Journal of Architecture, Engineering & Fine Arts

2022 4(2): 240-253

Available online at http://dergipark.org.tr/artgrid

Research Article

EFFECT OF DEVELOPMENT STAGES ON SOIL ORGANIC CARBON AND NITROGEN STOCKS OF SESSILE OAK (*Quercus petrea* (Matt.) Liebl): A CASE STUDY OF TAŞKÖPRÜ, KASTAMONU

Gamze SAVACI[1,*,a], Gülay AKTAŞ TÜMER[2,b]

[1] Kastamonu University, Faculty of Forestry, Department of Forest Engineering, Kastamonu, Türkiye
[2] Balıkesir Forest Enterprise Directorate, Bandırma Forest Sub-district Directorate, Balıkesir, Türkiye

[*]Correspondence: gsavaci@kastamonu.edu.tr

Received: 12 November 2022; Accepted: 25 December 2022; Published: 31 December 2022

ORCID[a]: 0000-0003-4685-2797 ORCID[b]: 0000-0002-3676-0875

Citation: Savacı, G., & Aktaş Tümer, G. (2022), Effect of development stages on soil organic carbon and nitrogen stocks of Sessile Oak (Q*uercus petrea* (Matt.) Liebl): A case study of Taşköprü, Kastamonu. *ArtGRID*, 4(2), 240-253

Abstract

This study aimed to determine the effects of four different development stages of sessile oak (*Quercus petrea* (Matt.) Liebl) stands on soil organic carbon (SOC) and total nitrogen (TN) stocks in northwest Turkey. According to the diameter at breast height (dbh), sessile oak stands were classified into four development stages namely: a development stage (<8cm), b development stage (8 to 19.9 cm), c development stage (20 to 35.9 cm) and d development stage (36 to 51.9 cm). Soil samples were taken from three different soil depths (0-10, 10-20, and 20-30 cm). Total 72 soil samples were collected from all development stages. Forest floor litters were also sampled from each development stage. Results showed that soil organic carbon varied significantly between the four development stages (R^2=0.714, p=0.000) with the highest stocks under the d development stage (55.0 Mg ha^{-1}) and the lowest under the b development stage (10.6 Mg ha^{-1}). Total N stock was highest under the a development stage (3.39 Mg ha^{-1}), whereas it was lowest under the b development stage (1.18 Mg ha^{-1}). About 71% of SOC was deposited in the upper 30 cm of the soil. The forest floor litter also varied between the four development stages with the highest values under the b development stage and the lowest under the a development stage. As a result, the results of the study indicated that sessile oaks can play a significant role in storing organic carbon and nitrogen in the soil. On the other hand, amounts of SOC and TN stocks can be significantly varied according to stand development stages.

Keywords: Diameter at breast height, sessile oak, mineral soil, carbon stocks, Kastamonu

Araştırma Makalesi

SAPSIZ MEŞENİN (*Quercus petrea* (Matt.) Liebl) TOPRAK ORGANİK KARBON VE AZOT STOKLARI ÜZERİNDE GELİŞİM ÇAĞLARININ ETKİSİ: TAŞKÖPRÜ, KASTAMONU ÖRNEĞİ

Özet

Çalışmada, Türkiye'nin kuzeybatısında yayılış gösteren sapsız meşenin (*Quercus petrea* (Matt.) Liebl) toprak organik karbon ve toplam azot stokları üzerinde dört farklı gelişim çağının etkisinin ortaya koyulması amaçlanmıştır. Göğüs yüzeyi çapına göre, sapsız meşe meşcereleri dört farklı meşcere gelişim çağlarına ayrılmıştır; a gelişim çağı (<8cm), b gelişim çağı (8-19.9 cm), c gelişim çağı (20-35.9 cm) and d gelişim çağı (36-51.9 cm). Farklı meşcere gelişim çağına sahip meşe ağaçları altından 0-10 cm, 10-20 cm ve 20-30 cm toprak derinlik kademesinden toplam 72 adet toprak örneği alınmıştır. Her deneme alanından ölü örtü örneklemesi de yapılmıştır. Toprak organik karbon stokları, meşcere gelişim çağları arasında önemli ölçüde farklılık göstermiştir (R^2=0.714, p=0.000). En yüksek değer d gelişim çağında (55.0 Mg ha^{-1}), en düşük değer ise b gelişim çağında (10.6 Mg ha^{-1}) bulunmuştur. Toplam azot stoku a gelişim çağında (3.39 Mg ha^{-1}), en yüksek b gelişim çağında (1.18 Mg ha^{-1}) en düşük belirlenmiştir. Sapsız meşelerde toplam toprak organik karbonun yaklaşık %71'i toprağın ilk 30 cm'sinde birikmiştir. Meşcere gelişim çağları ile ölü örtü birikimi arasında da farklılıklar bulunmuştur. En yüksek ölü örtü miktarı b gelişim çağında, en düşük ise a gelişim çağında tespit edilmiştir. Sonuç olarak, çalışmanın sonuçları sapsız meşenin TOK ve TA depolanmasında önemli bir rol oynadığını göstermiştir. Diğer yandan, sapsız meşenin TOK ve TA stoklarının meşcere gelişim çağlarına göre önemli değişiklikler gösterebilmektedir.

Anahtar kelimeler: Göğüs çapı, sapsız meşe, mineral toprak, karbon stoku, Kastamonu

1. INTRODUCTION

Forest ecosystems can play an important role in storing carbon in terrestrial ecosystems, which contain 80% of C (Dixon et al., 1994). Therefore, forest existence has an important place in itself in terms of the C cycle. Forest ecosystems are the most important source that can reduce the increased atmospheric CO_2 (Savacı 2017). Many studies have shown that forest soils, which are a significant element of the global C cycle, contribute approximately 70-73% of the global soil organic carbon pool (Six et al., 2002). About 500 billion tons of carbon stored in terrestrial ecosystems is not only stored in plants but a large part of the C is stored in soils. This amount is estimated as approximately 2000 billion tons for soils at a depth of one meter (Janzen 2004).

A number of studies have shown that soil organic carbon (SOC) and total nitrogen (TN) stored in the soil vary with soil texture (Baritz et al., 2010; Laganiere et al., 2010), soil depth (Augusto et al., 2010; Díaz-Pinés et al., 2011), stand density (Ares et al., 2010; Oubrahim et al., 2016), stand type (Pretzsch, 2005), stand age (Tian et al., 2015; Sariyildiz et al., 2016), management practices (Paul et al., 2002). The amount of carbon stored above-ground (mostly plants) (Alptekin, 2013) and belowground soil biomass (mostly roots) has been determined (Tüfekçioğlu & Küçük, 2010; Güner et al., 2010). However, the effects of stand development stage on SOC and TN stocks have received less attention.

