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Biomass and Soil Organic Carbon Stocks Under *Cedrus deodara* Forests in Mandi District of Himachal Pradesh

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ABSTRACT

The estimation of carbon sequestration in forest ecosystem is necessary to plan for mitigating the impacts of climate change. The present study was conducted in the *Cedrus deodara* (CD) forests of Mandi district in Himachal Pradesh to estimate the biomass and soil organic carbon stock at various sites of the study area. Overall, 18 plots of 0.1 ha were laid at six sites randomly in the year 2014-15. In CD forest, the mean stem density was 354 trees/ha and the mean basal area and mean volume were 62.28 m^2/ha and 719.71 m^3/ha respectively. The mean carbon stock for tree aboveground, tree belowground, understorey and litter were 189.93 ton/ha, 37.99 ton/ha, 1.71 ton/ha and 0.72 ton/ha respectively. The soil organic carbon percentages varied from 1.98-2.83%, 1.72-2.11% and 1.56-1.74% at soil depth of 0-15cm, 15-30cm and 30-45cm respectively, and the soil organic carbon stocks ranged from 24.41-32.22 ton/ha, 21.59-29.03 ton/ha and 19.17-26.78 ton/ha at soil depths of 0-15cm, 15-30cm and 30-45cm respectively. The total mean soil organic carbon (SOC) stock up to a depth of 0-45cm was found to be 76.16 ton/ha. The organic carbon percentage showed a decreasing trend with increasing soil depth.

INTRODUCTION

Among the global common concerns, climate change has been identified as the most important environmental challenge that the humanity is facing. Emissions of carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, hydrofluorocarbons and perfluorocarbons are identified as greenhouse gases causing warming of earth globally. Of these, CO_2 alone accounts for 60 percent share (Khurana 2012). Human beings are accelerating the rate of increase in atmospheric CO_2 concentration through fossil fuels burning, land use, land-use changes and forestry activities, resulting in global warming and climate change during the recent times (Upadhyay et al. 2005). The increase of carbon dioxide (CO_2) in the atmosphere has become one of the global environmental issues in recent years because of its potential to change world climate (Brown & Lugo 1982). An increase in the rate of destruction of terrestrial vegetation is considered as an important source contributing significant amounts of carbon to the environment (Clark 1982, Houghton 1990, 1991). Absorbing atmospheric CO_2 and moving into the physiological system and plant biomass, and finally into the soil, is considered as the most practical way of removing excess carbon from atmosphere and storing it into a biological system. Studies have shown that carbon sequestration by trees and forests could provide relatively low-cost net emission reductions. Carbon management in forests is, therefore, one of the most important agenda in India in the 21st century in context of green house gases effects and mitigation of global climate changes.

The Intergovernmental Panel on Climate Change (IPCC) states in its Third Assessment Report (IPCC 2001) that most of the global warming observed over the last half century is attributed to human activities. IPCC predicts that anthropogenic emission of greenhouse gases (GHGs) will raise the global mean surface temperature from 1.4 to 5.8°C over the next century. Recognizing the importance of forest and soil in mitigating the greenhouse effect, an agreement was reached under the Kyoto Protocol to include forest and soil carbon sequestration in the list of acceptable offsets (UNFCCC 1997). Even if global warming is not as detrimental as many fear, an increased stock of timber will most likely have a positive marginal value product for forest products, and other environmental benefits (Hoen & Solberg 1994).

Depending upon the succession stage, specific disturbance, or management intervention, the forest can act as a source and as a sink (Masera et al. 2003). Forests act as sinks by increasing aboveground biomass through increased forest cover and by increased levels of soil organic carbon

(SOC) content. Approximately 80% and 40% of all terrestrial aboveground and belowground carbon, respectively, is contained by forest biomass (Goodale et al. 2002). 14% of worlds total forest carbon stock is contributed by temperate forests (Pan et al. 2011). Nearly 19% of dense forest vegetation in India is present in the Himalayan zone. Forests accumulate more CO_2 than the atmosphere (Prentice et al. 2001) and managing forests to enhance carbon sequestration is one of the possible means of reducing CO_2 concentration in the atmosphere (Smithwick et al. 2002). For better estimation of the total forest carbon stock, both aboveground biomass and belowground root biomass need to be accounted (Hamburg 2000). By using standard methodologies, periodical monitoring and assessment of variation in forest carbon need to be considered both at local and regional levels.

Therefore, in view of above-said facts, it becomes necessary to have more accurate and reliable estimates of the carbon stocks in our forests and to study their carbon sequestration potential for the implementation of appropriate strategies and policy to mitigate the effect of climate change. The need for reporting carbon stocks and stock exchange for the Kyoto Protocol have placed additional demands for accurate surveying methods that are verifiable, specific in time and space (IPCC 2003).

Cedrus deodara (deodar) is the state tree of Himachal Pradesh and its forests are found between the altitudinal ranges of 1200 m to 2700 m approximately. The present study was an attempt made to quantify carbon stored under the different carbon pools of *Cedrus deodara* (deodar) forests. The objectives of the study were to estimate biomass and carbon stocks under different pools like aboveground, belowground, litter, soil, etc. of the *Cedrus deodara* (deodar) forest of the study area.

