Sains Malaysiana 52(3)(2023): 723-740
http://doi.org/10.17576/jsm-2023-5203-04

Carbon Sequestration, Biomass and Soil Carbon Pool Estimation in Oak-Dominated Forests of Hindu-Kush Range Mountains of Pakistan

(Penyerapan Karbon, Biojisim dan Anggaran Takungan Karbon Tanah di Hutan Didominasi Oak di Banjaran Hindu-Kush di Pakistan)

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Received: 15 June 2021/Accepted: 20 February 2023

ABSTRACT

The present study aimed to determine the vegetation biomass, soil carbon stocks and carbon sequestration potential of Oak-dominated forests. Thirty forest stands having 10 quadrats of 20×20 were randomly sampled. Out of eighteen tree species, twelve species were associated with Group II followed by Groups I and III, with eight species each. *Quercus dilatata* was the only Oak species recorded in all three groups having maximum density in Group II (56.14). *Quercus semecarpifolia* accounted the highest proportion of carbon (235 MgC/ha) in Group II. *Quercus baloot*, being the dominant species of Group I, is found to accommodate the highest quantities of BMC (335±43 Mg/ha) for all size classes. The highest nitrogen content, total nitrogen and carbon-nitrogen ratio were 0.185%, 8.23 and 59.64, respectively, in Group II. The mean bulk density was 1.519 g/cm^3 in Group III. The highest soil organic carbon (SOC) was recorded in Group II (2.69%, 119.82 tons/ha). Because of their large aerial scale and high carbon density, Oak-dominated forests in Group II store most of the carbon. These results suggest that organic carbon is a major source of forest carbon with significant climate change mitigation potential that must be conserved and improved by sustainable forest management.

Keywords: Bulk density; carbon sequestration; forest carbon; mitigation potential; vegetation biomass

ABSTRAK

Kajian ini bertujuan untuk menentukan biojisim tumbuh-tumbuhan, stok karbon tanah dan potensi penyerapan karbon hutan yang didominasi Oak. Tiga puluh dirian hutan yang mempunyai 10 kuadrat 20×20 telah diambil secara rawak. Dalam lapan belas spesies pokok, dua belas spesies dikaitkan dengan Kumpulan II diikuti oleh Kumpulan I dan III, dengan lapan spesies setiap satu. *Quercus dilatata* adalah satu-satunya spesies Oak yang direkodkan dalam ketiga-tiga kumpulan yang mempunyai ketumpatan maksimum dalam Kumpulan II (56.14). *Quercus semecarpifolia* menyumbang bahagian tertinggi karbon (235 MgC/ha) dalam Kumpulan II. *Quercus baloot*, sebagai spesies dominan Kumpulan I, didapati dapat menampung kuantiti tertinggi BMC (335±43 Mg/ha) untuk semua kelas saiz. Kandungan nitrogen tertinggi, jumlah nitrogen dan nisbah karbon-nitrogen adalah 0.185%, 8.23 dan 59.64, masing-masing dalam Kumpulan II. Purata ketumpatan pukal ialah 1.519 g/cm^3 dalam Kumpulan III. Karbon organik tanah (SOC) tertinggi dicatatkan dalam Kumpulan II (2.69%, 119.82 tan/ha). Oleh kerana skala udaranya yang besar dan ketumpatan karbon yang tinggi, hutan yang didominasi oleh Oak dalam Kumpulan II menyimpan kebanyakan karbon. Keputusan ini menunjukkan bahawa karbon organik adalah sumber utama karbon hutan dengan potensi pengurangan perubahan iklim yang ketara yang mesti dipelihara dan diperbaiki oleh pengurusan hutan yang mampan.

Kata kunci: Biojisim tumbuhan; karbon hutan; ketumpatan pukal; penyerapan karbon; potensi mitigasi

Introduction

The important plant species found in different altitudinal gradients in temperate forests (Rahman et al. 2020b), where significant carbon stocks and sequestration have been recorded, are Oak trees (*Quercus* spp.). Overall, carbon stocks in temperate forest ecosystems are comparable to those found in tropical forest ecosystems, according to Lal and Lorenz (2012). Temperate forests sequester 0.2-0.4 PgC year^{-1}, or around 37% of the global annual carbon intake (CCTF 2016). The temperate forest in the Pacific Northwest is estimated to store 334 MgC ha^{-1} on average, while forest carbon stocks in New Zealand range from 364 MgC ha^{-1} to 672 MgC ha^{-1} (Keith, Mackey & Lindenmayer 2009). Chile's temperate forests' carbon reserves range from 326 MgC ha^{-1} to 571 MgC ha^{-1} (Keith, Mackey & Lindenmayer 2009). Because of the favourable climatic and soil conditions for tree growth, temperate forests can have high carbon stocks per unit area (Poudel, Sasaki & Abe 2020). Other variables, including high plant species diversity, rapid growth, slow decomposition, mature stands, dense canopy cover, and less human disturbance, can contribute to the high carbon stocks and carbon sequestration per unit area in temperate forests (Wei et al. 2013).

Green houses gases (GHGs) play a vital role in the current climate change. The concentration of carbon dioxide increases the temperature of the earth, which results in the form of global warming. The heat emitted from the earth into the atmosphere badly affects our atmosphere, plants, and animals (IPCC 2007a). Climate change is a global issue (Ali et al. 2014). The primary causes for these abrupt changes are anthropogenic factors like urbanization, energy production, fossil fuel consumption, industrialization and land use for agriculture (Stern 2007). Likewise, increasing concentrations of gases like hydro-fluorocarbons, carbon dioxide, sulfur dioxide, and other hazardous gases are not only affecting the environment (IPCC 2007b), but also rising the global temperature day by day which might lead to 1.8 °C to 4 °C at the end of the century (Ali et al. 2019). Carbon dioxide is the initial cause of global warming; forests are the main sources of mitigating the CO_2 and are known as the store house of global warming which can absorb CO_2 from the atmosphere (Goers, Lawson & Garen 2012).

The removal process of CO_2 from the atmosphere by plants using sunlight producing biomass and oxygen is called carbon sequestration (Tagupa et al. 2010). Forest carbon sequestration is a key process in reducing carbon concentrations from the environment and storing them in plants (Chavan & Rasal 2012). It is a safe, environmentally acceptable, and cost-effective way to capture and store substantial amounts of atmospheric carbon (Vikrant & Chauhan 2014). Forest ecosystems account for about 76% of all carbon in the terrestrial biosphere and play a vital role in the environment to cycle carbon dioxide in a proper way (Justine et al. 2015), but due to certain human activities, for example, deforestation, the emission of CO_2 increases, resulting in global warming (Larsson et al. 2007). Forests are important carbon sinks, but the mitigation rate would depend upon the species of the forest; it may be broadleaved forest and coniferous (Watson et al. 2000). The main issue is losing of biodiversity day by day which is leading to the decline of such great natural reservoirs (Körner et al. 2005). New forest management such as ecological service forest (ESF) is developing in China, which helps in decreasing anthropogenic factors and increase carbon storage in forests. These forests provide benefits ecologically and should not be used for fuel (Zhou, Yu & Zhao 2000). Due to the woody nature of trees (Ali et al. 2017), they can accommodate more carbon in the current climate changing era because the carbon percentage is increasing in the atmosphere on daily basis, which may lead to the extinction of certain plant and animal species (Hughes 2017).