Oak is a tree species that has the highest distribution in Turkey and is important in terms of species richness. Forest areas in Türkiye are 22.933,000 hectares, according to the 2020 inventory data of the General Directorate of Forestry. The general site of oak in Türkiye is 6.747,440 hectares. Approximately 2.666,577 hectares of these are productive forest, the remaining 4.080,863 hectares is coppice and degraded oak coppice forests. The oak forests, which have the widest distribution in Türkiye cover approximately 29.42% of the Turkish forests (General Directorate of Forestry, 2020). Sessile oak (*Quercus petraea* (Matt.) Liebl) is important tree species in Türkiye. SOC and TN stocks, which are necessary for nutrients and C cycle in the soil, are very important to a better understanding of how sessile oaks respond to different stand development stages and for effective management practices. However, the variation in the stocks of SOC and TN with different stand development stage is poorly understood. Therefore, in this study, we aimed to determine the effects of four different stand development stages on SOC and TN stocks of sessile oak namely: a development stage (a DS) (<8cm), b development stage (8 to 19.9 cm), c development stage (20 to 35.9 cm) and d development stage (36 to 51.9 cm).

2. MATERIALS AND METHODS

2.1. Study site description and sampling

This study was carried out in Taşköprü, which is 44 km away from Kastamonu and located in the east part of Kastamonu in Türkiye. The study sites (Tekçam and Sarıkaya Chiefdoms) were located between 41°24'52"N-41°40'06"N latitudes and 34°14'41"E-34°24'34"E longitudes (Figure 1).

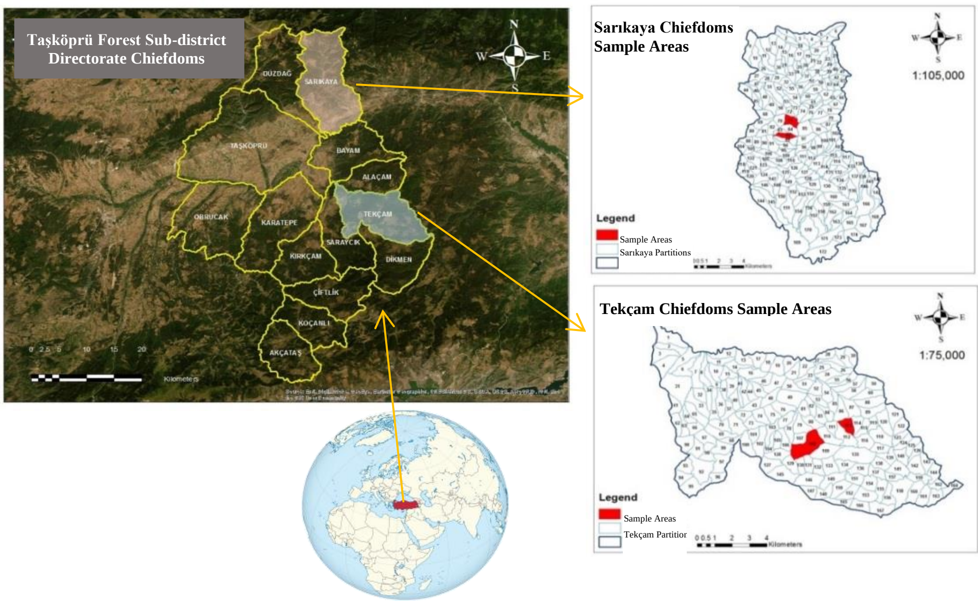

Figure 1. View of the study areas in northeastern Turkey

The basic characteristics of stands, geology, and soil types are shown in Table 1. The altitude of study areas varied between 993 m and 1198 m. They were exposed south (S) and northwest (NW) aspects and the slope varied between 15% and 50%. In the 1:1.250.000 scaled geological map, the bedrock type was schists with clay and unsorted basic and ultrabasic rocks (Akbaş et al., 2011). In the FAO's soil classification system (1978), soil type was Eutric Cambisols. These soils generally contain eutric A horizons and have 50% or less base saturation between 20 and 50 cm from the soil surface (Atalay, 2006). The humus type of the sessile oak stands was mull. The annual rainfall was 565.4 mm and the temperature was 10.4°C (Aktaş Tümer, 2022).

Table 1. Description of physiographic, geological, and silvicultural characteristics of four different stages of stand development in sessile oak (*Quercus petrea* (Matt.) Liebl)

Site Factors	**Stand Development Stages**			
	a (<8 cm diameter)	**b** (8 cm -19.9 cm)	**c** (20 cm -35.9 cm)	**d** (36 cm-51.9 cm)
Latitude	41°25'21"	41°24'52"	41°39'39"	41°40'06"
Longitude	34°24'34"	34°22'49"	34°14'41"	34°14'41"
Aspect	south	northwest	northwest	northwest
Altitude (m)	1191	1155	993	1198
Slope (%)	20%	15%	45%	50%
Bedrock type	Schist	Schist	Ultrabasic rocks	Ultrabasic rocks
Soil	Eutric Cambisols	Eutric Cambisols	Eutric Cambisols	Eutric Cambisols
Total soil samples	18	18	18	18
Tree number	140	35	40	24
Mean diameter(cm)	7.1	8.6	25.4	36.0
Stand density (%)	0-40%	71-100%	71-100%	41-70%

According to a diameter at breast height (DBH) for sessile oak stands, stages of stand development were divided into four parts: a, b, c, and d development stages. For each development stage, three subplots (20m × 20m = 400 m^2) were selected. The area measurements and sampling were carried out in September 2020. The canopy closure and diameter of trees for each subplot were determined. DBH measurements of all trees at each development stage were done by using a diameter taper. 72 undisturbed soil samples were taken under the four different stand development stages. Soil samples were collected from four different depths: 0-10, 10-20, and 20-30 cm. A steel cylinder (10 cm inner diameter) was used for undisturbed soil samples. Disturbed soil samples were also taken from a depth of between 0 and 30 cm to be used for soil physical and chemical analyses. In each stand development stage, forest floor litter was also collected from a total of thirty-six subplots. The litter samples were brought to the laboratory and dried under the laboratory conditions and then oven-dried at 65°C for 48 hours to constant weight to determine the ratio of fresh to dry weight.