MATERIALS AND METHODS

Study Site

The present study on estimation of biomass and soil organic carbon stocks in *Cedrus deoadara* (Deodar) forests was undertaken in Mandi district (H.P.), during the years 2014 and 2015. The Mandi district lies between 31°13'50" and 32°04'30" north latitude and 76°37'20" and 77°23'15" east longitude with altitude ranging from 549 to 3962 meters covering a total geographical area of 3,951 km^2 in Himachal Pradesh. Mandi district features a subtropical highland climate under the Köppen climate classification. The climate is composite having hot summers and cold winters. These regions enjoy a wet-sub temperate climate of the foot hills (450-900m) as well as the dry-cold alpine climate with snow fall at higher altitudes (2400 m and above). The average total annual precipitation is 832 millimetres (32.76 in). Temperatures typically range from 6.7°C (44.06°F) to 39.6°C (103.28°F) over the course of a year. The average temperature during summer is between 18.9°C (66.02 °F) and 39.6°C (103.28°F), and between 6.7°C (44.06°F) and 26.2°C (79.16°F) in winter.

Sampling, Plot Demarcation and Enumeration for Measurements

Stratified random sampling approach was used for site selection and layout of the plots for surveys of soil and vegetation. A total number of six sites were selected randomly. After a reconnaissance survey of the study sites, 3 plots of size 50 × 20 m (0.1 ha) were laid at each site for the estimation of tree biomass, thus 18 plots were laid in 6 sites in total. The total number of trees in a particular plot were enumerated according to diameter at breast height (DBH). These trees were then classified into three-four diameter classes for measuring various parameters.

Estimations

Volume and tree biomass: Tree biomass was estimated by adopting non-destructive methods for different plant parts, viz. stem, branch and leaf. The diameters at breast height (DBH) of the trees falling in the plot of size 50×20 m were measured with diameter tape and height with Speigel Relaskop respectively. Form factor and volume was calculated by using the following formula given by Pressler (1865) and Bitlerlich (1984):

$$f = 2h1/3h$$

Where, f = form factor, h1 = height at which diameter is half of DBH, h = total height.

The volume (V) was calculated by Pressler's formula (1865):

$$V = f \times h \times g$$

Where, f = form factor, h = total height (m), g = basal area, g = πr^2 or $\pi\ (dbh/2)^2$, where, r = radius, dbh=diameter at breast height

Specific gravity: The stem cores were taken to find out the specific gravity of wood, taking into account the variation in different parts of the tree, which was used further to determine the biomass of stem using the maximum moisture method (Smith 1954).

$$Gf = \frac{Mn - Mo}{Mo} + \frac{1}{Gso}$$

Where, Gf = specific gravity based on gross volume, Mn = weight of saturated volume sample, Mo = weight of oven dried sample, Gso = Average density of wood substance

Table 1: Stand structure properties (Mean ± Standard Error).

Site	Tree density (trees ha^{-1})	DBH (cm)	Height (m)	Basal Area ($m^2.ha^{-1}$)	Volume ($m^3.ha^{-1}$)
1. Majhwar	351.00(±6.81)	31.52(±2.91)	20.77(±1.45)	40.84(±1.45)	490.03(±6.37)
2. Mehni	513.00(±9.66)	23.92(±2.34)	15.45(±1.86)	27.50(±1.20)	204.40(±6.90)
3. Barot	274.00(±7.32)	60.65(±2.91)	31.37(±2.31)	82.92(±1.77)	1055.70(±35.36)
4. Shikari	265.00(±4.62)	62.29(±3.76)	31.12(±2.91)	83.43(±3.18)	1132.90(±21.65)
5. Jiuni	331.00(±5.69)	42.74(±3.18)	21.88(±1.45)	51.78(±2.03)	537.50(±5.20)
6. Balu	390.00(±6.36)	50.16(±4.34)	20.38(±1.20)	87.21(±3.29)	897.70(±8.75)
Mean	354.00(±37.16)	45.21(±6.33)	23.50(±2.61)	62.28(±10.45)	719.71(±149.09)

DBH = Diameter at Breast Height

Table 2: Tree biomass (Mean ± Standard Error) ($ton.ha^{-1}$).

Site	Stem Biomass	Branch Biomass	Needle Biomass	Tree AGB	Tree BGB	Total Tree Biomass
1. Majhwar	216.43(±5.21)	54.07(±4.06)	9.79(±1.45)	277.88(±10.10)	55.58(±2.02)	333.46(±11.92)
2. Mehni	84.06(±4.36)	25.87(±2.34)	7.90(±0.88)	117.83(±5.76)	23.57(±1.15)	141.39(±6.51)
3. Barot	434.08(±7.13)	96.34(±4.05)	17.54(±1.45)	547.98(±12.64)	109.59(±2.53)	657.58(±13.56)
4. Shikari	518.48(±5.37)	132.36(±5.30)	27.82(±1.77)	678.66(±11.06)	135.73(±2.21)	814.40(±12.87)
5. Jiuni	238.51(±4.98)	50.14(±4.36)	13.97(±1.20)	302.49(±9.85)	60.50(±1.96)	362.99(±10.62)
6. Balu	407.90(±4.41)	91.53(±4.06)	19.03(±1.86)	518.46(±8.92)	103.69(±1.78)	622.15(±9.90)
Mean	316.58(±66.60)	75.05(±15.80)	16.01(±2.94)	407.22(±85.11)	81.44(±17.02)	488.66(±102.13)

AGB = Aboveground biomass, BGB = Belowground biomass

equal to 1.53

Thus, the weight of stem wood was estimated using the formula, i.e. mass per unit volume.