The estimated forest area in the world is 4 billion hectares, having a significant role in mitigating CO_2 (Adams 2012). Forests plantations have little input as compared to the entire balance of terrestrial ecosystem. Globally, only 3.8% area of the earth is covered by forests (FAO 2005), these forests, according to their capacity, are sequestering carbon and play vital role in mitigating climate change (Canadell et al. 2007).

In Pakistan, provincial forest departments conduct forest inventories to prepare forest working plans for their respective provinces. Nevertheless, there is a lack of information on carbon reserves in forest resources. There have been several studies on the role of planted forests in climate change mitigation (Justine et al. 2015), but very little information has been documented on the distribution pattern of carbon pools with respect to natural forests. Similarly, no relevant study has been conducted regarding carbon stock in the Hindukush mountains range, especially, on the broadleaved forests in the district Swat of Khyber Pakhtunkhwa, Pakistan. Therefore, the current study was develop (1) to determine the vegetation biomass and soil carbon stocks of the Oak-dominated forests, (2) identify the factors influencing their distribution of carbon stock and (3) to estimate the carbon sequestration potential of the local and regional forest ecosystem. The current research will provide the preliminary baseline informations to the forest managers for utilizing these resources for carbon.

Materials and Methods

STUDY AREA

Swat was selected for this study due to some vital reasons, i.e., it is a zone of rich diversity having important plant species but, are exposed to the recent climate changes due to excessive man-mad anthropogenic activities as reported by Rahman et al. (2020b). Although the area was hit by flood in 2010 due to its prone nature to climate changes, however, in 2022, the area has been again hit by massive flood further strengthening the view that the area is under intense climate changes and it's an issue of utmost importance to be addressed. Swat district is located in the northern Hindukush Mountain range (34° 34' to 35° 55' N and 72° 08' to 72° 50' E) of Pakistan (Ali et al. 2018; Iqbal et al. 2018; Zeb et al. 2020). The total area of the Swat Valley is 5337 km2 and spanning between an altitudinal range from 1000 m-3000 m above sea level. This region is covered with thick Oak forests and distributed in three major vegetation types (Group I-III) where *Quercus baloot*, *Q. incana*, *Q. dilatata*, and *Q. semecarpefolia* are indicator species apart from fourteen other tree species growing in association (Figure 1). These Oak species are the dominant tree species in the region and therefore, were taken as representative for estimating the carbon sequestration potential.

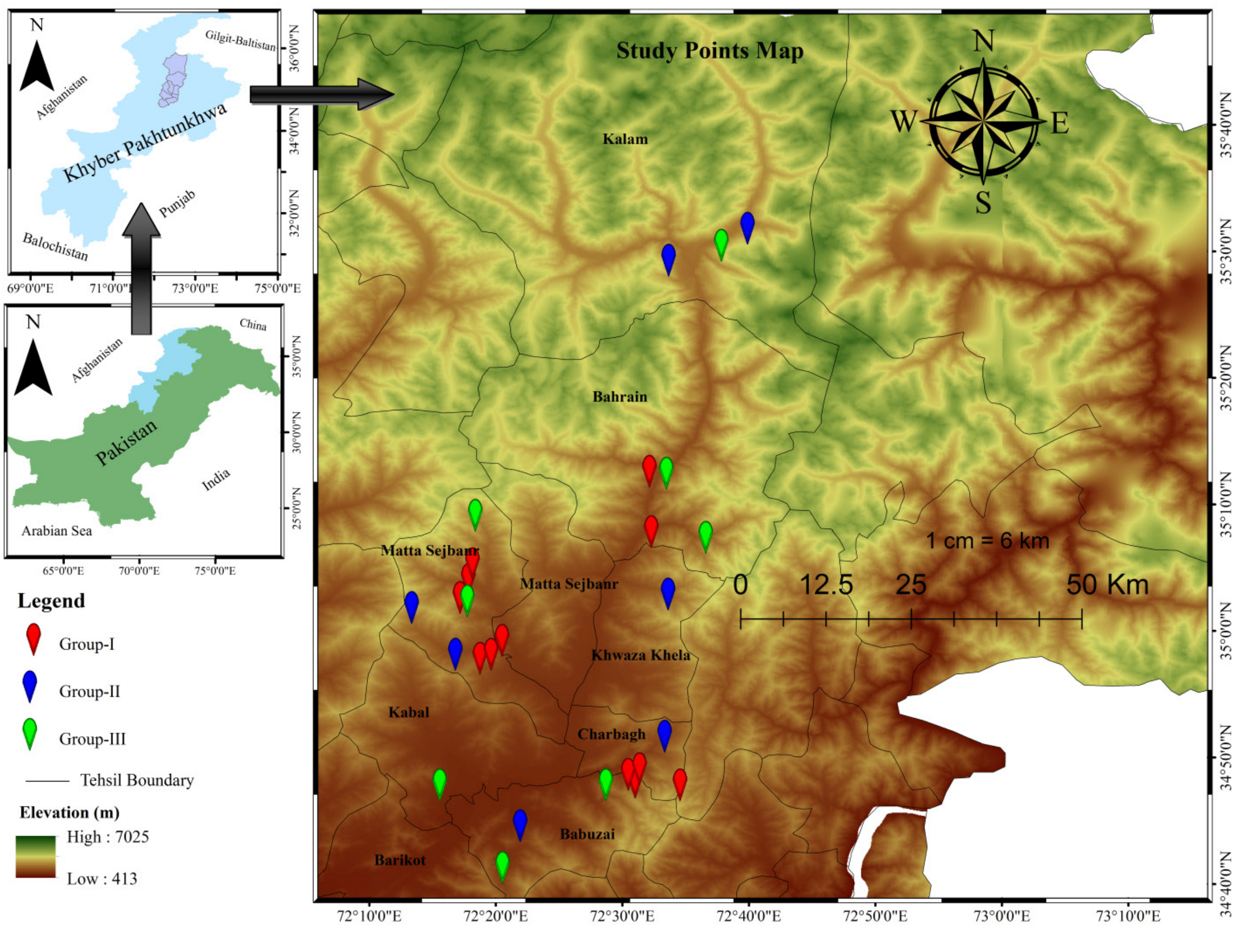

FIGURE 1. Study area map, indicating sampling points group wise with different colour symbols

DATA COLLECTION AND DESIGN

A total of 30 forest stands were selected for data collection. In each forest, a total of 10 quadrats of 20×20 (400m^2) were randomly sampled for vegetation analyses. Trees having diameter greater than 5 cm were measured for diameter (1.3 m above ground level) and height respectively. The phytosociological attributes i.e., relative basal area (RBA), relative density (RD), and relatively frequency (RF) following Rahman et al. (2020a, 2017) were calculated to obtain importance value index (IVI) of all the woody species in a forest stand (McCune, Grace & Urban 2002).

