



Assessment of Soil Organic Carbon Stock under Different Density Classes of Oak (*Quercus leucotricophora*) Forests in Uttarakhand, India

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Authors' contributions

This work was carried out in collaboration among all authors. Author AS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors PB and UD managed the analyses of the study. Author UD managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Soil organic carbon (SOC) is one of the most important and essential constituents of soil. It is the largest reservoir of terrestrial carbon. Here, an investigation was carried for the assessment of Soil Organic Carbon in three different density classes of Oak forest of Chakrata (Distt. Dehradun), Itarna (Distt. Tehri Garhwal) and Lansdowne (Distt. Pauri Garhwal) forest divisions of Uttarakhand. Three soil samples from each forest system at 0-30 cm depth were collected from each density to assess soil organic carbon stock. A total of 81 soil sample were collected in three seasons. In summer season among all three division maximum Soil Organic Carbon was assessed in Chakrata dense forest division (81.65 t ha⁻¹), followed by moderate forest (47.66 t ha⁻¹) and open forest (37.68 t ha⁻¹) of Chakrata forest division. In Lansdowne forest division maximum SOC was found in dense forest (79.82 t ha⁻¹) followed by moderate (48.53 t ha⁻¹) and open forest (35.37 t ha⁻¹)

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respectively. A similar trend was reported in case of Itarna forest division. Where (78.47 t ha⁻¹) come up to maximum reservoir of SOC followed by moderate forest (46.50 t ha⁻¹) and open forest (34.52 t ha⁻¹) respectively. In rainy season among all three division maximum Soil Organic Carbon was assessed in Chakrata dense forest division (66.24 t ha⁻¹), followed by moderate forest (45.62 t ha⁻¹) and open forest (29.53 t ha⁻¹) of Chakrata forest division. In Lansdowne forest division maximum SOC was found in dense forest (75.48 t ha⁻¹) followed by moderate 48.65 t ha⁻¹) and open forest (22.36 t ha⁻¹) respectively. Similar trend was reported in case of Itarna forest division. In winter season among all three divisions maximum Soil Organic Carbon was assessed in Chakrata dense forest division (81.89 t ha⁻¹), followed by moderate forest (56.62 t ha⁻¹) and open forest (32.32 t ha⁻¹) of Chakrata forest division. In Lansdowne forest division maximum SOC was found in dense forest (81.90 t ha⁻¹) followed by moderate (57.43 t ha⁻¹) and open forest (35.99 t ha⁻¹) respectively. A similar trend was reported in case of Itarna forest division. This study reveals that in the Soil Organic Carbon is maximum in the dense forest followed by moderate and open forest which could be possibly due the more flora and fauna in the dense forest followed by moderate and open forest. Possibly the activities of flora and fauna lead to the addition of more carbon content in the soil. The study demonstrated similar trends of SOC in three different dense, moderate and open density classes of Oak forest. These outcomes of the study may explore the possibility to improve the scientific basis of forest management and land use in the near future.

Keywords: *Q. leuchotricophora*; forest density classes; soil organic carbon; forest management.

1. INTRODUCTION

Soil organic carbon (SOC) is one of the most important and essential constituents of soil. Forest soil is one of the main sinks of carbon on earth. The sink is in the form of trees above the ground or living biomass below the ground in soil (roots and microorganisms) or in the deeper sub surface environment [1]. Soil carbon includes both inorganic carbons as carbonate minerals, and as soil organic matter. Soil carbon plays a key role in the carbon cycle, and thus it is important in global climate models. Soil inorganic carbon consists of mineral forms of C, either from weathering of parent material or from the reaction of soil minerals with atmospheric CO₂. Carbonate minerals are the dominant form of soil carbon in desert climates. Soil organic carbon is present as soil organic matter. It includes relatively available C as fresh plant remains and relatively inert C in materials derived from plant remains: Humus and charcoal [2]. World soil contains an important pool of active carbon that plays a major role in the global carbon cycle [3,4]. Soil store 2.5 to 3.0 times carbon as much that is stored in plants and two to three times more than the atmospheric as CO₂ [5]. Soil microbial biomass is an important component of soil organic matter constituting from 2 to 5% of the soil organic carbon and plays a significant role in the cycling of nutrients and overall organic matter dynamics [6,7] evaluated the impact of predominant land uses on the Physico-chemical and biological properties of soils along an altitudinal gradient in Indian

Central Himalaya to enhance the scientific knowledge and identify suitable land use pattern.