Stem biomass = average specific gravity of stem wood × volume

Branch biomass: The total number of branches irrespective of size was counted on each of the sample tree, then these branches were categorized on the basis of basal diameter into three groups viz. small, medium and large. Fresh weight of two sampled branches from each group was recorded separately. The following formula (Chidumaya 1990) was used to determine the dry weight of branches:

Bdwi = Bfwi/ (1 + Mcbdi)

Where, Bdwi = oven dry weight of branches, Bfwi = Fresh/ green weight of branches, Mcdbi = Moisture content of branches on oven dry weight basis

Total branch biomass (Fresh/dry) per sample tree was determined as given by:

Bbt = n1bw1 + n2bw2 + n3bw3 - Σnibwi

Where, Bbt = Branch biomass (fresh/dry) per tree, Ni = Number of branches in the ith branch group, bwi = Average weight of branch of ith group.

I = 1, 2, 3,.... the branch groups

Leaf biomass: Leaves from the branches were removed, weighed and oven dried separately to a constant weight at 80 ±5°C. The average leaf biomass was then arrived at by multiplying the average biomass of the leaves per branch with the number of branches in a single tree and the number of trees in a plot (Koul & Panwar 2008).

The total tree aboveground biomass was the sum of stem, branch and leaf biomass. The tree belowground or root biomass of tree was calculated indirectly with the help of relationship of root/shoot ratio by multiplying aboveground biomass with a factor of 0.20 (IPCC 2003).

Understory biomass (shrubs and herbs): The understory biomass was estimated by destructive method randomly at 3 points in a plot size of 3m×3m for shrubs and climbers and 1m×1m for herbs and grasses within the main plot (50m×20m) by uprooting aboveground and belowground parts of undergrowth vegetation and weighing the total fresh weight of undergrowth vegetation within the measurement plot. A sample of ± 300 gram for shrubs and herbs from each point was weighed and taken to the laboratory, where it was dried in oven at a temperature of 70°C to 85°C until reaching a constant weight; then again it was weighed to find out the dry weight of the undergrowth plants and organic carbon analysis was conducted in the laboratory to examine the carbon content.

Litter biomass: Litter biomass was measured by collecting the litter randomly from three points in the measurement plot of 1m×1m size within the main plot (50m×20m) and then weighing the total weight of each of them. A sample of

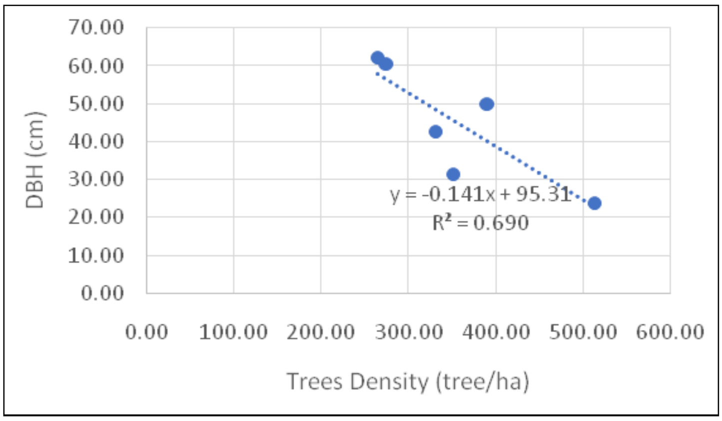

Fig. 1: Relationship between tree density and DBH.

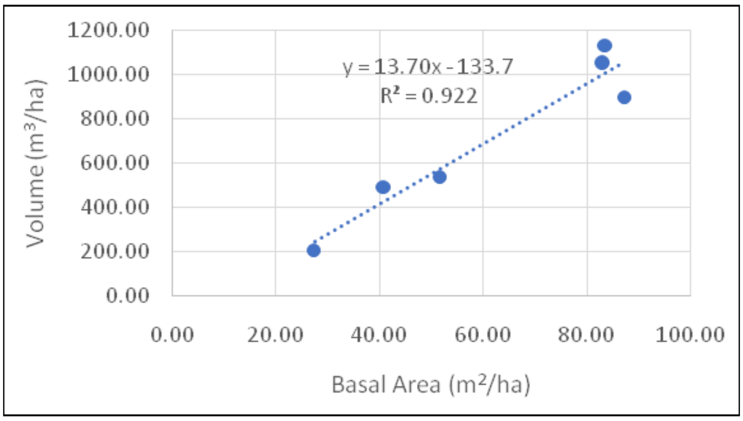

Fig. 2: Relationship between tree basal area and volume.

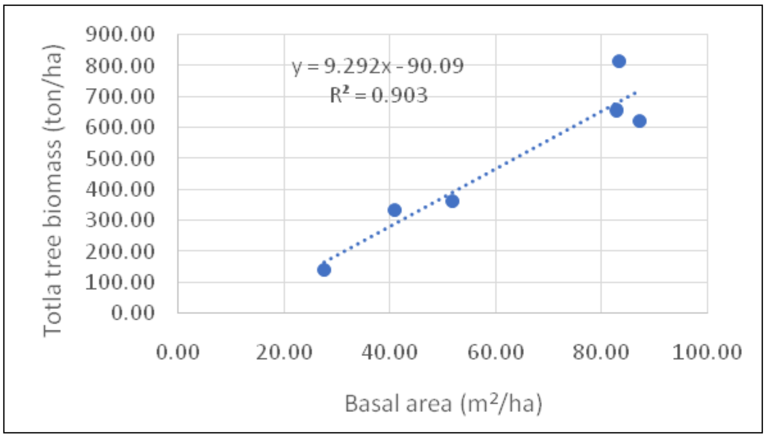

Fig. 3: Relationship between tree basal area and tree biomass.