GROWING STOCK CHARACTERISTICS AND BIOMASS CARBON ANALYSIS

Parameters such like density of tree/ha, height in meters, diameter in centimeter, basal area (BA) of stand (m^2/ha) and volume of stand/ha were determined. The volume of each tree was measured by 0.42×H×BA (Philip 1994). Wood density and volume were measured by using stem biomass (SB) with the formula SB (t/ha) = wood density (kg^{-3})×stem volume (m^3/ha), whereas tree biomass in t/ha was estimated from stem biomass expansion factor (BEF) and SB, by computing the formula TB/tha= SB×BEF (Nizami 2012). The conversion factor 0.5×TB(t/ha) was used for estimating total carbon density (TCD) (Roy, Saugier & Mooney 2001). Different statistical softwares including SPSS, Sigma-plot and PAST were used for data analysis and various descriptive and inferential statistics like coefficient of variance (CV%), Mean±SE and regression models were computed for different dendrometric parameters i.e., stem density/ha, diameter (cm), BA (m^2/ha), tree height (m), tree volume (m^3/ha) and SB (t/ha), respectively.

SOIL SAMPLING AND ANALYSIS

Soil samples were taken from each stand of the forest at a depth of 0-30 cm (Rahman et al. 2021) and then further analyses were carried out in the soil laboratory. Total soil in tons ha^{-1} was calculated by using the following formula (Nizami 2012).

$$SC = SOC\% \times SBD \times TH(CM) \times 100$$

where SC means soil carbon (tons ha^{-1}); SOC-soil organic carbon (tons ha^{-1}); SBD-soil bulk density (gm cm^{-3}), and TH -thickness of horizon (cm).

SOIL ORGANIC CARBON (SOC)

The soil organic carbon (SOC) was determined by following a factor of 0.58 (Rahman et al. 2011). Soil carbon density ha^{-1} was calculated following Ali et al. (2019) and Penman et al. (2003).

$$\text{SOC} = \rho \times d \times \text{C} \times 10$$

where SOC is the soil organic carbon; ρ is the bulk density; d is the soil depth; and C is the carbon content.

SOIL BULK DENSITY

The wet weights of the samples were measured on site with a digital balance. Samples were packed in polythene bags and transported to the laboratory where these were air-dried, and then placed in an oven at 105 °C for 24 h. The dehydrated samples were weighed and moisture content (MC%) was determined following Hartley and Marchant (2005).

$$\text{MC}\% = \frac{Ww - Wd}{Wd} \times 10$$

where MC (%) is the moisture content; Ww is the wet weight; and Wd is the dry weight. Bulk density was calculated by the following equation (Agus et al. 2010).

$$\text{BD} = \frac{Wd}{Vs}$$

where B_D is the bulk density; Wd is the oven dry weight of sample (g); Vs is the volume of soil core (cm^3).

SOIL ORGANIC MATTER

Organic matter in soil was estimated through the loss on ignition (LoI) method (Nelson & Sommers 1996, 1983; Schumacher 2002). The dehydrated sample was placed in a china dish and then in muffle furnace. Temperature was set at 400 °C and run continuously for about 8 hours to burn it till ash production. Each ash sample was weighted, and the OM was evaluated following the equation (Rahman et al. 2011).

$$OM = Wd - Wa$$

where OM is the organic matter (g); Wd is the weight of oven- dried sample (g); Wa is the weight of ash (g).

RESULTS

CARBON STOCK IN OAK-DOMINATED COMMUNITIES

Based on the analysis of stored carbon stock in the biomass samples, Table 1 also shows the variations of carbon stock among three major groups. *Quercus semecarpifolia* accounted the highest proportion of carbon (235 MgC/ha) from Group II. *Q. incana* was recorded in Groups III and I with 159.6 MgC/ha and 93.75 MgC/ha, respectively, in living trees biomass than in other forest associates due to their dominance. *Q. incana* was followed by *Q. dilatata* with 85 MgC/ha in Group II, 1.37 MgC/ha in Group I and 0.4 MgC/ha in Group III. Similarly, carbon in litters (LiC) was estimated 75.91 MgC/ha and 7.85 MgC/ha in Group I and II, respectively. The rest of 10 tree species associated were estimated with lower carbon in litters (13 MgC/ha). As these results clearly demonstrates that the indicators species stored most of the carbon stock in Oak-dominated forests (Table 1).

TABLE 1. Descriptive statistics of volume/hectare for different Oak-dominated communities sampled in District Swat Hindukush mountain range of Pakistan

Species name	Code	Group I	Group II	Group III
		Mean±SE	Mean±SE	Mean±SE
Quercus incana	Qi	93.75±44.16	0	159.6±32.05
Quercus dilatata	Qd	1.37±1.11	85±35	0.4±0.4
Quercus baloot	Qb	75.91±37.85	7.85±5.07	0
Quercus semecarpifolia	Qs	0	235±120	0
Pinus roxburghii	Pr	0.87±0.74	1.85±1.85	2±1
Pinus wallichiana	Pw	-	9.14±7.21	0
Olea ferruginea	Of	1.5±1.5	12.14±9.1	3.6±2
Diospyrus lotus	DI	0	0	1.3±0.6
Diospyrus kaki	Dk	0	0	0.1±0.1
Melia azedarach	Ma	0	0.85±0.85	1.13±1.13
Cedrus deodara	Cd	11.62±11.62	0	0.46±0.46
Taxus baccata	Tf	0	1.57±1.57	0
Abies pindrow	Ap	0	1.85±1.85	0
Picea smithiana	Ps	0	7.28±5.54	0
Pinus gerardiana	Pg	1.75±1.75	0	0
Juglans regia	Jr	0.25±0.25	0	0
Parratiopsis jacquemontiana	Pj	0	1±1	0
Aesculus indica	Ai	0	0.57±0.57	0

CARBON AND NUTRIENT STOCKS FROM OAK-DOMINATED COMMUNITIES

The nitrogen content was determined among all three major groups which resulted into non-significant differences ($p > 0.7567$). The highest nitrogen content was found in Group II (0.185%) followed by Group III (0.153%) and Group I (0.1336%, Table 2). Significant differences ($p < 0.0771$) were found in the organic matter content. Maximum organic matter content was found in Group II with 4.63% followed by Group I with 2.46% and Group III with 2.43% (Table 2).

The estimates of soil organic carbon (SOC) in major groups were recorded with significant differences ($p < 0.0771$). Maximum SOC was found in Group II with a mean of 2.69% followed by Group I with 1.43% and Group III with 1.41% (Figure 2(A)). Significant differences ($p < 0.0771$) were also recorded in the estimates of soil organic carbon (SOC) densities among major groups. Highest SOC amount was found in Group II with a mean of 119.82 tons/ha followed by Group I with 3.97 tons/ha and Group III with 62.69 tons/ha (Table 2, Figure 2(C)).