Soil is the major pool of terrestrial organic carbon in the biosphere, storing more C than is contained in plants and the atmosphere combined [8,9]. Plenty of organic C in the soil is influenced by plant production, and its function as a key control of soil fertility and agricultural production has been accepted for more than a century [10]. The patterns and controls of SOC storage are critical with the viewpoint of the biosphere [11,12,13,14]. SOC storage is controlled by the balance of C inputs from plant production and outputs through decomposition [9]. In humid climates, both production and decomposition increase with temperature, but relative increases in decomposition are greater [1,15,9]. Precipitation constrains plant production and decomposition in arid to sub-humid ecosystems [16,17,18] with a greater response of plant production relative to decomposition.

The concern about increasing atmospheric CO₂ and its role in future global climate change has lead soil scientists to quantify soil organic carbon content (also referred to as stocks or storage) [19]. Tree growth serves as an important means to capture and store atmospheric carbon dioxide in vegetation, soils and biomass products [20]. Soil organic carbon can also increase or decrease depending on numerous factors, including climate, vegetation type, and nutrient availability, and disturbance and land use and management practices. Based on the above, the

present study has been undertaken to assess the SOC in different density classless (Dense, moderate and open) of oak forest under three forest divisions of Uttarakhand. In addition to this, the variation in SOC among the identified density classes was also examined.

2. MATERIALS AND METHODS

2.1 Site Description and Collection of Samples

After the preliminary survey of the study area, the following sites were selected: In the present study, the selected study sites were Chakrata (Distt. Dehradun), Itarna (Distt. Tehri Garhwal) and Lansdowne (Distt. Pauri Garhwal) forest division of Uttarakhand. The general description of the sampling sites is represented in Table 1. In addition to this, Fig. 1 (a)-(d) shows the area map of the sampling sites. Soil samples were randomly collected for estimation of organic carbon, bulk density and a coarse fragment from Oak forest. For organic carbon pool status, three sampling points were selected under Oak forest cover and soil sample were collected from 0-30 cm from each sampling site. The samples were kept in polythene bags and closed tightly with proper labelling. Separate samples were collected for bulk density and coarse fragment estimation from every sampling point. After collection of samples, these samples were processed for air drying, grinding and sieved through 100 mesh sieves in the laboratory. SOC was estimated for these processed samples.

2.2 Sample Plots

There were 27 number of sampling sites in dense, moderate, open forest SOC. The sites

were circular in shape, and the sizes varied according to depth i.e 0-30 cm. Field measurement was done by systematic sampling.

2.3 Sampling Method

Three replicate soil samples were collected from each sample plot, using clean empty poly bags, labelled and taken to the laboratory for analysis. The extra moisture of sampled soil was air-dried in the laboratory and then processed further.

2.4 Analysis of Soil Samples

2.4.1 Soil carbon stock

The soil organic carbon was estimated by standard Walkley and Black [21]. According to this: 1 g of soil sample was taken and passed through 100 mesh in 500 ml conical flask and then 10 ml 1N $K_2Cr_2O_7$ solution using a pipette & 20 ml H_2SO_4 (Conc.) using measuring cylinder was added to it slowly. It was shaken along with the contents for half a minute and left undisturbed for about 30 minutes for cooling. 200 ml distilled water and 10 ml Orthophosphoric acid was added. 4-5 drops of diphenylamine indicator were added and titrated the contents against 0.5N ferrous ammonium sulphate until the end point which is green appears (violet colour turn into green color). A blank titration of contents was run without soil.