±300 gram was weighed and taken to the laboratory from each point, and further estimation was done like the understory biomass.

Carbon percentage estimation: The carbon percentage was estimated by the ash content method described by Negi et al. (2003). In this method, oven dried plant components (bark, leaves, stem wood and litter) were burnt in a muffle furnace at 400°C. The ash content left after burning was weighed and carbon content was calculated by using the following equation:

Carbon % = 100 – [ash weight + molecular weight of O_2 (53.3) in $C_6H_{12}O_6$]

The carbon (%) was then multiplied with the biomass to get biomass carbon stock.

Carbon stock = Biomass × carbon (%)

Soil sampling and analysis: Soil samples were collected randomly from 3 sites within the main plot (50m×20m) at three different soil depths of 0-15 cm, 16-30 cm and 31-45 cm. Samples from all the three sites at each soil depth from study site were dried and sieved through 2 mm mesh before analysis. For organic carbon estimation Walkley and Black's method (Walkley 1934) was used. In this method, about 60-86% of SOC is oxidized, therefore, a standard correction factor of 1.32 was used to obtain the corrected SOC value.

For bulk density in each sample plot, aggregated undisturbed soil cores were taken by soil corer at three different soil depths of 0-15 cm, 15-30 cm and 30-45 cm. When taking cores for measurements of bulk density, extra care was taken to avoid any loss of soil from the samples. The soil samples were weighed immediately and transported to the laboratory where they were oven dried at 105 ± 5°C for 48 h and again weighed. In the soils containing coarse rocky fragments, the coarse fragments were separated by sieve and weighed. The bulk density of the mineral soil core was calculated with the help of the following formula described by (Pearson et al. 2005).

$$\text{Bulk density } (g/cm^3) = \frac{\text{Oven dry mass (g)}}{\text{Core volume}(cm^3) - (\text{Mass of coarse fragments(g)}/2.65(g/cm^3)}$$

Where, 2.65 was taken as constant for the density of rock fragments (g/cm^3). Soil carbon stock was then calculated for each soil layer based on the thickness of the soil layer, its bulk density and carbon concentration. The total carbon content of 45 cm depth was finally estimated by summing all layers (Pearson et al. 2005).

$$\text{SOC } (Mg.ha^{-1}) = [\text{Soil bulk density } (g.cm^{-3}) \times \text{soil depth (cm)} \times C)] \times 100$$

RESULTS AND DISCUSSION

Forest stand structure: The tree density varied from lowest 265 trees/ha at Shikari site to highest 513 trees/ha at Mehni site, however, the mean tree density was 354 trees/ha for all the 6 sites, which was slightly higher than the tree density of 198 trees/ha and 238 trees/ha reported by Ahmad et al. (2014) and Amir et al. (2015), but was lower than the findings of Sharma et al. (2011), i.e. 447.5 tree/ha. The DBH ranged from 23.92 cm to 62.29 cm with a mean value of 45.21 cm for all the 6 sites. The tree density showed a significant negative relationship with DBH (R^2=0.69, $P<0.05$, Fig. 1). The total tree height varied from 15.45 m to 31.37 m with a mean height of 23.50 m. The mean basal area and volume were found to be 62.28 m^2/ha and 719.71 m^3/ha respectively, which are in close conformity with the values reported by Dar & Sahu (2018), i.e. 63.03 m^2/ha and 665.3 m^3/ha in a similar study in Kashmir Himalaya. The basal area showed a significant positive relationship with volume (R^2=0.92, $P<0.05$, Fig. 2), which is in conformity with the similar trend observed by Ahmad et al. (2014). The details of forest stand structure are given in Table 1.

Tree biomass and carbon: The above ground tree biomass ranged from lowest 117.83 ton/ha at Mehni site to highest 678.66 ton/ha at Shikari site with a mean value of 407.22 ton/ha for all six sites. The contribution of stem, branch and needles to the total aboveground biomass ranged from 71.34-78.85 %, 16.58-21.95 % and 3.52-6.71 % respectively. The belowground biomass ranged from 23.57 ton/ha at Mehni site to 135.73 ton/ha at Shikari site with a mean value of 81.44 ton/ha. Similarly, the total tree biomass also ranged from 141.39 ton/ha at Mehni site to 814.40 ton/ha at Shikari site with a mean value of 488.66 ton/ha for all the six sites, which is in line with the findings of Dar & Sahu (2018) (i.e. 496.7 ton/ha) for *Cedrus deodara* forests of Kashmir Himalaya and are in close conformity with the findings of Sharma et al. (2011) (i.e. 533.2 ton/ha) in a similar study on forest types of temperate region of Garhwal Himalaya. The basal area showed a significant positive relationship with tree biomass (R^2=0.90, $P<0.05$, Fig. 3), which is similar to the results obtained by Brown et al. (1989), Chaturvedi et al. (2011) and Dar & Sundarapandian (2015). The detailed component wise and site wise findings for tree biomass are given in Table 2.

Aboveground carbon stocks (AGC) of tree varied among different sites (Table 3). Data reveal that maximum aboveground carbon (AGC) stock, 317.68 ton/ha was obtained at Shikari site, whereas minimum AGC stock, 54.48 ton/ha was found at Mehni site. The mean AGC stock for all the 6 sites was found to be 147.66 ton/ha. The belowground carbon (BGC) also showed a similar trend with maximum

Table 3: Tree carbon content (Mean ± Standard Error) (ton.ha^{-1}).