2.2. Analysis of Soils

The organic matter content of the soil was determined by an ash furnace method (Gülçur, 1974), soil pH was determined by using a pH meter (1:2.5 distilled water + soil) (Jackson, 1962), and soil bulk density was determined according to Blake & Hartge (1986) method. Maximum water holding capacity (MWHC) was calculated from the difference between these two weights (Özyuvacı, 1975). The skeleton content of the soil which was the amount of stone and gravel remaining on the sieve was determined as the volume (Güner et al., 2011). N and C contents were determined by CHN-S Elemental Analyzer (Eurovector EA 3000 Series) in Kastamonu University Central Laboratory. TN and SOC stocks were calculated by multiplying bulk density, soil volume, SOC, or TN stock (Sariyildiz et al., 2015). The mass of soils was calculated with the following Equation 1.

$$M_i = BD_i \times T_i \times 10^4 \qquad (1)$$

where M_i is the mass of dried soil (Mg/ha), BD_i is bulk density (Mg/m^3), T_i is the thickness of the (i^{th}) soil layer (m), and 10^4 is the unit conversion factor (m^2/ha). The determination of SOC or TN stock in field soils was calculated by the following Equations 2 and 3.

$$SOC = SOC_i \times M_i \tag{2}$$

$$TN = TN_i \times M_i \tag{3}$$

where TN_i and SOC_i are N and C concentrations, respectively.

2.3. Statistical Analysis

ANOVA test was constituted by using the IBM SPSS Statistics 22 program to analyze the effects of four different stand development stages on TN and SOC stocks of sessile oak. Tukey Honest Significant Difference was performed for multiple comparisons of TN and SOC stocks with stand development stages and soil depths.

3. RESULTS AND DISCUSSION

3.1. Soils

Some soil properties of the sessile oak from the four different stand development stages are shown in Table 2.

Table 2. Some soil properties of the studied areas

Stand development Stages	Soil depth (cm)	Organic matter (%)	pH	Bulk density (g cm^{-3})	MWHC (%)	Soil skeleton (%)	N (%)	C (%)	TN stock (Mg ha^{-1})	SOC stock (Mg ha^{-1})
a	0-10	4.8^{e} ±1.4	6.9^{d} ±0.2	0.79^{abc} ±0.1	12.3^{c} ±4.9	37.9^{a} ±6.7	0.289^{ef} ±0.15	2.793^{e} ±0.78	1.31^{d} ±0.75	11.72^{de} ±7.07
	10-20	4.5^{de} ±2.6	6.1^{b} ±0.3	0.90^{c} ±0.2	7.7^{ab} ±2.9	41.5^{ab} ±10	0.256^{def} ±0.09	2.626^{de} ±1.48	1.08^{cd} ±0.69	10.91^{cd} ±3.09
	20-30	3.1^{cd} ±2.3	6.6^{cd} ±0.1	0.89^{c} ±0.2	6.5^{a} ±0.9	41.5^{ab} ±11	0.226^{cde} ±0.13	1.819^{cd} ±1.34	1.00^{cd} ±0.35	8.86^{bcd} ±6.80
	0-30	**4.13**	**6.53**	**0.86**	**8.83**	**40.3**	**0.26**	**2.41**	**3.39**	**31.49**
b	0-10	2.6^{bc} ±1.2	6.4^{bc} ±0.2	0.79^{abc} ±0.1	9.7^{b} ±3.6	50.5^{bc} ±6.8	0.127^{ab} ±0.03	1.519^{bc} ±0.68	0.49^{ab} ±0.12	5.79^{ab} ±2.42
	10-20	0.85^{a} ±0.2	6.2^{b} ±0.1	0.89^{c} ±0.1	6.05^{a} ±0.9	58.3^{c} ±8.2	0.082^{a} ±0.009	0.492^{a} ±0.13	0.36^{a} ±0.04	2.62^{a} ±0.59
	20-30	1.1^{ab} ±0.3	6.2^{b} ±0.1	0.85^{bc} ±0.2	5.5^{a} ±0.7	61.3^{c} ±7.9	0.079^{a} ±0.009	0.634^{ab} ±0.18	0.33^{a} ±0.03	2.23^{a} ±0.75
	0-30	**1.52**	**6.27**	**0.84**	**7.08**	**56.7**	**0.09**	**0.88**	**1.18**	**10.64**
c	0-10	4.9^{e} ±0.2	5.6^{a} ±0.5	0.65^{a} ±0.1	7.6^{ab} ±1.4	53.3^{c} ±6.7	0.179^{bcd} ±0.029	2.837^{e} ±0.14	0.68^{abc} ±0.15	9.18^{bcd} ±1.62
	10-20	3.7^{cde} ±0.7	6.7^{cd} ±0.3	0.85^{bc} ±0.1	5.05^{a} ±0.6	39.3^{ab} ±7.3	0.161^{abc} ±0.029	2.123^{cde} ±0.38	0.57^{ab} ±0.03	8.91^{bcd} ±1.42
	20-30	2.6^{bc} ±0.7	6.4^{bc} ±0.1	0.87^{bc} ±0.2	5.2^{a} ±1.4	41.3^{ab} ±5.9	0.130^{ab} ±0.026	1.499^{bc} ±0.39	0.56^{ab} ±0.09	6.67^{abc} ±2.41
	0-30	**3.73**	**6.23**	**0.79**	**5.95**	**44.63**	**0.16**	**2.15**	**1.81**	**24.76**
d	0-10	10.7^{g} ±1.6	8.5^{f} ±0.3	0.69^{ab} ±0.1	6.9^{a} ±1.8	31.3^{a} ±15.1	0.327^{f} ±0.05	6.195^{g} ±0.93	1.13^{d} ±0.17	21.53^{g} ±3.89
	10-20	7.5^{f} ±1.2	8.5^{f} ±0.5	0.83^{abc} ±0.2	6.2^{a} ±0.9	31.6^{a} ±9.5	0.243^{cdef} ±0.04	4.327^{f} ±0.72	1.00^{cd} ±0.26	17.89^{fg} ±4.60
	20-30	6.8^{f}	7.5^{e}	0.79^{abc}	5.5^{a}	32.8^{a}	0.226^{cde}	3.943^{f}	0.90^{bcd}	15.62^{ef}

		±0.7	±0.3	±0.1	±1.8	±10.5	±0.03	±0.39	±0.17	±2.46
	0-30	**8.33**	**8.17**	**0.77**	**6.2**	**31.9**	**0.27**	**4.82**	**3.03**	**55.04**

It is expressed as Means ± Standard Error. Where letters in superscript differ, data are significantly different ($p<0.05$). EC: Electrical conductivity, MWHC: maximum water holding capacity, N: nitrogen, C: carbon, TN: Total nitrogen, SOC: Soil organic carbon.