Calculation of SOC stock:

The SOC stock was calculated using the equation suggested by Intergovernmental Panel on Climate Change (IPCC) [22]. The data for SOC stock was calculated by using the following equation as suggested by IPCC Good Practice Guidance for LULUCF: [6]

Table 1. General description of the study area

S. No	Forest division	Forest type (Oak forest)	Elevation (mts.)	Latitude	Longitude
1.	Lansdowne	Dense forest	1744	N-29°50'21.1"	E-78°41'13.8"
		Moderate forest	1768	N-29°50'42.5"	E-078°10'13.0"
		Open forest	1618	N-29°50'04.6"	E-078°41'35.5"
2.	Itarna	Dense forest	1381	N30°25'35.20"	E078°29'17.08"
		Moderate forest	1945	N30°24'68.10"	E078°29'83.94"
		Open forest	1763	N30.21'02.64"	E078°29'94.41"
3.	Chakrata	Dense forest	1900	N30°40'35.5"	E077°51'47.1"
		Moderate forest	1934	N30°40'43.4"	E077°51'58.0"
		Open forest	1568	N30°29'36.0"	E077°51'23.0"

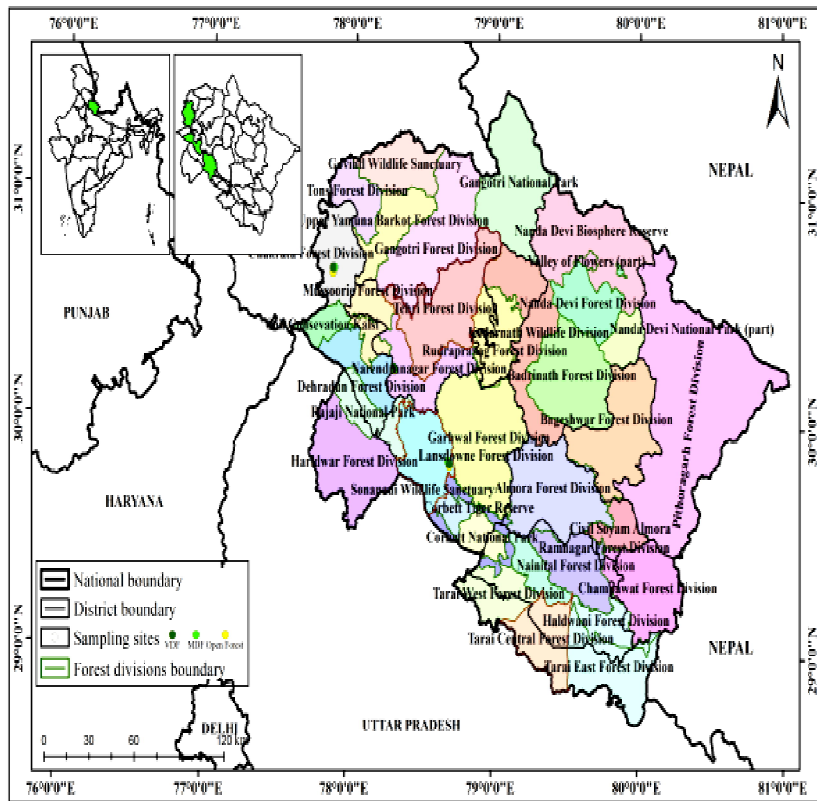


Fig. 1a. Area map of Uttarakhand

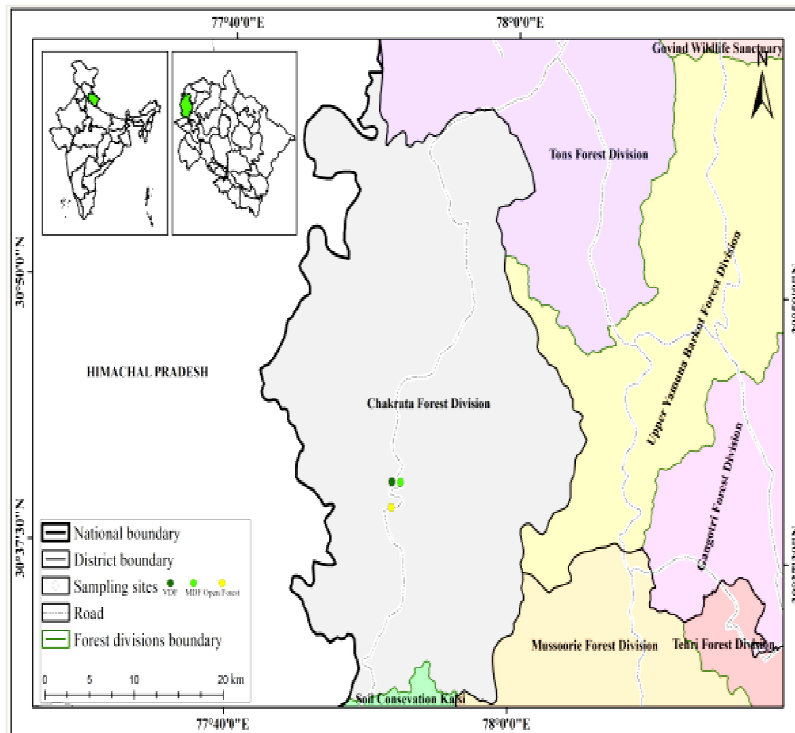


Fig. 1b. Area map of Chakrata

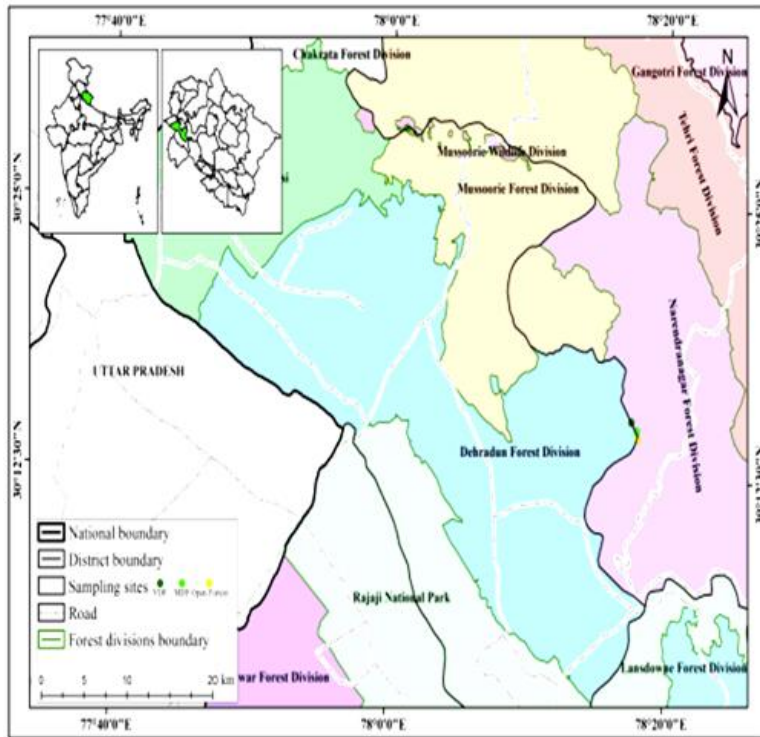


Fig. 1c. Area map of Itrana

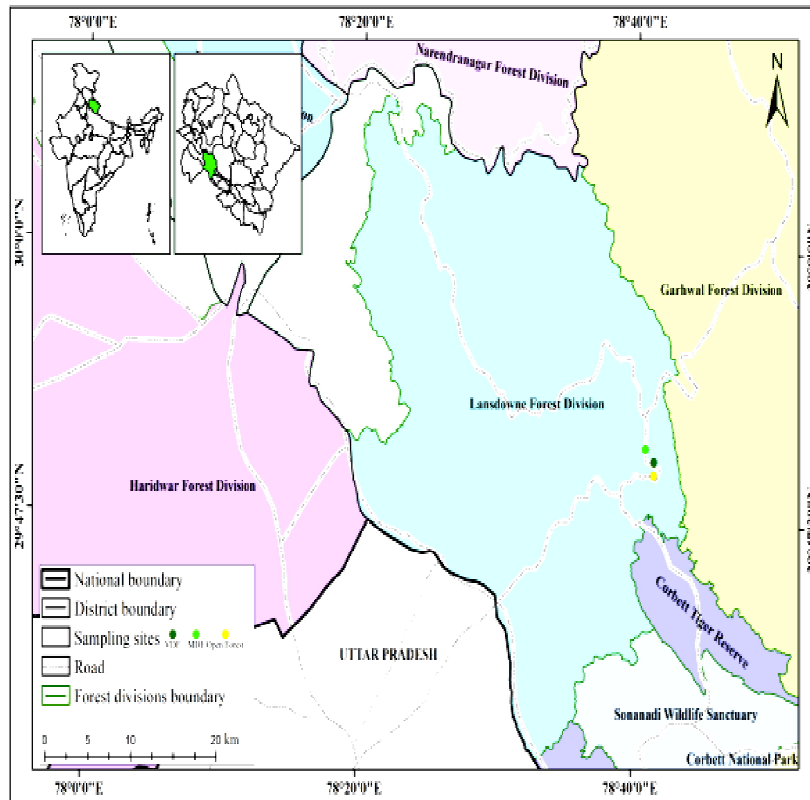


Fig. 1d. Area map of Lansdowne

Where,

SOC = Representative soil organic carbon content for the forest type and soil of interest,

$$\text{Tones C ha}^{-1}$$