Site	Stem Carbon	Branch Carbon	Needle Carbon	Tree AGC	Tree BGC	Total Tree Carbon
1. Majhwar	101.09(±2.73	24.35(±2.03	4.17(±0.88	129.80(±4.65	25.96(±0.93	155.76(±4.05
2. Mehni	38.87(±3.76	11.96(±1.77	3.65(±0.87	54.48(±2.65	10.90(±0.53	65.38(±2.98
3. Barot	203.67(±3.53	45.20(±3.18	8.23(±0.77	257.11(±5.81	51.42(±1.16	308.54(±7.16
4. Shikari	242.70(±2.91	61.96(±3.67	13.02(±0.60	317.68(±5.08	63.54(±1.01	381.22(±5.14
5. Jiuni	109.64(±2.97	23.05(±2.91	6.42(±0.71	139.05(±4.53	27.81(±0.91	166.87(±4.21
6. Balu	189.96(±3.76	42.63(±3.18	8.86(±0.78	241.45(±4.14	48.29(±0.82	289.73(±4.69
Mean	147.66(±60.27)	34.86(±14.23)	7.39(±3.02)	189.93(±40.02)	37.99(±8.00)	227.92(±48.02)

AGC = Aboveground carbon, BGC = Belowground carbon

Table 4: Understory (shrubs and herbs) and litter biomass and carbon (Mean ± Standard Error) (ton.ha^{-1}).

Site	Understorey Biomass	Litter Biomass	Understorey Carbon	Litter Carbon
1. Majhwar	3.96(±0.12)	1.47(±0.06)	1.71(±0.05)	0.62(±0.02)
2. Mehni	2.57(±0.07)	1.26(±0.04)	1.13(±0.03)	0.54(±0.01)
3. Barot	4.85(±0.06)	2.01(±0.04)	2.10(±0.02)	0.86(±0.01)
4. Shikari	3.84(±0.04)	2.12(±0.06)	1.68(±0.01)	0.90(±0.02)
5. Jiuni	4.23(±0.06)	1.41(±0.04)	1.86(±0.02)	0.60(±0.01)
6. Balu	4.15(±0.05)	1.89(±0.05)	1.80(±0.02)	0.81(±0.02)
Mean	3.93(±0.31)	1.69(±0.15)	1.71(±0.06)	0.72(±0.06)

Table 5: Soil organic carbon stock (Mean ± Standard Error) (ton.ha^{-1}):

Sites	Soil Depth (cm)			Total
	0-15	16-30	31-45	
1. Majhwar	24.41(±0.48)	21.59(±0.36)	19.17(±0.31)	65.17(±0.89)
2. Mehni	26.97(±0.55)	23.15(±0.35)	20.48(±0.42)	70.61(±1.14)
3. Barot	29.08(±0.66)	25.45(±0.37)	22.19(±0.41)	76.72(±1.38)
4. Shikari	32.22(±0.52)	29.03(±0.56)	26.78(±0.56)	88.03(±1.62)
5. Jiuni	30.43(±0.69)	26.73(±0.41)	23.65(±0.65)	80.81(±1.73)
6. Balu	27.35(±0.68)	24.51(±0.66)	23.77(±0.41)	75.63(±1.71)
Total Mean Soil Organic Carbon Stock				76.16(±3.24)

Table 6: Total carbon stocks (ton/ha).

Tree Carbon (AG + BG)	Understory Carbon	Litter Carbon	Soil Organic Carbon	Total Carbon Stocks
227.92(±48.02)	1.71(±0.13)	0.72(±0.06)	76.16(±3.24)	306.51(±51.45)

AG = Above ground, BG = Below ground, Value in parenthesis is standard error of mean

BGC stock of 63.54 ton/ha at Shikari site and lowest BGC stock at 10.90 ton/ha at Mehni site with a mean of 37.99 ton/ha. The total tree carbon stock varied from 65.38 ton/ha to 381.22 ton/ha among the six sites with a mean value of 227.92 ton/ha, which is in line with the findings of Dar & Sahu (2018) and Sharma et al. (2011), i.e. 228.47 ton/ha and 245.32 ton/ha, respectively. It is higher than the value reported by Ahmad et al. (2014), i.e. 140.37 ton/ha, but lower than the findings of Amir et al. (2015) for similar forest types in Pakistan Himalaya.

Understory (shrubs and herbs) biomass and carbon: The understory biomass of shrubs and herbs varied from lowest 2.57 ton/ha at Mehni site to highest 4.85 ton/ha at Barot site, with a mean value of 3.93 ton/ha for all the six sites. The understory carbon stock showed a similar trend and ranged from 1.13 ton/ha to 2.10 ton/ha with a mean value of 1.71 ton/ha (Table 4). These understory species are adaptable and tolerant to habitat types and environment stresses like temperature, erratic rainfall and aridity (Holmgren & Holmgren 1977, Gleason & Cronquist 1991, Speranza 1995), therefore, distributional pattern seems to be not dependent on a particular soil condition (Bell et al. 2000, Hubbell 2001).