In general, organic matter decreased with soil depth (except for the b stage). The d stage of sessile oak stands was highest in organic matter (OM) content at any soil depth (10.7%, 7.5%, and 6.8%, respectively) compared to the other stages. According to the results of OM in the soil, the a and c stages had medium humus soils, the b stage had low humus soils, and the d stage had very humus soils. While the soil pH was moderately alkaline in the d stage (8.17), the other stand development stages had slightly acidic soil. The soil bulk density varied between 0.65 and 0.90 g cm^{-3}. Each stand development stage had the lowest bulk density at 0-10 cm soil depth. Maximum water holding capacity was the highest at all soil depths for the a stage. The soil skeleton was the lowest under the d stage (31.3%). The a, c, and d stages had a moderately stony or gravelly skeleton, whereas the b stage had very much stony or gravelly soil. Mean N concentration, TN, and SOC stocks decreased with soil depth (Table 2). The b stage stands had the lowest carbon (0.88%), nitrogen concentrations (0.09%), SOC (10.64 Mg ha^{-1}), and TN (1.18 Mg ha^{-1}) stocks at 0-30 cm, whereas the d stage stands showed the highest carbon (4.82%), nitrogen concentrations (0.27%), SOC (55.04 Mg ha^{-1}) stocks (Table 2). The distribution of TN for different stand development stages at 0-30 cm soil depth was in the order of the a (3.39 Mg ha^{-1}) > the d (3.03 Mg ha^{-1}) > the c (1.81 Mg ha^{-1}) > the b (1.18 Mg ha^{-1}). The distribution of SOC for different stand development stages was in the order of the d (55.04 Mg ha^{-1}) > the a (31.49 Mg ha^{-1}) > the c (24.76 Mg ha^{-1}) > the b (10.64 Mg ha^{-1}) (Table 2).

SOC stock at 0-10 cm for sessile oak stands varied between 5.79 Mg ha^{-1} and 21.53 Mg ha^{-1}. The highest stock of SOC was in the d stage (21.53 Mg ha^{-1}), followed by the a (11.72 Mg ha^{-1}), the c (9.18 Mg ha^{-1}), and the b (5.79 Mg ha^{-1}), respectively. At 10-20, 20-30, and 0-30 cm, SOC stocks for sessile oak stands were the highest in the d stage (17.89, 15.62, and 55.04 Mg ha^{-1}, respectively) stands, the a (10.91, 8.86, and 31.49 Mg ha^{-1}, respectively), the c stage (8.91, 6.67, and 24.76 Mg ha^{-1}, respectively), and the b stage (2.62, 2.23, and 10.64 Mg ha^{-1}, respectively) were ranked from highest to lowest (Figure 2).

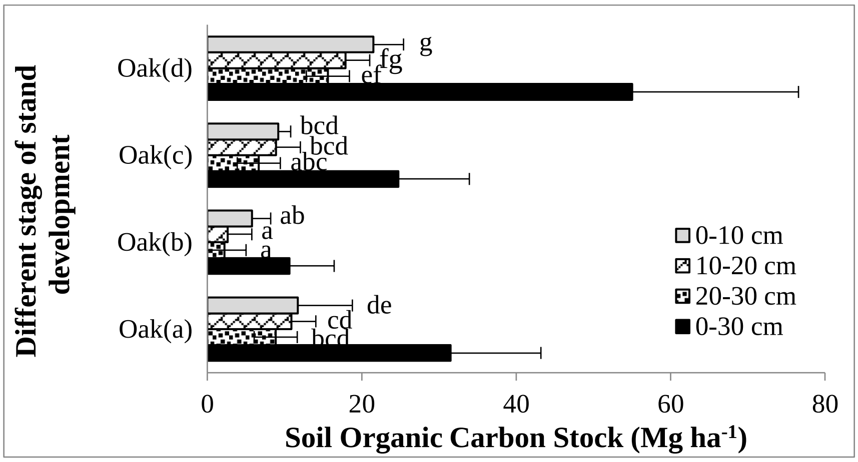

Figure 2. SOC stock at different soil depths in four stand development stages in sessile oak

SOC varied significantly among the stages of stand development (Table 3). The main effects of stand development stage on SOC stock was significant (R^2=0.714, p=0.000, n=72). Similarly, Makineci et al (2015) found that SOC stock was significantly correlated with a diameter at breast height (R^2=0.51, p=0.000, n=122) for sessile oak in Turkey. Eduardo et al.

(2010) in Germany showed that SOC stocks in topsoil decreased with increasing oak age (R^2=0.58, $p<0.10$) and this was probably due to the faster decomposition rate of the O layer (Eduardo et al., 2010). Verma et al. (2019) found for oak and pine stands that there was a good relationship between diameter at breast height and SOC stock (R^2=0.9). However, our study showed that SOC stock in the soil increased with increasing the diameter at breast height of sessile oak (except for the b stage). These differences may be due to the different depths of soil sampling in the profile. In our case, the soil profile to a depth of 30 cm was used, and this may underestimate the total SOC stock for the stand with deeper soil horizons. Similarly, Cao et al. (2012) reported that SOC taken from the depths of 0–10, 10–20, and 20–40 cm increased with stand age from 21.11, 14.94, and 9.38 g/kg, respectively, in 25-year-old stand to 36.79, 24.54, and 14.45 g/kg, respectively, in 105-year-old stand and SOC diminished significantly with increasing soil depth in Chinese pine (*Pinus tabulaeformis*) stands. This increase in SOC may be due to the accumulation of sessile oak litter on the forest layer. Similarly, Chao et al. (2019) noted that the mineral SOC stock increased with tree age, up to 81.23 Mg ha^{-1} under 51- to 60- year-old oak trees. On the other hand, Verma et al. (2019) SOC stock in soils under 10-20 cm diameter at breast height banj oak trees (*Quercus leucotrichophora*) was between 11.29 and 21.42 Mg ha^{-1}. They stated that SOC stock under 20-30 cm diameter at breast height banj oak trees was between 7.05 and 17.59 Mg ha^{-1} in Almora, Central Himalaya. Since SOC stock was calculated by multiplying the C concentration with the soil bulk density, likely, high SOC stocks in oak soils at different stand development stages were related to the high C concentration. Also, these variations can be associated with bedrock type, slope, stand age, physiographic characteristics, and litter quality.