SOC_{horizon} = Soil organic carbon content for a constituent soil horizon, tones 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 tones soil m⁻³ (equivalent to Mg m⁻³)

Depth = Horizon depth or thickness of soil layer, m

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

$$\begin{aligned} \text{SOC} &= \sum_{\text{Horizon}=1}^{\text{Horizon}=n} \text{SOC horizon} \\ &= \sum_{\text{Horizon}=1}^{\text{Horizon}=n} ([\text{SOC}] \times \text{Bulk density} \\ &\quad \times \text{depth} \times (1 - \text{C fragments}) \\ &\quad \times 10)_{\text{horizon}} \end{aligned}$$

2.4.2 Bulk density

Amount of coarse fragments were estimated in each sample collected from different sites and deducted from the soil weight to get an accurate soil weight on hectare basis. Bulk density at every site was estimated by standard core method [13]. The methods used in this study are in accordance to Ravindranath, and Ostwald [23].

$$\text{Bulk density (g/cm}^3\text{)} = \frac{\text{Mass of oven - dried sample (g)}}{\text{Volume of the sample (cm}^3\text{)}}$$

3. RESULTS AND DISCUSSION

Estimation of carbon sequestration in a forest ecosystem is necessary to mitigate impacts of climate change. Here, SOC pool was estimated for different density classes of oak forest region which falls under Lansdowne, Itarna, Chakrata forest division of Uttarakhand at different altitudes. A comparison among different density classes of oak forests in the different forest divisions was observed which showed that dense forest supports more soil organic carbon as compared to the moderate and open forest as shown by Fig. 2. Where, the study of three

selected sites shows that carbon stock is more in the dense forest in the winter season, followed by summer and monsoon season. Similar results were observed by Raina and Gupta [24] they suggested that it is possibly due to the decreased microbial activities in the winter due to low temperature. Which leads to the decrease in microbial decay. In turn, it leads to less release of carbon from the soil, keeping a store of carbon in it. The in this study it was observed that in all three seasons dense forest supports more carbon stock as compared to moderate and open forest. This can be clearly depicted in the Fig. 2 which is showing study data for the year 2018.

The data were statistically analyzed and observation showed that there is a relation between the density of forest and altitude *i.e.*, more the altitude, lesser the density of the forest. Simultaneously, more the soil organic carbon content was observed in low altitudes. This trend was observed in the all the District of Uttarakhand forest region except in Lansdowne. The values of soil organic carbon along with the density and altitude of the different forest.