The results for soil bulk density in the top 15-30 cm layers of hosting major groups are presented in Table 2. Mean bulk densities in Group III, Group I, and Group II were 1.519 g/cm^3, 1.473 g/cm^3 and 1.465 g/cm^3, respectively (Figure 2(F)). Total nitrogen was determined among all three major groups, which resulted into non-significant differences ($p > 0.7541$). The highest nitrogen content was in Group II (8.23 tons ha^{-1}) followed by Group III (6.99 tons ha^{-1} and Group I (5.84 tons ha^{-1}, Table 2 and Figure 2(B)).

The carbon-nitrogen ratio was also determined in the Oak-dominated forests among the major groups which showed significant differences. The maximum ratio was recorded in Group II (59.64 tons ha^{-1}) followed by Group III (31.98 tons ha^{-1}), and Group I (31.34 tons ha^{-1}, Table 2 and Figure 2(D)). As far as distribution range of these major groups along the elevation is concerned, Group II was recorded at the highest elevational range followed by Group I. However, Group III was found at the lowest elevation (Figure 2(G)).

TABLE 2. Descriptive statistics and ANOVA of carbon and Nutrients stock for the Oak-dominated communities

Parameters	Abbreviation (Unit)	Group I	Group II	Group III	F-Statistics	P-value
		Mean±SD	Mean±SD	Mean±SD		
Nitrogen	N (%)	0.1336±0.04	0.185± 0.03	0.153±0.03	0.2819	0.7567
Organic matter	OM (%)	2.4673±0.85	4.6334±0.73	2.439±0.55	2.8437	0.0771
Soil organic carbon	SOC (%)	1.4345±0.49	2.6939±0.42	1.418±0.325	2.8437	0.0771
Bulk density	BD (g/cm)	1.473±0.015	1.4651±0.02	1.519±0.016	2.803	0.0797
Soil organic carbon	SOC (Tons/ha)	62.69±21.36	119.82±18.9	63.97±14.5	2.8109	0.0792
Total nitrogen	TN (ha^{-1})	5.8431±2.12	8.2361±1.75	6.99±1.75	0.2854	0.7541
Carbon: Nitrogen	C: N	31.3452±10	59.6412±9.48	31.98±7.25	2.8109	0.0792
Inter species		9.225±2.473	3.1150±0.58	4.6129±1.89	2.8451	0.0877
Total community		16.3±7.1	7.14±1.62	4.72±1.9	1.8683	0.1847

DENSITY OF THE ASSOCIATES IN MAJOR GROUPS

A total of eighteen tree species were found in the Oak-dominated forests, but their distribution varied among the major recorded groups. Twelve species were found as associated species in Group II followed by Groups I and III with eight species each. *Quercus dilatata* was the only Oak species recorded in all the three groups but had the maximum density in Group II (56.14). *Quercus*

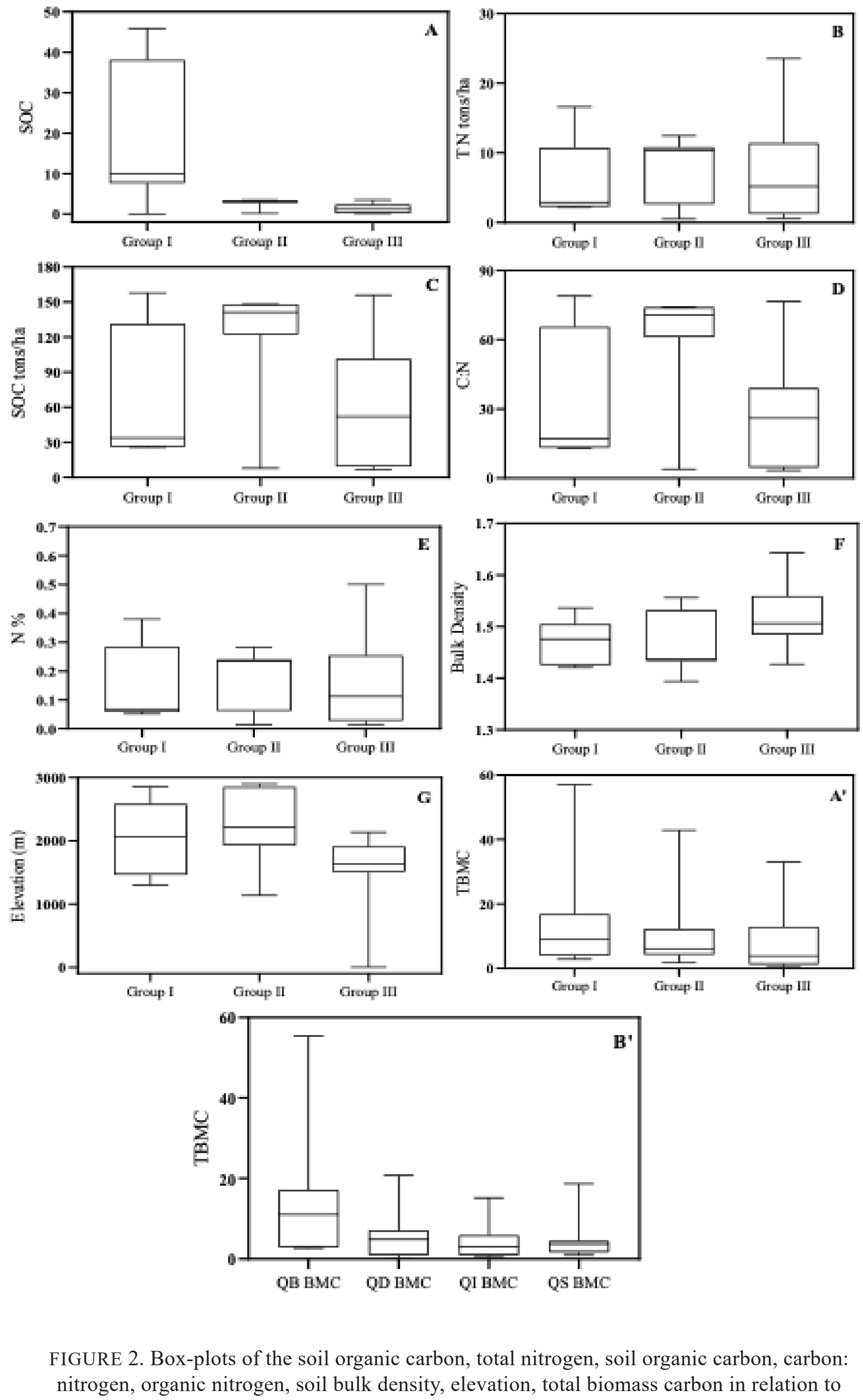

FIGURE 2. Box-plots of the soil organic carbon, total nitrogen, soil organic carbon, carbon: nitrogen, organic nitrogen, soil bulk density, elevation, total biomass carbon in relation to major groups and total biomass carbon in Oak-dominated communities

baloot and *Q. semecarpifolia* were recorded in Groups I and II, however, *Q. baloot* dominated Group I with 117.12 density and *Q. semecarpifolia* dominated Group II with a density of 52.42. Nonetheless, *Q. incana* was recorded in Group II only, but with the highest density (118.6) as compared to others. Among other fourteen species, *Olea ferrugenia* was the only associate that had the highest densities (9.14, 385 and 2.62) in Groups II, III and I, respectively (Table 3). The density (ha^{-1}) of all Oak species (i.e., *Quercus incana, Q. dilatata, Q. baloot* and *Q. semecarpifolia*) were determined in relation to the DBH classes. In Group I, *Q. semecarpifolia* was recorded with maximum saplings, DBH (11-20 cm) and seedlings had 260, 191 and 117 densities ha^{-1}. *Q. baloot* was recorded with maximum saplings and seedlings in Group II with 260 and 117 densities ha^{-1}, respectively, but found limited in other DBH classes. However, in Group III *Q. incana* was recorded with maximum saplings, DBH (11-20 cm) and seedlings with 229, 156.5 and 150 densities ha^{-1} (Figure 3).

