | Vegetation | Mean Difference | P value |
|---|---|---|---|
| 1 | Cypress Vs Eucalyptus | 23.5948* | 0.000 |
| 2 | Cypress Vs Khair | 24.6574* | 0.000 |
| 3 | Cypress Vs Teak | 25.6167* | 0.000 |
| 4 | Cypress Vs Shisham | 33.3640* | 0.000 |
| 5 | Cypress Vs Barren land | 38.5883* | 0.000 |
| 6 | Eucalyptus Vs Barren land | 14.9935* | 0.003 |
| 7 | Khair Vs Barren land | 13.9309* | 0.005 |
| 8 | Teak Vs Barren land | 12.9716* | 0.004 |

* *Mean difference is significant at the 0.05 level*

**Distribution of SOC Pool in Different Forest Covers of Uttarakhand**

Total SOC pool in 24,414.80 $km^2$ of forest land of Uttarakhand was 149.73 million tones. Out of this SOC pool, 1.78 % (2.67 million tons) was in the plantation forests, 10.02 % (15.01 million tons) in the barren lands and 88.19 % (132.05 million tons) in the natural forests.

Percent share occupied by the individual forests covers out of the total SOC pool of the was worked out. Maximum proportion was held by Quercus forests (24.67%) followed by Miscellaneous forests (24.19%), Chir forests (16.09 %), Sal forests (12.22%), barren land (10.02%), Fir & Spruce forests (8.69%) and Deodar forests (1.48%). The Kail, Shisham, Eucalyptus, Khair, Teak and Cypress forest contributed less than 1% each (Fig.1).

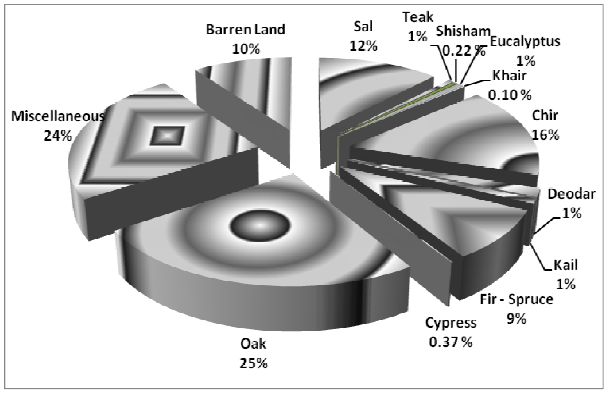


**Figure 1** Contribution to SOC pool by individual forest cover

**Distribution of SOC Pool in Different Zones of Uttarakhand**

SOC pool was also worked out in the forest lands in Kumaon zone, Garhwal zone and National parks and Wild life sanctuaries. The Kumaon zone comprises of Almora, Pithoragarh, Bageshwer, Champawat, Chamoli, US Nagar and Nainital districts, whereas the Garhwal zone includes Dehra Dun, Hardwar, Pauri, Tehri, Uttarkashi and Rudrapryag districts. The National parks and Wild life sanctuaries are comprised of Rajaji National Park, Nandadevi Biosphere Reserve, Kedarnath Wild life Division, Kalagarh Tiger Reserve, Corbett National Park, Binser Wild Life Sanctuary, Govind Wild life Sanctuary and Gangotri National Park in Uttarakhand state. Maximum share of SOC pool was found under forests of Garhwal zone *i.e.* 43.69 % (65.43 mt) followed by National Parks and Sanctuaries i.e. 31.48 % (47.13 m t) and the Kumaon zone contained 37.17 m t (24.83 %) (Fig. 2).

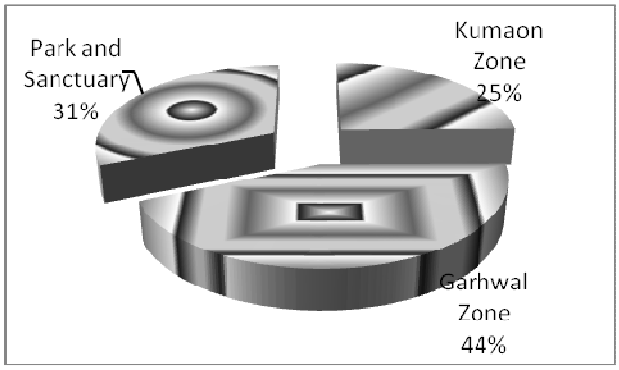


**Figure 2** Contribution to SOC pool by Kumaon & Garhwal zones and National Parks and Sanctuaries

SOC pool was higher under natural forests as compared to planted forests. This may be due to production and return of higher amount of litter in natural forests. The release of nutrients from litter decomposition is a fundamental process in the internal biogeochemical cycle of an ecosystem, and decomposers recycle a large amount of carbon that was bounded in the plant or tree to the atmosphere [14]. SOC pool under Silver fir & spruce, Deodar and Quercus forests which grow at higher altitudes was high as compared to Chir, Sal and Miscellaneous forests which grow at relatively lower altitudes. Higher SOC content at higher altitude is a natural phenomenon as there is sufficient moisture and lower temperature at higher altitudes which facilitates accumulation of higher litter layer and soil organic matter due to slow decomposition. These conditions restrict the $CO_2$ emission from the soil, therefore, higher SOC levels. Dai and Huang [15] reported that in eastern and southern China, variables of precipitation and altitude are key factors regulating surface soil organic matter concentration. The relationship between soil organic matter and altitude has also been investigated and positive correlations were reported by Sims and Nielsen [16] and Tate [17]. A study was conducted by Rawat [18] on soil characteristics along an altitudinal gradient from 1,700 to 2,100 m in a mountain flank of Garhwal Himalayas and results of soil organic carbon and potassium were positively correlated with the altitudinal gradient. Temperate climate favours organic carbon accumulation in soils [19, 20] in and a major concern for such regions is the change that may take place in the large SOC stocks as temperatures rise. Even 1 to 2 $^0$C change in temperature in these temperate regions, can accelerate the decomposition and during this process large amount of $CO_2$ can be emitted from the soil.

## Conclusion

Total SOC pool in 24,414.80 $km^2$ forest area of Uttarakhand state was 149.73 million tones. Out of this pool 132.05 million tons was in the natural forests, 15.01 million tons in barren lands and 2.67 million tons s in the planted forests. Within the natural forest covers the SOC pool under *Abies pindrow & Picea smithiana* forests was the maximum followed by *Cedrus deodara*, *Quercus leucotrichophora*, *Pinus wallichiana*, *Pinus roxburghii*, Miscellaneous forests and the minimum SOC pool was under *Shorea robusta* forest. SOC pool, under planted forests (plantation on the area under control of the State Forests department) was also estimated and data revealed that maximum SOC pool was under *Cypress cashmeriana* plantations (66.32 t $ha^{-1}$) followed by *Eucalyptus spp.* (42.73 t $ha^{-1}$), *Acacia catechu* (41.67 t $ha^{-1}$), *Tectona grandis* (40.71 t $ha^{-1}$) and *Dalbergia sissoo* plantations (32.96 t $ha^{-1}$). However, the SOC was minimum in the barren land (27.73 t $ha^{-1}$). The Garhwal zone contained maximum i.e. 65.43 mt (43.69 %) of the total SOC pool, followed by 47.13 m t (31.48 %) in the National Parks and Sanctuaries and 37.17 m t (24.83 %) in the Kumaon zone of the Uttarakhand state.

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