The data reveals that as far as Oak forest is concerned, maximum SOC in summer season under dense forest was reported in Chakrata forest division (81.65 t ha⁻¹) followed by Lansdowne forest division (79.82 t ha⁻¹) and Itarna forest divisions (78.47 t ha⁻¹). In case of moderate forest maximum, SOC was under Lansdowne (48.53 t ha⁻¹) which is followed by Itarna forest division (46.50 t ha⁻¹) and Chakrata forest division (47.66 t ha⁻¹). Similarly in open forest maximum, SOC was found under Chakrata forest division (37.68 t ha⁻¹) followed by Lansdowne (35.37 t ha⁻¹) and Itarna forest division (34.52 t ha⁻¹). The maximum SOC in winter season under dense forest was reported in Itarna forest division (93.02 t ha⁻¹) followed by Lansdowne forest division (81.90 t ha⁻¹) and chakrata forest divisions (81.89 t ha⁻¹). In case of moderate forest maximum SOC was under Lansdowne (57.43 t ha⁻¹) which is followed by Itarna forest division (53.16 t ha⁻¹) and Chakrata forest division (56.62 t ha⁻¹). Similarly in open forest maximum, SOC was found under Lansdowne forest division (35.99 t ha⁻¹) followed by Itarna (35.53 t ha⁻¹) and chakra forest division (34.51 t ha⁻¹). The maximum SOC in rainy season under dense forest was reported in Lansdowne forest division (75.48 t ha⁻¹) followed by Itarna forest division (69.68 t ha⁻¹) and Chakrata forest divisions (66.24 t ha⁻¹). In case of moderate forest maximum, SOC was under

Itarna (53.05 t ha⁻¹) which is followed by Lansdowne forest division (48.65 t ha⁻¹) and Chakrata forest division (45.62 t ha⁻¹). Similarly in open forest maximum, SOC was found under Itarna forest division (33.38 t ha⁻¹) followed by Chakrata (29.53 t ha⁻¹) and Lansdowne forest division (22.36 t ha⁻¹). On the other hand, the study during year 2017 follows a similar trend as the highest carbon stock in the dense forest followed by moderate and open forest respectively, which is clearly depicted in Fig. 3.

The results of the study reveal that SOC content was significantly higher under the dense forest as compared to moderate and open oak forest. The soil having high SOC content under tree-based systems might be because of several factors such as the addition of litter, annual recycling of fine root biomass and root exudates. Moreover, the reduced oxidation of organic

matter under dense Oak forest may also increase the SOC content [25]. In addition to this, under dense forest, the greater canopies may provide the litter in large quantity therefore; accumulation of carbon is higher leading to higher SOC content. As we move in different density classes of Oak forest from high to moderate followed by open, the canopy cover is decreased leading to lower SOC pool. The soil organic carbon in forest depends upon the forest type, climate, moisture, temperature and type of soil. Soil organic carbon is sensitive to the impact of anthropogenic activities. The conversion of natural vegetation to various land uses results in a rapid decline in soil organic matter. The data was statistically analyzed using SPSS 16 software. Demonstrates the SD and SE for every SOC stock value under different density classes of *Q. leucotrichophora* forest. The statistical tool further confirmed that the data achieved against

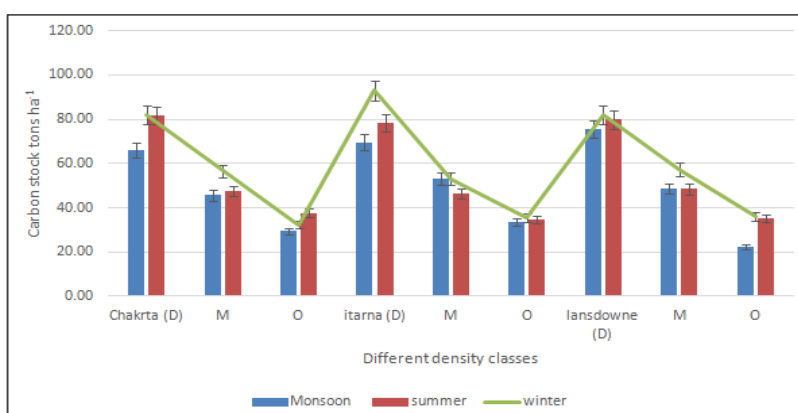


Fig. 2. SOC stock in different density classes of *Q. leucotrichophora* in three seasons dense (D), Moderate (M), and Open (O) in the year 2018