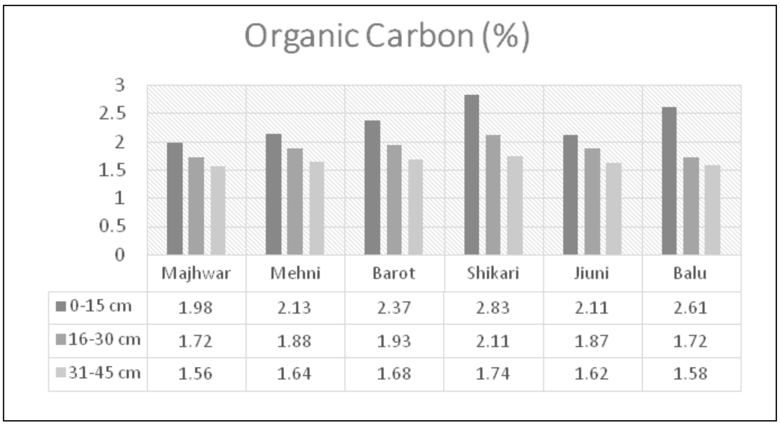

Fig. 4: Variation of organic carbon percentage with soil depth.

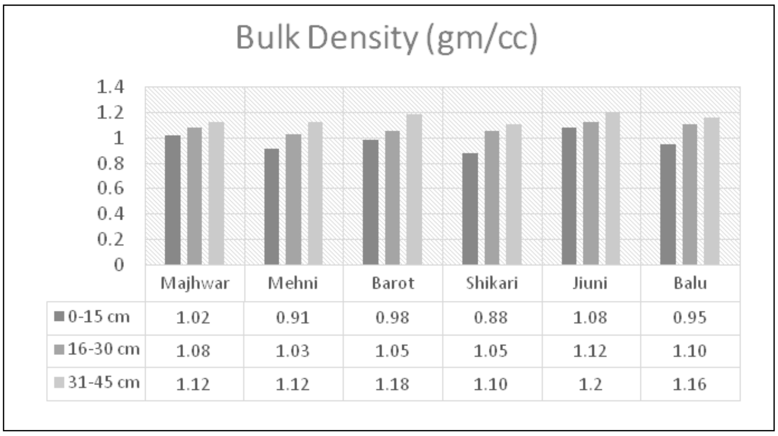

Fig. 5: Variation of bulk density with soil depth.

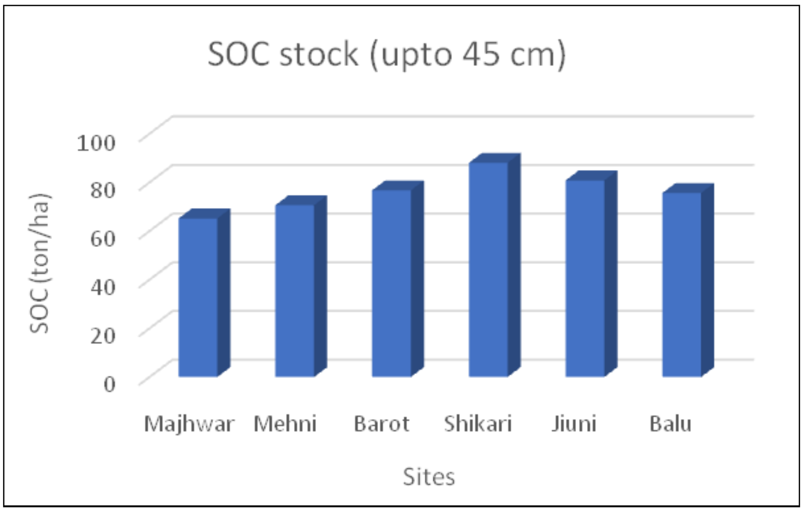

Fig. 6: Variation of total soil organic carbon stock up to 45 cm depth in different sites.

Litter biomass and carbon: Evaluation of litterfall production is important for understanding nutrient cycling, forest growth, successional pathways and interactions with environmental variables in forest ecosystems. Litter production varies with climate, season, substrate quality and type of vegetation (Hobbie 1992, Melillo et al. 1982, Upadhyay et al. 1989, Vitousek et al. 1994).

In this study, the litter biomass varied from 1.26 ton/ha to 2.12 ton/ha with a mean value of 1.69 ton/ha for all sites, whereas, the litter carbon stocks varied from 0.54 ton/ha to 0.90 ton/ha among the sites with a mean value of 0.72 ton/ha (Table 4). The higher litter stocks here might imply that the forest floor was an important carbon pool in the forest ecosystem. However, the carbon pool on the forest floor was neglected in many studies (Guo et al. 2004, Liu et al. 2004, Sun et al. 2003).

Soil organic carbon (SOC): The soil organic carbon percentages varied from 1.98-2.83 %, 1.72-2.11 % and 1.56-1.74 % at soil depth of 0-15 cm, 16-30 cm and 31-45 cm respectively, with mean values of 2.34 %, 1.87 % and 1.64 % (Fig. 4). Whereas, the soil bulk density varied from 0.88-1.08 g/cc, 1.03-1.12 g/cc and 1.10-1.20 g/cc at soil depth of 0-15 cm, 16-30 cm and 31-45 cm respectively, with mean values of 0.97 g/cc, 1.07 g/cc and 1.15 g/cc (Fig. 5). The soil organic carbon showed a decreasing trend with increasing soil depth, whereas the bulk density increased with increasing soil depth. Similar results, i.e. trend of decreasing SOC values with increase in depth have also been reported by Dar & Somaiah (2013) and Jobbagy & Jackson (2000).