In our study, there was a decrease in SOC stocks as soil depth increased and an increase in mineral soils (especially at 0-10 cm). This may be a result of C accumulation in the mineral topsoil as a result of organic matter decomposition. Similarly, Corral-Fernández et al. (2013) stated that SOC stock decreased with soil depth under oak stand (*Quercus ilex* ssp. *ballota*). Bruckman et al. (2011) stated that SOC stock of sessile oak stands (*Quercus petraea*) steadily decreased with increasing soil depth. The presence and accumulation of litter might have also affected the content of SOC. In the soil mineral layers (up to 30 cm), SOC stocks were found to be 10.64 Mg ha^{-1} for the b stage, 24.76 Mg ha^{-1} for the c stage, 31.49 Mg ha^{-1} for the a stage, and 55.04 Mg ha^{-1} for the d stage. Cha et al. (2019) reported that oaks including Mongolian oak (*Quercus mongolica*), Chinese cork oak (*Quercus variabilis*), sawtooth oak (*Quercus acutissima*), and Jolcham oak (*Quercus serrata*) stands included 66 Mg ha^{-1} of SOC at 0-30 cm in the Republic of Korea (South Korea). SOC stock at 0-10 cm soil depth under Norway spruce stands (*Picea abies* (L.) Karst.) and beech (*Fagus sylvatica* L.), while Scots pine (*Pinus sylvestris* L.) and common oak (*Quercus petreae* Liebl.) or beech (*Fagus sylvatica* L.) stands investigated by Koch and Makeschin (2004) was between 15.0 and 55.0 Mg ha^{-1}. Quideau et al. (1998) found that SOC stock at 0–100 cm by Coulter pine (*Pinus coulteri* B. Don) was 20.30 Mg ha^{-1} and scrub oak (*Quercus dumosa* Nutt) to 37.6 Mg ha^{-1}. Considering some studies that found nearly twice our values, Eduardo et al. (2010) found that in the organic and mineral layers (0-20 cm), SOC stocks amounted to 79.2 Mg ha^{-1} at Scots pine (*Pinus sylvestris* L.) and 64.3 Mg ha^{-1} at Scots pine mixed with 124 years-old sessile oak (*Quercus petraea* (Matt.) Liebl.), respectively. In our study, SOC stock tended to soil depths and stages of stand development. However, Cha et al. (2019) found that SOC stock increased from 66.14 to 84.24 Mg ha^{-1} as soils deepen and this increase is because the downward seepage of dissolved C from the organic horizon could increase SOC stock. Koch and Makeschin (2004) reported that sessile oak and European beech forests could store C over a longer period within deeper soil compared to coniferous forest soils.

TN stocks at 0–10 cm varied among the four stand development stages ($p<0.001$) (Figure 3). In general, the highest TN stock was observed in the reproduction stage of sessile oak stands and significantly lower values in the sapling and large pole stages of stand development (Table 2). In the sessile oak stands at 4 different stand development stages, TN stock at 0-10 cm was the highest in the a stage (1.31 Mg ha^{-1}) followed by the d stage (1.13 Mg ha^{-1}), the c stage (0.68 Mg ha^{-1}), and the b stage (0.49 Mg ha^{-1}), respectively. TN stocks at 10-20 cm were the highest in the a stage (1.08 Mg ha^{-1}), followed by the d stage (1.00 Mg ha^{-1}), the c stage (0.57 Mg ha^{-1}), and the b stage (0.36 Mg ha^{-1}), respectively. TN stocks of sessile oak stand at 4 different development stages in soils at 20-30 cm and 0-30 cm showing a tendency to increase and decrease, similar to the results in 0-10 cm soils (Figure 3). The highest TN stock was observed in the a stage (3.39 Mg ha^{-1}) and the d stage (3.03 Mg ha^{-1}) stands and the lowest in the b stage (1.18 Mg ha^{-1}) stands at 0-30 cm (Figure 3).

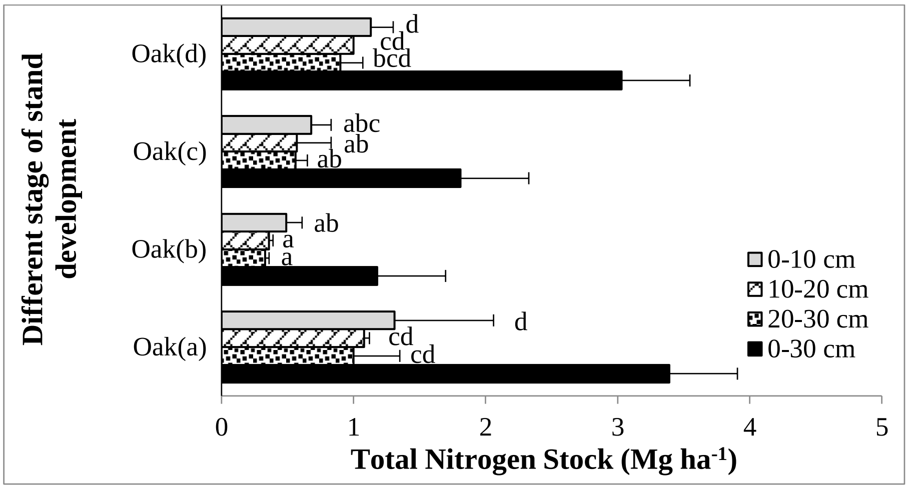

Figure 3. TN stock at different soil depths in four stand development stages in sessile oak

When sessile oak trees developed from young to middle-aged, TN stock significantly increased in the reproduction stages of stand development, whereas the sapling or pole stages and the large pole stages significantly decreased, and then increased in the medium wood stage of stand development (Figure 3). However, Eduardo et al. (2010) found that TN stock in the mineral soil and organic horizon was not affected by increasing in oak age ($R^2=0.31$, $p=0.16$). Quideau et al. (1998) found that TN stock at 0–100 cm by pine was 0.44 Mg ha^{-1} compared to oak was 1.12 Mg ha^{-1}. Eduardo et al. (2010) reported that at 0-20 cm, TN stocks were 2.71 Mg ha^{-1} under Scots pine and 2.70 Mg ha^{-1} under Scots pine mixed with 124 years-old sessile oak, respectively. Compton et al. (1998) reported that TN stock was 2.0 Mg ha^{-1} at 0-15 cm under mixed oak and pine in America. Liu et al. (2022) stated that the average soil total N contents recorded in near-mature, young, and middle-aged *Picea mongolica* forests in China were 18.32 mg kg^{-1}, 17.87 mg kg^{-1}, and 15.96 mg kg^{-1}, respectively. Savacı et al. (2021) stated that at 0-30 cm, TN stocks found 1.62 Mg ha^{-1} at Kazdağı fir (*Abies nordmanniana* subsp. *equi-trojani*), 0.96 Mg ha^{-1} at black pine (*Pinus nigra* Arnold.), and 1.46 Mg ha^{-1} at Scots pine (*Pinus sylvestris* L.), respectively.