TABLE 3. Descriptive statistics of the Oak and associated tree species density (ha^{-1}) in District Swat, Pakistan

Species name	Species code	Group I	Group II	Group III
		Mean±SE	Mean±SE	Mean±SE
Quercus incana	Qi	0	0	118.6±15.98
Quercus dilatata	Qd	0.62±0.62	56.14±23.80	0.66±0.66
Quercus baloot	Qb	117.125±23.95	5.14±3.85	0
Quercus semecarpifolia	Qs	12.37±12.09	52.42±25.75	0
Pinus roxburghii	Pr	1.25±0.90	1.57±1.57	2.62±1.67
Pinus wallichiana	Pw	0.125±0.125	1.14±0.98	0
Olea ferruginea	Of	2.62±2.62	9.14±6.21	3.85±2.11
Diospyrus lotus	Dl	0	0	1.4±0.67
Diospyrus kaki	Dk	0	0	0.13±0.13
Melia azedaracha	Ma	0	0.85±0.85	1±1
Cedrus deodara	Cd	0	0	0.86±0.86
Taxus baccata	Tf	0	0.28±0.28	0
Abies pindrow	Ap	0	0.28±0.28	0
Picea smithiana	Ps	1.25±1.25	1.71±1.40	0
Pinus gerardiana	Pg	0	0	0
Juglans regia	Jr	0	0	0
Parratiopsis jacquemontiana	Pj	0	0.71±0.71	0
Aesculus indica	Ai	0.125±0.125	0.14±0.14	0

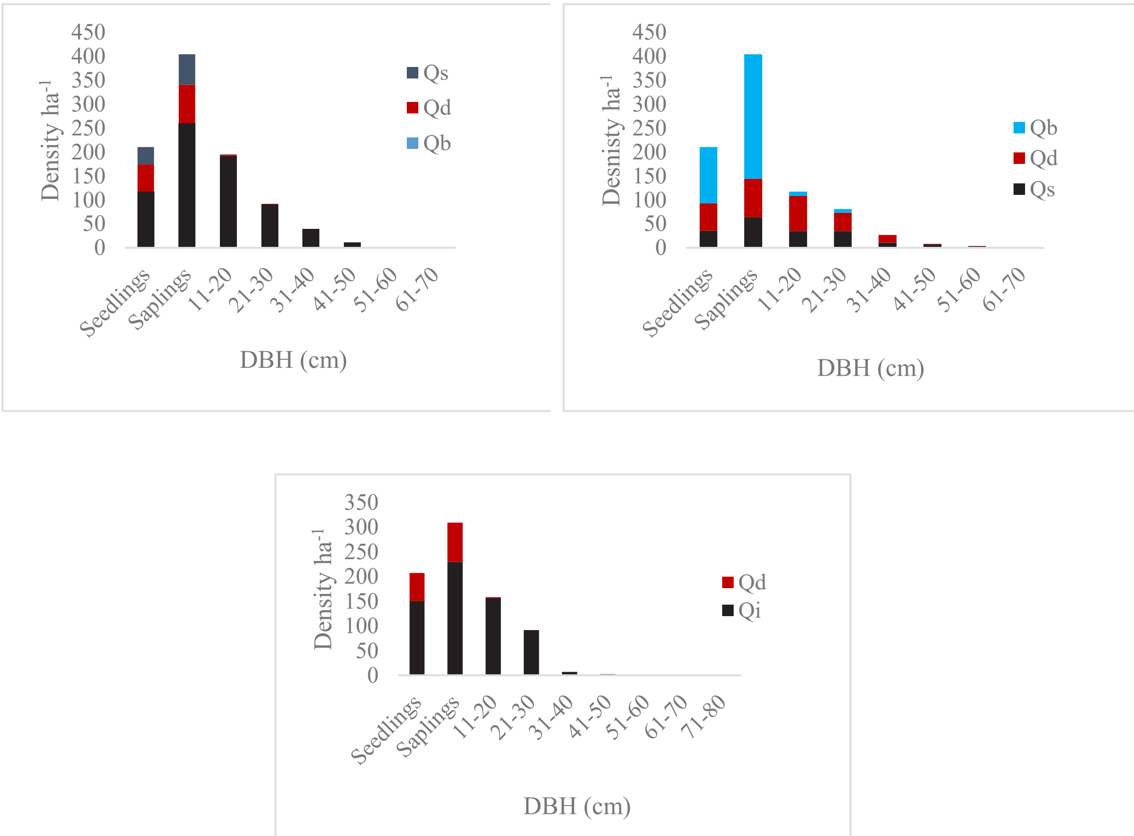

FIGURE 3. Density per hectare of Oak tree species in different DBH size classes for Groups I-III

VARIATION IN SOC ALONG THE BULK DENSITY AND ELEVATIONAL GRADIENT

Regression analysis was used to assess the variation between elevation and the total carbon stocks (and their components). Simple linear, quadratic and exponential regression were used according to the data structure and tested for their suitability. The SOC tons/ha across the studied plots showed that 40% of plots ranged 125-160 Mg C/ha and about 45% plots had 10-55 Mg C/ha, but all of these plots were found scattered in bulk density of 1.40 to 1.60 g/cm^3. The quadratic model was the most parsimonious model for the relationship between SOC and elevation, it shows decreasing trend till 2000-meter elevation and increasing trend onwards (Figure 4).