The soil organic carbon stocks ranged from 24.41-32.22 ton/ha, 21.59-29.03 ton/ha and 19.17-26.78 ton/ha at soil depths of 0-15 cm, 16-30 cm and 31-45 cm respectively, with mean values of 28.41 ton/ha, 25.08 ton/ha and 22.67 ton/ha for respective depth zones. However, the total SOC stocks up to 45 cm depth ranged from lowest 65.17 ton/ha at Majhwar site to highest 88.03 ton/ha with a mean value of 76.16 ton/ha for all six sites (Table 5, Fig. 6). The results are in close conformity with the findings of Negi et al. (2010) (i.e. 82.14 ton/ha), but less than the values reported by Gupta & Sharma (2011) (i.e. 120.35 ton/ha). Our findings are also in line with the value reported (55.42 ton/ha only up to 30 cm soil depth) by Dar & Sahu (2018) for *Cedrus deodara* forest in Northern Kashmir Himalaya.

Total carbon stocks: The total mean carbon stock in tree, understory, litter and soil was found to be 227.92(±48.02) ton/ha, 1.71(±0.13) ton/ha, 0.72 (±0.06) ton/ha and 76.16 (±3.24) ton/ha respectively. The total carbon stock under *Cedrus deodara* forest of Mandi district was calculated by adding the carbon stocks under all the four carbon pools and was found to be 306.51(±51.45) ton/ha (Table 6). Sharma et al. (2011) in their study on temperate forests of Garhwal Himalaya reported a total carbon stock value of 390.67 ton/ha for similar forests which is slightly higher than our findings. A similar study by Dar & Sahu (2018) in Kashmir Himalaya reported a total tree carbon stock value 228.47 ton/ha for *Cedrus deodara* forests, which is in conformity with our study. Ahmad et al. (2014) reported a total tree carbon stock value of 140.37 ton/ha for similar forest in Pakistan, which was slightly lower than that of our findings.

CONCLUSIONS

In the present study, it was found that the *Cedrus deodara* (CD) forest stored about 306.51 ton/ha of carbon. Among the different tree components, stem recorded the maximum carbon stock followed by root, branch and needle, respectively. Also, soil is the second largest carbon pool after trees contributing 24.85 % of the total carbon stocks of CD forests ecosystem. So, it can be suggested from the study that increase in the coverage of protected area and afforestation using CD species will provide long term carbon fixation capacity, thus the use of such trees with higher carbon sequestration capacity could improve carbon stocks, thus mitigating the carbon dioxide in the atmosphere.

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REFERENCES

Ahmad, A., Mirza, S.N. and Nizami, S.M. 2014. Assessment of biomass and carbon stocks in coniferous forest of Dir Kohistan, KPK. Pak. J. Agri. Sci., 51(2): 335-340.

Amir, M., Khan, A., Ahmad, A. and Khan, A. 2015. Carbon stocks of pure Cedrus deodara forest in Kumrat Valley, Dir Upper, KPK, Pakistan. International Journal of Scientific & Engineering Research, 6(4).

Bell, G. 2000. Environmental heterogeneity and species diversity of forest edges. Journal of Ecology, 88: 67-87.

Bitlerlich, W. 1984. The Relaskop Idea Slough: Common Wealth Agricultural Bureause. Farnham Royal, England.

Brown, S. and Lugo, A.E. 1982. The storage and production of organic matter in tropical forests and their role in the global carbon cycle. Biotropica, 14: 161-187.

Brown, S., Gillespie, A.J.R. and Lugo, A.E. 1989. Biomass estimation methods for tropical forests with applications to forest inventory data. Forest Science, 35: 881-902.

Chaturvedi, R.K., Raghubanshi, A.S. and Singh, J.S. 2011. Carbon density and accumulation in woody species of tropical dry forest in India. Forest Ecology and Management, 262: 1576-1588.

Chidumaya, E.N. 1990. Above ground woody biomass structure and productivity in a Ambezian woodland. Forest Ecology and Management, 36: 33-46.

Clark, W.C. 1982. Carbon Dioxide Review. Oxford University Press, Oxford.

Dar, J.A. and Sundarapandian, S. 2015. Variation of biomass and carbon pools with forest type in temperate forests of Kashmir Himalaya, India. Environmental Monitoring and Assessment, 187: 1-7.

Dar, D.A. and Sahu, P. 2018. Assessment of biomass and carbon stock in temperate forests of Northern Kashmir Himalaya, India. Proceedings of the International Academy of Ecology and Environmental Sciences, 8(2): 139-150.

Dar, J.A. and Somaiah, S. 2013. Soil organic carbon stock assessment in two temperate forest types of Western Himalaya of Jammu and Kashmir, India. Forest Res., 3(114): 2.

Gleason, H.A. and Cronquist, A. 1991. Manual of Vascular Plants of Northeastern United States and Adjacent Canada. 2nd Edition, The New York Botanical Garden, Bronx, NY.

Goodale, C.L., Apps, M.J., Birdsey, R.A., Field, C.B., Heath, L.S., Houghton, R.A., Jenkins, J.C., Kohlmaier, G.H., Kurz, W., Liu, S., Nabuurs, G.J., Nillson, S. and Shvidenko, A.Z. 2002. Forest carbon sinks in the Northern Hemisphere. Ecological Applications, 12: 891-899.

Guo, R., Wang, X.K., Liu, K. and Yang, F. 2004. Carbon and nitrogen pool in forest soil under *Pinus sylvestris* var. mongolica. Soils, 36(2): 192-96. (in Chinese)

Hamburg, S.P. 2000. Simple rules for measuring changes in ecosystem carbon in forestry-offset projects. Mitigation and Adaptation Strategies for Global Change, 5: 25-37.