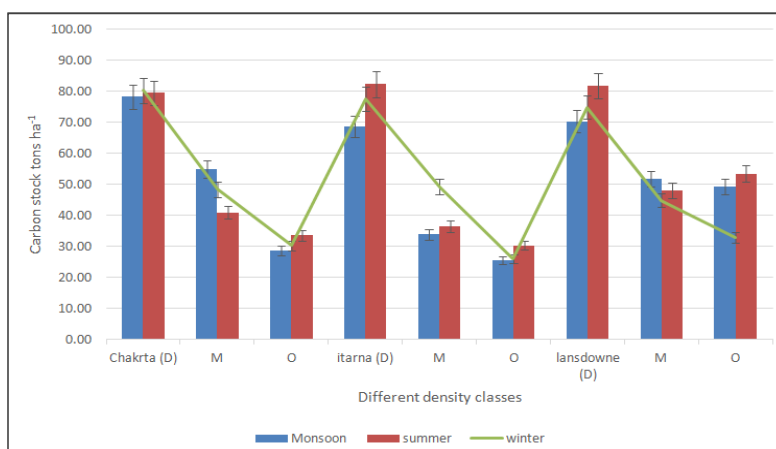


Fig. 3. SOC stock in different density classes of *Q. leucotrichophora* in three seasons dense (D), Moderate (M), and Open (O) in the year 2017

SOC stock is statistically significant at 0.05 levels. Although the present study is limited to different density classes of Oak (*Quercus leucotricophora*) forests still it is quite informative. Previously authors also estimated the organic carbon pool in the soils under different forest covers and land uses i.e. forests, tree plantations, horticulture and grasslands in Garhwal Himalayan region of India [26,27,18]. The present study investigated the SOC stock on some different specified sites based on density classes instead of general working sites as reported elsewhere. The extension may be performed through assessment of some other important factors like soil respiration rate, bulk density, soil texture, pH, Nitrogen (N) content, Phosphorous (P) content, Potassium (K) content and microbial activities etc. In summary, the information presented here concerning SOC stock under different density classes of Oak (*Quercus leucotricophora*) forests combined with a better understanding may (1) develop better performing soil carbon models, (2) help us to understand the importance of vegetation and (3) help to further improve the scientific basis of forest management and land use to ameliorate rising atmospheric CO₂ levels.

4. CONCLUSION

There was considerable variation in the open, dense and moderate forest carbon stock according to forest and its geographical location. However, carbon sequestration rate of forest type depended on the growing nature of the forest stands. Among all the selected sites, soil organic stock under different density classes of oak forest was found maximum in dense forest of Chakrata forest division followed by moderate and open forest respectively. Similarly, maximum SOC in Lansdowne forest division was reported in the dense forest followed by moderate forest and open forest. Similar trend was observed in the Itarna forest division. It was observed that dense forest supports maximum share of SOC pool followed by moderate forest and open forest of Oak. The present study; it was also observed that SOC stock decreased with the decrease in forest density. Overall, among all different density classes of Oak forest, the dense Oak forest has highest SOC pool which may be attributed to the presence of dense canopy, higher elevation, slow decomposition and higher accumulation of leaf litter. Meanwhile, Oak forest contains high moisture content, they act as a source of water. At higher altitude, sufficient moisture and lower temperature lead to

accumulation of higher litter layer and soil organic matter due to slow decomposition as in case of Chakrata forest division. It is evident that the organic carbon content of soil is a key factor in respect of the overall health of soil. The outcomes of this study may further explore the possibilities to further improve the scientific basis of forest management and land use.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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