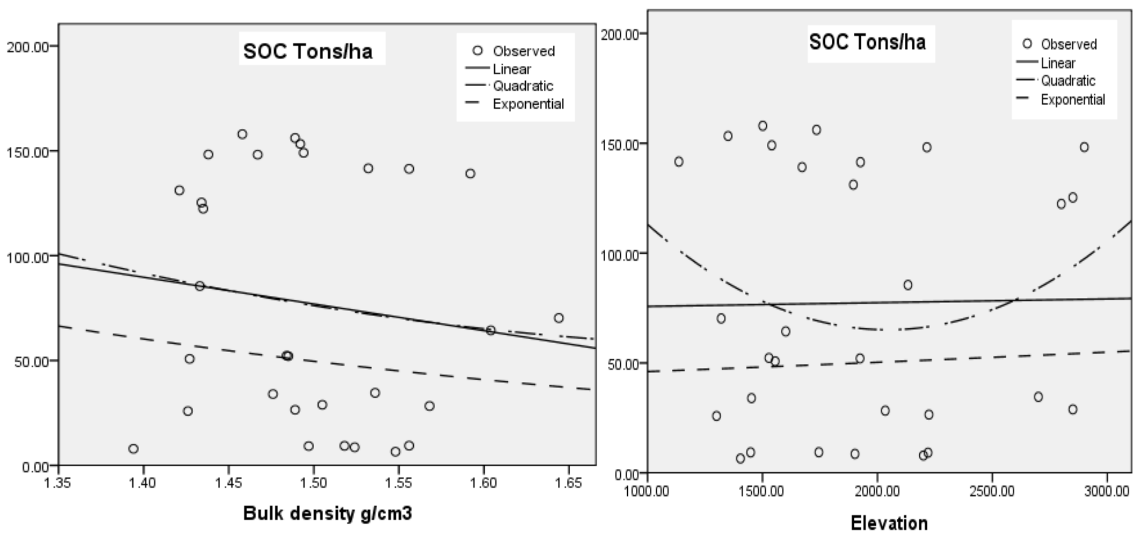

FIGURE 4. Soil organic carbon variation along the bulk density (g/cm^3) and elevational gradient in the Oak-dominated forests of Swat, Pakistan

FOREST STRUCTURE, COMPOSITION AND BIOMASS CARBON OF COMMUNITIES

Different size classes of tree species found in Group I and biomass of carbon present in each class represented in Table 4. The diameter size class 31-40 cm showed highest biomass carbon i.e., 17.88 Mg/ha followed by 21-30 cm with BMC of 14.88. In plant community, QB was found to be the most efficient in BMC, accommodating 55.35 Mg/ha of carbon. The lowest BMC was for QS and PR, is 0.05±0.02 and 0.04±0.02, respectively (Table 4). Group type II is dominated by QD with highest BMC of 20.74±2.95 followed by QS accommodating

TABLE 4. Biomass carbon (Mg/ha) estimates of Groups I, II and III associated species in different size classes (cm)

Group I							
Size classes	QB BMC	PR BMC	QD BMC	QS BMC	OF BMC	CD BMC	TBMC
11-20	6.94	0.04	0.11	0.05	0.15	0.00	7.31
21-30	14.64	0.00	0.16	0.00	0.00	0.08	14.88
31-40	17.15	0.00	0.00	0.00	0.00	0.43	17.57
41-50	11.04	0.00	0.00	0.00	0.00	0.00	11.04
51-60	2.71	0.00	0.00	0.00	0.00	0.67	3.38
61-70	2.87	0.00	0.00	0.00	0.00	0.00	2.87
Total	55.35	0.04	0.27	0.05	0.15	1.17	57.05
SD	6.06	0.02	0.07	0.02	0.06	0.28	6.05
Group II							
Size classes	QS BMC	QD BMC	QB BMC	PR BMC	OF BMC	AP BMC	PS BMC
11-20	0.96	4.83	0.33	0.06	0.62	0.01	0.03
21-30	4.21	6.20	1.29	0.00	0.98	0.00	0.12
31-40	3.59	7.04	0.00	0.00	0.00	0.00	0.00
41-50	4.48	0.99	0.00	0.00	0.00	0.00	0.00
51-60	3.71	1.68	0.00	0.00	0.00	0.00	0.00
61-70	1.74	0.00	0.00	0.00	0.00	0.00	0.00
Total	18.70	20.74	1.62	0.06	1.60	0.01	0.15
SD	1.43	2.95	0.52	0.02	0.43	0.01	0.05
Group III							
Size classes	QI BMC	QD BMC	PR BMC	OF BMC	DL BMC	DK BMC	MA BMC
11-20	5.87	0.07	0.02	0.04	0.06	0.06	0.03
21-30	15.20	0.00	0.00	0.00	0.00	0.00	0.00
31-40	4.29	0.00	0.00	0.00	0.00	0.00	0.46
41-50	2.52	0.00	0.00	0.00	0.00	0.00	0.00
51-60	0.94	0.00	0.00	0.00	0.00	0.00	0.00
61-70	0.47	0.00	0.00	0.00	0.00	0.00	0.00
71-80	3.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	32.29	0.07	0.02	0.04	0.06	0.06	0.49
SD	5.023	0.028	0.007	0.015	0.023	0.024	0.174

18.70±1.43 with minor contribution from other species (i.e., 3.44 Mg/ha) in total from other associated species. Among the diameter size classes, the most efficient was found to be the 21-30 cm size class accommodating 12.81 Mh/ha of carbon. The total amount of carbon sequestered by dominant and associated plant species was found to be 42.89±3.99 Mg/ha (Table 4). Group type III is the QI dominated with associated species for which the BMC quantities were calculated and presented in Table 3. The total BMC of the community was found to be 33.04±5.03, which is intermediate of Group I and Group II. The highest quantity of BMC was found to be of QI, which is 32.29±5.02. The diameter size classes 21-30 cm size accommodate highest quantities of BMC i.e., 15.20 Mg/ha, whereas the lowest is for the 61-70 cm size class, which is 0.47 Mg/ha (Table 4).

In Oak-dominated forests QB which is the dominant species of Group I was found to accommodate highest quantities of BMC (335±43 Mg/ha) for all size classes. QI was also found to accumulate sufficient quantities of BMC (i.e., 291±39 Mg/ha) compared to QD which is 251±120 Mg/ha (Table 5). QS was in Groups I and II where it accumulates 129±63 Mg/ha and 0.62±0.62 MG/ha of carbon, respectively. In associated species, PR and OF were relevant contributors in BMC of Oak-dominated communities accommodating an average of 6.44±4.4 Mg/ha and 14.22±5.21 Mg/ha of BMC. The other associated species had very minor contributions in carbon sequestration of Oak-dominated communities, which might be due to smaller number of tree species and also because they are artificially introduced in the forest where the environmental factors do not favour the growth of these species.

TABLE 5. BMC of different plant species of Oak and other associated species found in Oak-dominated communities

Species name	Species code	Group I Mean±SE	Group II Mean±SE	Group III Mean±SE
Quercus incana	QI	0	0	291±39
Quercus dilatata	QD	4.12±2.7	251±120	1.78±1.78
Quercus baloot	QB	335±43	28.29±24	0
Quercus semecarpifolia	QS	0.62±0.62	129±63	0
Pinus roxburghii	PR	3.12±2.2	10.95±10.95	6.26±4.4
Pinus wallichiana	PW	-	3.21±2.48	0
Olea ferruginea	OF	3.75±3.75	31±20	8.3±5.3
Diospyrus lotus	DI	0	0	3.7±1.7
Diospyrus kaki	DK	0	0	0.35±0.35
Melia azedaracha	MA	0	3.9±3.9	2.67±2.67
Cedrus deodara	CD	4.75±4.75	0	2.32±2.32
Taxus baccata	TF	0	0.71±0.71	0
Abies pindrow	AP	0	0.71±0.71	0
Picea smithiana	PS	0	4.2±3.5	0
Pinus gerardiana	PG	1.25±1.25	0	0
Juglans regia	JR	0.37±0.37	0	0
Parratiopsis jacquemontiana	PJ	0	1.78±1.78	0
Aesculus indica	AI	±	0.35±0.35	0