The main effects of development stage were only significant for soil TN stocks (Table 3). The highest TN stocks in young-aged (reproduction stages) sessile oak stands suggest that the availability of soil N was at its highest concentration in the young stands. TN stock was observed to decline with soil depth, but non-significant. A similar result was observed by

Corral-Fernández et al. (2013) in Pedroches Valley in Spain. Liu et al. (2022) reported that Total N declined with an increase at 0–50 cm.

The single effects and interactions of soil depth (SD) and stage of stand development (SSD) on SOC and TN stocks were listed in Table 3. The main effects of stage of stand development on SOC stock (R^2=0.714, p=0.000, n=72) and TN stock (R^2=0.489, p=0.000, n=72) were significant, while the main effects of soil depth were only significant for SOC stocks (R^2=0.144, p=0.009, n=72). Soil depth x Stage of stand development interaction was nonsignificant for SOC and TN stocks (Table 3).

Table 3. Two-way ANOVA values of SOC and TN stocks variations depending on oak stands at different developmental stages, soil depth and the effects of both (%)

Soil Organic Carbon (Mg ha^{-1})	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Eta Squared**
Corrected Model	2262.278 a	11	205.662	14.923	.000	.732
Intercept	7434.357	1	7434.357	539.433	.000	.900
Stage of Stand Development (SSD)	2061.097	3	687.032	49.851	.000	.714
Soil Depth (SD)	139.357	2	69.678	5.056	.009	.144
SSD* SD	61.824	6	10.304	.748	.614	.070
Error	826.909	60	13.782			
Total	10523.543	72				
Corrected Total	3089.187	71				
Total nitrogen (Mg ha^{-1})						
Corrected Model	7.013a	11	.638	5.705	.000	.511
Intercept	44.282	1	44.282	396.281	.000	.869
Stage of Stand Development (SSD)	6.408	3	2.136	19.115	.000	.489
Soil Depth (SD)	.189	2	.094	.843	.435	.027
SSD* SD	.417	6	.069	.622	.712	.059
Error	6.705	60	.112			
Total	58.000	72				
Corrected Total	13.718	71				

3.2. Litter on the Forest Floor and Soil Organic Carbon

The distribution of SOC at soil depths have shown in Fig. 4. About 71% of SOC was stored in the upper 30 cm of the mineral soil horizon in sessile oak trees, indicating that higher SOC stock was sequestrated in the upper soil. For the a stage of sessile oak stand development, the percentage of SOC at 0-10, 10-20, and 20-30 cm were 33.85%, 31.5%, and 25.58, respectively, and decreased with increasing soil depths for all stages. In sessile oak stands at the c stage, the percentage of SOC was the highest at 0-10 cm (31.3%) followed by 10-20 cm (30.4%), and 20-30 cm (22.8%), respectively. The percentage of SOC for different stages of sessile oak stand development was in the order of the d stage (90.9%) > the a stage (90.1%) > the c stage (84.5%) > the b stage (71.9%) (Figure 4). Carbon concentration of litter samples ranged from 3.14 Mg ha^{-1} in the a stage to 6.03 Mg ha^{-1} in the d stage of sessile oak stands. While the C concentration of the litter samples of sessile oak stands increased with stand development stages. The percentage of C within different stand development stages was shown in Fig. 4. According to the percentage distribution of carbon content in other mineral soil depths and forest layers, litter on the forest floor was predominant, representing 28.11% of SOC stocks in the b stage of sessile oak stands. The percentages of C for different stand development stages were in the order of the b stage > the c stage > the d stage > the a stage (Figure 4).

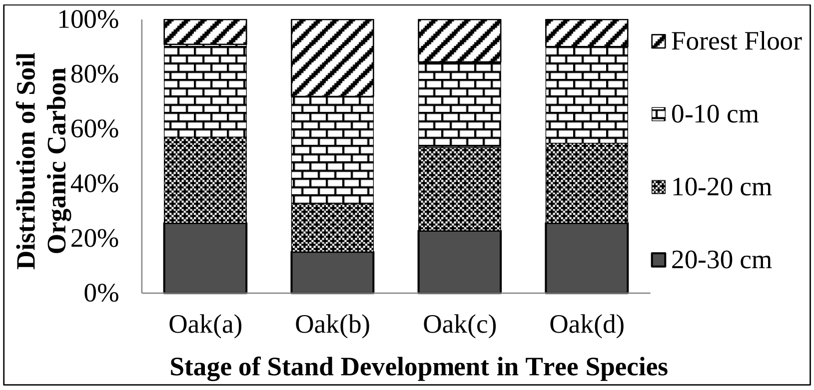

Figure 4. Percentage contribution of carbon pool in forest floor and different soil depths in four stand development stages (a, b, c, and d) in sessile oak

Litter on the forest floor accounts for a large portion of the litter quantity on oak trees with a large diameter breast height (the d stage=6.03 Mg ha^{-1}) compared with a small diameter breast height (3.14 Mg ha^{-1} and 4.16 Mg ha^{-1}), and the amount of litter at the d stage was approximately twice that of the a stage (Figure 4). Nitrogen content and total nitrogen stock were higher in middle-aged trees (the d stage) with the highest diameter at breast height (Table 2). The increase in N concentration and TN stock may be due to increased nutrient input in the soil via sessile oak litter. Also, this is a common expectation that old forests have a large accumulation of litter fall on the soil surface compared with young forests (Berg et al., 2001). However, Law et al. (2001) argued the opposite of this situation. Verma et al. (2019) reported that N concentration and TN stock increased with an increase in tree diameter and tree density.

4. CONCLUSIONS AND RECOMMENDATIONS

Our data indicate that SOC and TN stocks can change in different stand development stages. SOC stocks for the surface to deeper soil depth ratio ranged from 11.72 Mg ha^{-1} to 8.86 Mg ha^{-1} under the a stage, from 5.79 Mg ha^{-1} to 2.23 Mg ha^{-1} under the b stage, from 9.18 Mg ha^{-1} to 6.67 Mg ha^{-1} under the c stage, but the highest SOC stock was only from 21.53 Mg ha^{-1} to 15.62 Mg ha^{-1} under the d stage. Also, it has been observed that the highest TN stocks in the soil were young (the a stage) and mature oak trees (the d stage).