Hobbie, S. E. 1992. Effect of plant species on nutrient cycling. Trends in Ecology and Evolution, 7: 336-339.

Hoen, H.F. and Solberg, B. 1994. Potential and economic efficiency of carbon sequestration in forest biomass through silvicultural management. Forensic Science International, 40(3): 429-451.

Holmgren, A.H. and Holmgren, N.H. 1977. Poaceae. In: A. Cronquist, A.H. Holmgren, N.H. Holmgren, J.L. Reveal and P.K. Holmgren (eds.), Intermountain Flora, Vol. 6. New York: Columbia Univ. Press.

Houghton, R.A. 1991. Release of carbon to the atmosphere from degradation of forests in tropical Asia. Canadian Journal of Forest Research, 21: 132-142.

Houghton, R.A. 1990. The future role of tropical forests in affecting the carbon dioxide concentration of atmosphere. Ambio, 19: 204-209.

Hubbell, S.P. 2001. The Unified Neutral Theory of Biodiversity and Biogeography. Princeton, U.S.: Princeton University Press, pp. 448.

IPCC 2003. Good Practice Guidance for Land Use, Land Use Change and Forestry. IPCC National Greenhouse Gas Inventories Programme, Hayama, Japan, pp. 295.

Jobbagy, E.G. and Jackson, R.B. 2000. The vertical distribution of soil organic carbon and its relation to climate and vegetation. Ecological applications, 10(2): 423-436.

Khurana, P. 2012. A study on carbon sequestration in natural forests of India. Journal of Applied and Natural Science, 4(1): 132-136.

Koul, D.N. and Panwar, P. 2008. Prioritizing land management option for carbon sequestration potential. Current Science, 95: 658-663.

Liu, X. W., Chen, B.M. and Shi, X.Z. 2004. A review of the research on land use and land cover change in China. Soils, 36(2): 132-135. (in Chinese)

Masera, O.R., Caligaris, J.F.G., Kanninen, M., Karjalainen, T., Liski, J., Nabuurs, G.J., Pussinen, A., Jong, B.H.J. and Mohren, G.M.J. 2003. Modeling carbon sequestration in afforestation, agroforestry and forest management projects: the CO_2FIX V.2 approach. Ecological Modelling, 164: 177-199.

Melillo, J. M., Aber, J. D. and Muratore, J. F. 1982. Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. Ecology, 63: 621-626.

Negi, J.D.S., Manhas, R.K. and Chauhan, P.S. 2003. Carbon allocation in different components of some tree species of India: A new approach for carbon estimation. Current Science, 85: 1528-1531.

Pearson, T., Walker, S. and Brown, S. 2005. Source book for land use, land-use change and forestry. VA, USA: Projects Winrock International.

Prentice, I.C., Farquhar, G.D., Fasham, M.J.R., Goulden, M.L, Heimann, M., Jaramillo, V.J., Kheshgi, H.S., LeQuere, C., Scholes R.J. and Wallace, D.W. 2001. The Carbon Cycle and Atmospheric Carbon Dioxide. CambridgeUniversity Press, USA

Pressler, M. 1865. Das Gesetzder Stambildung Leipzig, pp. 153.

Sharma, C.M., Gairola, S., Baduni, N.P., Ghildiyal, S.K. and Suyal, S. 2011. Variation in carbon stocks on different slope aspects in seven major forest types of temperate region of Garhwal Himalaya. India. J. Biosci., 36(4): 701-708.

Smith, D.M. 1954. Maximum Moisture Content for Determining Specific Gravity of Small Wood Samples. Forest Product Laboratory. USDA Forest Service Report, pp. 2014.

Smithwick, E.A.H., Harmon, M.E., Remillard, S.M., Acker, S.A. and Franklin, J.F. 2002. Potential upper bounds of carbon stores in forests of the Pacific Northwest. Ecological Applications, 12: 1303-1317

Speranza, F., Villa, I.M., Sagnotti, L., Florindo, F., Cosentino, D., Cipollari, P. and Mattei, M. 1995. Age of the Corsica-Sardinia rotation and Liguro-Provencal Basin spreading: New paleomagnetic and Ar/Ar evidence. Tectonophysics, 347: 231-25.

Sun, W.X., Shi, X.Z. and Yu, D.S. 2003. Distribution pattern and density calculation of soil organic carbon in profile. Soils, 35(3): 236-241. (in Chinese)

UNFCCC 1997. Report of the Conference of the Parties on its Third Session, Held at Kyoto, Japan from 1 to 11 December 1997.

Upadhyay, V.P., Singh, J. and Meentemeyer, V. 1989. Dynamics and weight loss of leaf litter in central Himalayan forests: Abiotic versus leaf litter quality influences. Ecology, 77: 147-161.

Upadhyay, T.P., Sankhayan, P.L. and Solberg, B. 2005. A review of carbon sequestration dynamics in the Himalayan region as a function of land-use change and forest/soil degradation with special reference to Nepal. Agric. Ecosys. Environ., 105: 449-465.

Vitousek, P.M., Turner, D.R., Parton, W.J. and Sanford, R.L. 1994. Litter decomposition on the Mauna Loa environmental matrix, Hawaii: Patterns, mechanisms and models. Ecology, 75: 418-429.

Walkley, A.J. and Black, I.A. 1934. Estimation of soil organic carbon by chromic acid titration method. Soil Science, 37: 29-38.