The C and N stock and C:N ratio presented in Table 6 shows highest C and N stocks in forest stand 20 followed by stand 9, while lowest nutrient stock was of stand 28. The average C stock was 56±19.68 tons/ha and N is 5.27±1.93 tons/ha with a C:N ratio of 28.00±9.84, which is suitable for sustaining forest growth. The C and N stocks along with ratios of Group II of Oak-dominated forests are tabulated in Table 6 which shows much higher C and N stocks than Group I, indicating a higher availability for these forests compared to Group I. All sites were found to have significant C:N ratio except for stand 27 which is much lower compared to other stands. The average C stock was found to be 119.28±18.97 tons/ha while average N stock was 8.24±1.75 tons/ha with C:N ratio of 59.64±9.49 which is much higher indicating fertile soil with high nutrient concentration. Group III is the largest group having fifteen stands with intermediate C and N stock with C:N ratio. The highest C stock was found to be that of stand 6 (85.48 tons/ha), while the N stocks of the same stand was (6.45 tons/ha) with C:N ratio of 42.74. The average C, N stock and C:N ratio for the community was found as 68.99±14.40 tons/ha, 7.61±1.74 tons/ha and 34.49±7.20, respectively (Table 6). Few of the stands i.e., 7, 8, 11 and 12 were found to have low C, N stocks and C:N ratios but on average the group was found to have suitable quantities of the nutrients that can support a forest ecosystem that can reduce significant amount of C from the atmosphere.

TABLE 6. Soil C and N stocks in Oak-dominated forests (Group I) in Swat Khyber Pakhtunhkwa, Pakistan

Group I							
Group I	% N	% Org Matter	Bulk density g/cm^3	SOC	SOC Tons/ha	T N tons/ha	C: N
St.1	0.052	1.041	1.426	0.605	25.892	2.225	12.946
St.9	0.252	5.29	1.421	3.076	131.112	10.743	65.556
St.20	0.38	6.21	1.458	3.610	157.922	16.621	78.961
St.22	0.061	1.32	1.476	0.767	33.982	2.701	16.991
St.24	0.063	1.29	1.536	0.750	34.560	2.903	17.280
St.25	0.075	1.1	1.505	0.640	28.875	3.386	14.438
St.26	0.052	1.02	1.489	0.593	26.490	2.323	13.245
St.28	0.028	0.351	1.497	0.204	9.165	1.257	4.582
Mean	0.12	2.20	1.48	1.28	56.00	5.27	28.00
SE	0.04	0.79	0.01	0.46	19.68	1.93	9.84
Group II							
St.10	0.231	5.21	1.556	3.03	141.40	10.78	70.70
St.11	0.234	5.3	1.532	3.08	141.62	10.75	70.81
St.15	0.283	5.79	1.467	3.37	148.15	12.45	74.07
St.23	0.062	5.91	1.438	3.44	148.23	2.67	74.12
St.27	0.013	0.324	1.394	0.19	7.88	0.54	3.94
St.29	0.24	4.89	1.435	2.84	122.39	10.33	61.20
St.30	0.235	5.01	1.434	2.91	125.31	10.11	62.65
Mean	0.19	4.63	1.47	2.69	119.28	8.24	59.64
SE	0.04	0.73	0.02	0.43	18.97	1.75	9.49
Group III							

St.2	0.102	2.04	1.427	1.19	50.77	4.37	25.39
St.3	0.102	2.02	1.484	1.17	52.29	4.54	26.14
St.4	0.102	2.01	1.485	1.17	52.06	4.54	26.03
St.5	0.501	1.034	1.568	0.60	28.28	23.57	14.14
St.6	0.15	3.42	1.433	1.99	85.48	6.45	42.74
St.7	0.0123	0.324	1.524	0.19	8.61	0.56	4.31
St.8	0.016	0.345	1.556	0.20	9.36	0.75	4.68
St.12	0.019	0.241	1.548	0.14	6.51	0.88	3.25
St.13	0.031	0.351	1.518	0.20	9.29	1.41	4.65
St.14	0.282	5.72	1.494	3.33	149.05	12.64	74.53
St.16	0.245	5.89	1.492	3.42	153.28	10.97	76.64
St.17	0.126	2.45	1.644	1.42	70.25	6.21	35.13
St.18	0.122	2.3	1.604	1.34	64.35	5.87	32.17
St.19	0.34	6.01	1.489	3.49	156.09	15.19	78.04
St.21	0.34	5.01	1.592	2.91	139.11	16.24	69.56
Mean	0.17	2.61	1.52	1.52	68.99	7.61	34.49
SE	0.04	0.55	0.02	0.32	14.40	1.74	7.20

In Oak-dominated forests, average mean stock value and C:N ratio is tabulated in Table 7, which shows that the %age organic matter of forest soil was 3.15±0.75 having soil organic carbon of 1.83±044%. The C and N stocks of the overall forest were found to be 81.42±19.20 tons/ha and 7.04±0.90 tons/ha with a C:N ratio of 40.71±9.65 which is suitable for sustaining of forest growth.

TABLE 7. Mean soil properties of all the Oak-dominated forest communities in Swat, Pakistan

Group	% N	% Org Matter	Bulk density g/ cm^3	SOC	SOC Tons/ha	T N tons/ha	C: N
I	0.12	2.20	1.48	1.28	56.00	5.27	28.00
II	0.19	4.63	1.47	2.69	119.28	8.24	59.64
III	0.17	2.61	1.52	1.52	68.99	7.61	34.49
Mean	0.16	3.15	1.49	1.83	81.42	7.04	40.71
SE	0.02	0.75	0.02	0.44	19.30	0.90	9.65

DISCUSSION

Forests function as a carbon sink increases by increasing above-ground biomass and increasing soil organic carbon content (Vikrant & Chauhan 2014). The quantification of carbon stocks in forests is important because it relates to estimates obtained in a vegetation type that has been understudied in relation to other ecosystems (Rosenfield & Souza 2013). *Quercus semecarpifolia* accounted the highest proportion of carbon (235 MgC/ha) from Group II having highest DBH. *Q. incana* was recorded in Group III and I with 159.6 MgC/ha and 93.75 MgC/ha, respectively, in living trees biomass than in other forest associates due to their dominance. There is substantial variation in carbon sequestration in Oak-dominated forests of Swat, Pakistan. These results are strongly supported by the statistical tests which showed distinct species segregation based on variations in the carbon stock levels. Similarly, Shaheen et al. (2016) reported the highest Carbon stock value of 326.32 t/ha in the *Pinus roxburghii* forest sites having highest DBH (150.78 cm). Low grazing and tree felling pressures, combined with improved environmental conditions, resulted in improved forest biomass growth (Semmartin, Di Bellade & Salamone 2010). These results clearly demonstrate that the indicator species stored most of the carbon stock in Oak-dominated forests because of better ecological and geographical gradients, greater density, DBH and height increment. The rest of 10 associated tree were estimated with lower carbon in litters (13 MgC/ha). Similarly, Shaheen et al. (2016) stated that mixed forest sites showed lower Carbon values attributed to low DBH, height, retarded regeneration, high deforestation and grazing.