Our study found that sessile oak stand was with a higher tree density of the stages. SOC and TN stocks under mineral soil were playing an important role in sessile oak stands. In our study, it was observed that litter accumulation increased due to an increase in stand development stages. Different stages of stand development could play an important role in litter quantity and affect OM accumulation. Therefore, we can reveal a relation to site productivity.

As a result, our study showed that sessile oaks play an important role in SOC and TN stocks in soil and as a significant sink for CO_2 in the atmosphere. SOC and TN stocks have high values for the studied stand, making these results very important for C and N cycles. More extensive studies will be needed on the effects on N and C stocks by studying different oak species with different stand development stages in other regions.

ACKNOWLEDGEMENT

We are thankful to Kastamonu Forest Regional Directorate for permitting us to collect the soil data in a forest. The subject of the article was given to Gülay AKTAŞ TÜMER as a Master's Degree thesis at Kastamonu University, Graduate School of Natural and Applied Sciences, Department of Forest Engineering.

AUTHOR CONTRIBUTIONS

Gamze Savacı: Took soil samples in the study areas, evaluated them, interpreted the statistical analysis, and wrote the manuscript. Gülay Aktaş Tümer: Took soil samples in the study areas and prepared soil sample analyses in the laboratory.

FUNDING STATEMENT

This study was supported by Kastamonu University, Scientific Research Projects Coordination Department, Kastamonu, Turkey (Project Number: KÜ-HIZDES/2021-14).

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest

ETHICS COMMITTEE APPROVAL

This study does not require any ethics committee approval.

REFERENCES

Akbaş, B., Akdeniz, N., Aksay, A., Altun, İ. E., Balcı, V., Bilginer, E., Bilgiç, T., Duru, M., Ercan, T., Gedik, İ., Günay, Y., Güven, İ. H., Hakyemez, H. Y., Konak, N., Papak, İ., Pehlivan, Ş …Yurtsever, A. (2011). 1:1.250.000 ölçekli Türkiye Jeoloji Haritası. *Maden Tetkik ve Arama Genel Müdürlüğü Yayını*, Ankara-Türkiye (in Turkish publication).

Aktaş Tümer, G. (2022).Sapsız meşenin toprak organik karbon ve toplam stokları üzerinde gelişme çağlarının etkisi: Taşköprü, Kastamonu Örneği. Yüksek Lisans Tezi, Kastamonu Üniversitesi Fen Bilimleri Enstitüsü, Orman Mühendisliği Bölümü, s.44, Turkiye.

Alptekin, B. L. (2013). Torosların iç kısmında kermes meşesi ağırlıklı makilik alanların toprak üstü biokütle ve karbon depolama kapasitesi. Yüksek Lisans Tezi, Süleyman Demirel Üniversitesi, Fen Bilimleri Enstitüsü, Orman Mühendisliği Anabilim Dalı, Isparta.

Ares, A., Neill, A. R., & Puettmann, K. J. (2010). Understory abundance, species diversity and functional attribute response to thinning in coniferous stands. *For. Ecol. Manag.* 260(7), 1104-1113. https://doi.org/10.1016/j.foreco.2010.06.023

Atalay, İ. (2006). Toprak oluşumu, sınıflandırılması ve coğrafyası. *Meta Basım Matbaacılık, Çevre ve Orman Bakanlığı*, Izmir.

Augusto, L., Bakker, M. R., Morel, C., Meredieu, C., Trichet, P., Badeau, V., ..., Ranger, J. (2010). Is 'grey literature'a reliable source of data to characterize soils at the scale of a region? A case study in a maritime pine forest in southwestern France. *Eur. J. Soil Sci.* 61(6), 807-822. https://doi.org/10.1111/j.1365-2389.2010.01286.x

Baritz, R., Seufert, G., Montanarella, L., & Van Ranst, E. (2010). Carbon concentrations and stocks in forest soils of Europe. *For. Ecol. Manag.* 260(3), 262-277. https://doi.org/10.1016/j.foreco.2010.03.025

Berg, B., McClaugherty, C., Santo, A. V. D., & Johnson, D. (2001). Humus buildup in boreal forests: effects of litter fall and its N concentration. *Can. J. For. Res.*, 31(6), 988-998. https://doi.org/10.1139/x01-031

Blake, G. R., & Hartge, K. H. (1986). Bulk density 1. Methods of soil analysis: part 1-physical and mineralogical methods, (methodsofsoilan1), 363-375.

Bruckman, V. J., Yan, S., Hochbichler, E., & Glatzel, G. (2011). Carbon pools and temporal dynamics along a rotation period in *Quercus* dominated high forest and coppice with standards stands. *For. Ecol. Manag.* 262(9), 1853-1862. https://doi.org/10.1016/j.foreco.2011.08.006

Cha, J. Y., Cha, Y., & Oh, N. H. (2019). The effects of tree species on soil organic carbon content in South Korea. *J. Geophys. Res. Biogeosci*. 124(3), 708-716. https://doi.org/10.1029/2018JG004808

Corral-Fernández, R., Parras-Alcántara, L., & Lozano-García, B. (2013). Stratification ratio of soil organic C, N and C: N in Mediterranean evergreen oak woodland with conventional and organic tillage. *Agric Ecosyst Environ*. 164, 252-259. https://doi.org/10.1016/j.agee.2012.11.002

Díaz-Pinés, E., Rubio, A., Van Miegroet, H., Montes, F., & Benito, M. (2011). Does tree species composition control soil organic carbon pools in Mediterranean mountain forests? *For. Ecol. Manag.* 262(10), 1895-1904. https://doi.org/10.1016/j.foreco.2011.02.004

Dixon, R. K., Solomon, A. M., Brown, S., Houghton, R. A., Trexier, M. C., & Wisniewski, J. (1994). Carbon pools and flux of global forest ecosystems. *Science*, 263(5144), 185-190. https://doi.org/10.1126/science.263.5144.185

Fao-Unesco (1978). Soil Map of the World 1:5,000,000. 10 vols. Paris: UNESCO.

General Directorate of Forestry (2020). Turkey's forest presence 2020. General directorate of forestry publications, pp.56, Ankara.

Gülçür, F. (1974). Toprağın fiziksel ve kimyasal analiz metodları. *İ.Ü. Orman Fakültesi Yayını,* No: 201, İstanbul.