The results for soil bulk density in the top 15-30 cm layers of hosting major groups showed the mean bulk densities in Group III, Group I and Group II were 1.519 g/cm^3, 1.473 g/cm^3 and 1.465 g/cm^3, respectively. The lowest bulk density in Group III is because these forests occur at high elevations where temperatures are mostly low and soil organic matter accumulates, making the soil porous and rich. Liu et al. (2016) reported soil bulk density in cold temperate forests of north-eastern China as 1.3 g/cm^3 which is slightly higher than our estimates (0.85-0.95 g/cm^3). This is possibly due to the fact that soil samples were taken from greater depths, i.e., 40 cm compared to our sampling depth of 15-30 cm because he bulk density increases with increasing soil depth (Penman et al. 2003). Liu et al. (2016) also estimated bulk density for subtropical broad-leaved forests in south-eastern China as 1.28 g/cm^3, which is closer to our estimate of 1.45 g/cm^3. Our estimates for Oak forests are closer to Shrestha and Devkota (2013) who reported the bulk densities in Oak and pine forests of Nepal as 0.64-0.75 g/cm^3 and 1-1.13 g/ cm^3, respectively.

Maximum organic matter content was determined in Group II with 4.63% followed by Group I with 2.46% and Group III with 2.43%. The highest amounts of soil organic matter in major groups of Oak forests are due to mostly low temperatures throughout the year except for a few months of summer. Due to low temperatures, organic matter accumulation is high, and decomposition is slow (Ali et al. 2019). Such forests also have cold and wet months in which organic matter accumulates. The Oak forest type has thick undergrowth and high litter contents which continuously adds to the soil organic matter. Siddiqui, Shaukat and Ahmed (2014) reported similar findings, they determined organic matter ranging from 2.6 to 10.5% in moist temperate forests of Malakand, Hazara and Azad Kashmir. Khan (2000) found soil organic matter as 4.57% in moist temperate forests of Hilkot, Pakistan. Khattak and Hussain (2007) reported soil organic matter in subtropical forests of Abbottabad as 4.2%. Måren et al. (2015) noted organic matter levels in semi-arid trans-Himalayan forests as 3.8% in Nepal.

Estimating soil organic carbon (SOC) is important, because soil contains the world's largest terrestrial active C pool, which plays a major role in the global C cycle. The estimated amount of organic C stored in the world's soils is about 1100-1600 pentagrams (Pg), more than twice the C in living vegetation (560 Pg) or in the atmosphere (750 Pg) (Sundquist 1993). Forests contribute to the soil carbon in the form of litter (leaves and twigs), large woody debris, roots and leaching from the litter layer (Ali et al. 2019). About 40% of the world's SOC is present in forest ecosystems (Sheikh, Kumar & Bussmann 2009). In the present study, maximum SOC was found in Group II with a mean of 2.69% followed by Group I with 1.43% and Group III with 1.41% in Oak-dominated forests. Highest SOC amount was found in Group II with a mean of 119.82 tons/ha followed by Group I with 3.97 tons/ha and Group III with 62.69 tons/ha. The Group III estimates of soil organic carbon are closer to the 71.0 t/ha in mountain temperate forests (Penman et al. 2003) and 81.9 t/ha soil carbon levels in cold temperate forests of north-eastern China (Liu et al. 2016). Nonetheless, due to their large aerial scale and high carbon density, Oak-dominated forests in Group

II store the most carbon. This research shows that soil organic carbon is a vital source of forest carbon, with substantial potential for mitigating climate change, and that it must be conserved and improved by sustainable forest management. The Group II estimates 119.82 tons/ha of soil organic carbon in the present study which lies in the range (70.0–162.0 t/ha) reported by Chhabra, Palria and Dadhwal (2003) in temperate forests of India. This is probably due to the fact that these samples have been taken from greater depth. Soil organic carbon is higher in Group II than Group I and III, this might be due to the soils Group II of Oak dominant forest are deep and wet due to which dense undergrowth develops in these forests resulting in the accumulation of humus.

Any activities that damage the soil, such as agricultural expansion or mining, would result in substantial carbon emissions in this region. As many researchers (e.g., Lal 2004; Soto-Pinto et al. 2010) reported that soils have lost as much as 20 to 80 tons Carbon (ha^{-1}) due to conversion of forest to agricultural ecosystems that severely causes depletion of the SOC. Forest fires and free grazing are also poor for holding soil organic carbon levels up. Due to a variety of factors, including steep slopes, current, and past glaciation, high rainfall intensities due to aerographic impact, and disturbed vegetation cover, the Himalayan region is vulnerable to high rates of soil erosion (Myers 2001). Besides high erosion rates, the downstream effects of mountain erosion are perceived to have severe effects. This suggests that soil organic carbon is a significant carbon pool in Khyber Pakhtunkhwa's forest ecosystems, and that it should be preserved in order to mitigate climate change. The creation of tradable carbon credits at the same time offers financial incentives for forest managers to consider carbon storage while making decisions. Furthermore, forest establishment for carbon sequestration has ecological, cultural, social, and economic values, and its protection not only serves as a source of global C, but also provides humans with a wider range of services and products (Justine et al. 2015).

Conclusions

Carbon sequestration in soil is important for lowering CO_2 levels in the environment. *Quercus dilatata* was the only Oak species recorded in all of the three groups but had the maximum density in Group II (56.14). In Group I, *Q. semecarpifolia* was recorded with maximum saplings (260 ha^{-1}), *Q. baloot* in Group II with maximum saplings (260 ha^{-1}) and *Q. incana* in Group III with maximum saplings (229 ha^{-1}) densities. In Oak-dominated forests, QB was found to accommodate highest quantities of BMC (335±43 Mg/ha) for all size classes. Highest nitrogen content, total nitrogen and carbon-nitrogen ratio were recorded in Group II (0.185%, 8.23 and 59.64), respectively. Mean bulk densities were found in Group III (1.519 g/cm^3). Maximum SOC was found in Group II with a mean of 2.69% followed by Group I with 1.43% and Group III with 1.41%. Highest SOC amount was found in Group II with a mean of 119.82 tons/ha followed by Group I with 3.97 tons/ha and Group III with 62.69 tons/ha. Since the majority of the forests in Khyber Pakhtunkhwa are located at higher elevations, it is concluded that these forests contain large quantities of soil organic carbon and that their protection is crucial for climate change mitigation. The effects of deforestation and forest destruction on soil carbon levels, as well as changes in soil carbon associated with afforestation and reforestation should also be studied. This will measure greenhouse emissions and removal due to improvements in the land use of the forested areas. In order to improve policies for forest conservation and climate change mitigation, more methodologies for biomass estimation in various forest types are needed. To develop options for sustainable forest management, the relationship between stand structure and forest management practices should be considered. In addition, the Khyber Pakhtunkhwa government, non-governmental organizations, and environmental protection agencies working in the region can utilizes this information in taking practical steps for the utilization of soil and air carbon pool to mitigate air and soil pollution and climate improvement in the long run.

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