Güner, S., Tüfekçioğlu, A., Duman, A., & Küçük, M. (2010). Murgul yalancı akasya ağaçlandırmalarının ve bitişiğindeki otlak alanların toprak üstü biyokütle, kök kütlesi, kök üretimi ve karbon depolama yönlerinden karşılaştırılması. *III. Ulusal Karadeniz Ormancılık Kongresi*, 20-22 Mayıs 2010, 3, 1045-1055, Artvin.

Güner., Ş. T., Çömez, A., Karataş, R., Çelik, N., & Özkan, K. (2011). Eskişehir ve Afyonkarahisar illerindeki Anadolu karaçamı (*Pinus nigra* Arnold. subsp. *pallasina* (Lamb.) Holmboe) ağaçlandırmalarının gelişimi ile bazı yetişme ortamı özellikleri arasındaki ilişkiler. *TC Çevre ve Orman Bakanlığı, Orman Toprak ve Ekoloji Araştırmaları Enstitüsü Müdürlüğü Yayın*, 434/4.

Jackson, M. L. (1962). Soil chemical analysis. (Constable and Company, Ltd: London).

Janzen, H. H. (2004). Carbon cycling in earth systems-a soil science perspective. *Agric Ecosyst Environ.* 104(3), 399-417. https://doi.org/10.1016/j.agee.2004.01.040

Koch, J. A., & Makeschin, F. (2004). Carbon and nitrogen dynamics in topsoils along forest conversion sequences in the Ore Mountains and the Saxonian lowland, Germany. *Eur. J. For. Res.* 123(3), 189-201. https://doi.org/10.1007/s10342-004-0037-3

Laganiere, J., Angers, D. A.,& Pare, D. (2010). Carbon accumulation in agricultural soils after afforestation: a meta-analysis. *Glob. Change Biol.* 16(1),439-453. https://doi.org/10.1111/j.1365-2486.2009.01930.x

Law, B. E., Thornton, P. E., Irvine, J., Anthoni, P. M., & Van Tuyl, S. (2001). Carbon storage and fluxes in ponderosa pine forests at different developmental stages. *Glob. Change Biol.* 7(7), 755-777. https://doi.org/10.1046/j.1354-1013.2001.00439.x

Liu, Y., Chen, L., Duan, W., Bai, Y., & Li, X. (2022). Effects of litter decomposition on soil N in *Picea mongolica* forest at different forest ages. *Forests* 13, 520. https://doi.org/10.3390/f13040520

Makineci, E., Ozdemir, E., Caliskan, S., Yilmaz, E., Kumbasli, M., Keten, A., ...Yilmaz, H. (2015). Ecosystem carbon pools of coppice-originated oak forests at different development stages. *Eur. J. For. Res.*, 134(2), 319-333. https://doi.org/10.1007/s10342-014-0854-y

Matos, E. S., Freese, D., Ślązak, A., Bachmann, U., Veste, M., & Hüttl, R. F. (2010). Organic-carbon and nitrogen stocks and organic-carbon fractions in soil under mixed pine and oak forest stands of different ages in NE Germany. *J. Plant. Nutr. Soil Sci.* 173(5), 654-661. https://doi.org/10.1002/jpln.200900046

Oubrahim, H., Boulmane, M., Bakker, M. R., Augusto, L., & Halim, M. (2016). Carbon storage in degraded cork oak (*Quercus suber)* forests on flat lowlands in Morocco. iForest 9, 125-137. https://doi.org/10.3832/ifor1364-008

Özyuvacı, N. (1975). Topraklarda erozyon eğiliminin tahmini açısından yapılan bazı değerlendirmeler. *Tübitak V. Bilim Kongresi, Tarım ve Ormancılık Araştırma Grubu Tebliğleri Ormancılık Seksiyonu*, 29 Eylül-2 Ekim, 123-134, İzmir.

Paul, K. I., Polglase, P. J., Nyakuengama, J. G., & Khanna, P. K. (2002). Change in soil carbon following afforestation. *For. Ecol. Manag.*, 168(1-3), 241-257. https://doi.org/10.1016/S0378-1127(01)00740-X

Pretzsch, H. (2005). Diversity and productivity in forests: evidence from long-term experimental plots. In Forest diversity and function. pp. 41-64, Springer, Berlin, Heidelberg. https://doi.org/10.1007/3-540-26599-6_3

Quideau, S. A., Graham, R. C., Chadwick, O. A., & Wood, H. B. (1998). Organic carbon sequestration under chaparral and pine after four decades of soil development. *Geoderma*, 83(3-4), 227-242. https://doi.org/10.1016/S0016-7061(97)00142-0

Sariyildiz, T., Savaci, G., & Kravkaz, I. S. (2015). Effects of tree species, stand age and land-use change on soil carbon and nitrogen stock rates in northwestern Turkey. *iForest*, 9(1), 165-170. https://doi.org/10.3832/ifor1567-008

Savacı, G. (2017). Effects of land use type and stand age on some soil properties and organic carbon and total nitrogen stock capacity. Ph.D. Thesis, Kastamonu University, Graduate School of Natural and Applied Sciences, Department of Forest Engineering, s.179, Turkey.

Savacı, G., Sarıyıldız, T., Çağlar, S., Kara, F., & Topal, E. (2021). The effects of windthrow damage on soil properties in Scots pine, black pine and Kazdağı fir stands in the northwest Turkey. *Kastamonu University Journal of Forestry Faculty*, 21(3), 229-243. https://doi.org/10.17475/kastorman.1049328

Six, J., Conant, R. T., Paul, E. A., & Paustian, K. (2002). Stabilization mechanisms of soil organic matter: implications for C-saturation of soils. *Plant Soil*, 241(2), 155-176. https://doi.org/10.1023/A:1016125726789

Tian, Y., Cao, J., Yang, X., Shan, N., & Shi, Z. (2015). Patterns of carbon allocation in a chronosequence of *Caragana intermedia* plantations in the Qinghai-Tibet Plateau. *iForest*, 8(6), 756-764. https://doi.org/10.3832/ifor1193-007

Tüfekçioğlu, A., & Küçük, M. (2010). Saf sarıçam meşcerelerinde kök kütlesi, kök üretimi ve kök karbon depolama miktarlarının yaş sınıflarına göre değişimi. *III. Ulusal Karadeniz Ormancılık Kongres*i, 20-22 Mayıs 2010, s.1030-1037, Artvin.

Verma, A. K., & Garkoti, S. C. (2019). Population structure, soil characteristics and carbon stock of the regenerating banj oak forests in Almora, Central Himalaya. *Forest Sci Technol.* 15(3), 117-127. https://doi.org/10.1080/21580103.2019.1620135