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The Effects of Stand Development Stages on Soil Carbon and Nitrogen Stocks in Black Pine, Scots Pine and Fir Stands in Türkiye

Gamze SAVACI[1*], Yunus DOĞAN[2]

Highlights:

- TOC and TA stocks changed in different stand development stages of tree species
- The amount of litter decreased in stages from reproduction to medium wood for Kazdağı fir stands
- Litter and soil have been the two main factors contributing to TOC stocks for all tree species

Keywords:

- Stand development stages
- C accumulation, mineral soil, tree species
- Taşköprü

ABSTRACT:

The influence of stand development stages on soil organic carbon (SOC) and total nitrogen (TN) stocks was examined in black pine (*Pinus nigra* Arnold.), Scots pine (*Pinus sylvestris* L.), and Kazdağı fir (*Abies nordmanniana* subsp. *equi-trojanı* (Aschers. & Sint. ex Boiss) Coode et Cullen), differing in the mean tree diameters in which reproduction stages (RS)=<8 cm, sapling or pole stages (SPS)= 8-19.9 cm, large pole stages (LPS)= 20-35.9 cm, and medium wood stages (MWS)=36-51.9 cm in three tree species located in northwestern Turkey. A total of 216 soil samples were collected and analyzed for pH, organic matter, bulk density, maximum water holding capacity, carbon, and nitrogen concentrations, and the SOC and TN stocks were calculated. SOC and TN stocks varied significantly among the four stand development stage classes. The SOC stock at 0-30 cm increased significantly due to an increase in the diameter of black stands (BP_{LPS} and BP_{MWS}). SOC stocks in all stand development stages peaked in the large pole (44.94 Mg/ha) and declined as the sapling or pole (37.71 Mg/ha) was replaced by medium wood stands (30.17 Mg/ha), and a low point (27.94 Mg/ha) was found in the reproduction stages of stand development for Scots pine. The TN stock at a soil depth of 0-30 cm ranged from 1.66 to 6.46 Mg/ha. The highest TN stock was observed in the SP_{SPS} (6.46 Mg/ha) and Fir_{RS} (5.48 Mg/ha), and the lowest was observed in the BP_{LPS} (1.66 Mg/ha) stands. The results illustrate that soil was the main storage of C and N in all different stand development stages of tree species.

[1] Gamze SAVACI (**Orcid ID:** 0000-0003-4685-2797), Kastamonu University, Faculty of Forestry, Department of Forest Engineering, Kastamonu, Türkiye

[2] Yunus DOĞAN (**Orcid ID**: 0000-0001-8960-6161), Beyşehir Forest Enterprise Directorate, Üzümlü Forest Sub-district Directorate, Konya, Türkiye

***Corresponding Author:** Gamze SAVACI, e-mail: gsavaci@kastamonu.edu.tr

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INTRODUCTION

Globally, carbon reservoirs in soils store between 1500 and 2400 Gt C (1 gigaton = 1 billion tonnes) and approximately three to four times more carbon (C) than plants (450-650 Gt C) (Friedlingstein et al., 2020). The global soil carbon pool to a one-meter depth, estimated at 1500 Gt C, is soil organic carbon (FAO, 2017; Abdullahi et al., 2018). Therefore, soils are the largest carbon reservoirs of the terrestrial carbon cycle (Das 2019; Ozlu et al., 2022). The residence or accumulation time of C in the soil is longer than that in vegetation (Santonja et al. 2022). The soil holds this large carbon stock and prevents the accumulation of carbon dioxide in the atmosphere, which will increase the problem of climate change (Poeplau et al., 2021). Studies have shown that forest soils, a key element of the global C cycle, contribute approximately 70%-73% of the global SOC pool (Liu et al., 2016; Shen et al., 2018; Sun et al., 2021).

Global warming is an environmental problem that threatens the world. To prevent this threat, interest in forest soils, tree species, and management practices, which store most of the CO_2 in the atmosphere, has increased (Leuschner et al., 2013). Therefore, many studies on the effect of climate change on forest ecosystems have attracted increasing interest in Turkey (Sariyildiz et al., 2015; Lee et al., 2016; Güner and Makineci 2017; Savacı and Sarıyıldız 2020; Özbay and Tolunay, 2021; Işık ve Göl, 2021) and other countries (Wasak and Drewnik 2015; Bangroo et al., 2017; Angst et al., 2019; Dong et al., 2021; Nath et al., 2021; Nave et., 2022). They play an important role in C storage in forests, which bind most of the CO_2 in the atmosphere to aboveground (such as tree branches, leaves, trunk, and organic matter) and underground (roots, soil) biomass structures and regulate the climate regime.

In Turkey, Black Sea forests represent approximately 24.4% of the total forest cover (5.593.342 ha) and rank first in terms of forest assets compared to other geographical regions (OGM, 2020), with almost 27% dominated by black pine (*Pinus nigra* Arnold. - 237.600 ha), 7% dominated by Scots pine (*Pinus sylvestris* L.- 63.365 ha) and 5% dominated by Kazdağı fir (*Abies nordmanniana* subsp. *equi-trojani*) - 43.264 ha) (Kastabil, 2019). Black sea forests dominated by tree species may constitute an important C sink for the future. Understanding organic carbon inputs to soils as SOC in reducing climate change is extremely important. Many scientific studies have revealed that the C accumulated in the soil changes depending on many factors. In these studies, the amount of C in the soils was affected by latitude (Feeney et al., 2021; Wang et al., 2021), litter quantity and decomposition rate (Prietzel and Bachmann, 2012; Lukić et al., 2015), different land use (Li et al., 2015b), tree species (Prietzel and Bachmann, 2012; Sariyildiz et al., 2015), the chemical structure of litter (Sevgi et al., 2011), bulk density (Topa et al., 2021), and climate characteristics (Schrumpf et al., 2011). However, little is known about their carbon storage in different stand development stages of trees.

To enhance our knowledge of the contributions of these tree species to global C and N stocks, this study aimed to understand the impact of different stand development stages on the TN and SOC stocks of these forest ecosystems. We examined litter and soil C contents in four different stages of stand development (reproduction stage (RS), sapling or pole stage (SPS), large pole stage (LPS), and medium wood stage (MWS)) of pure black pine, Kazdağı fir, and Scots pine stands in Kastamonu, Turkey. We hypothesized a positive effect of diameter increase in trees on SOC and TN stocks in Black Sea ecosystems.

MATERIALS AND METHODS

Study Site Description and Sampling

This study was carried out in Taşköprü, which is 44 km away from Kastamonu in Turkey (Figure 1). The silvicultural characteristics of the stands, soil properties, and geology were investigated in pure Kazdağı fir, Scots pine, and black pine-dominated stands around the town of Taşköprü.

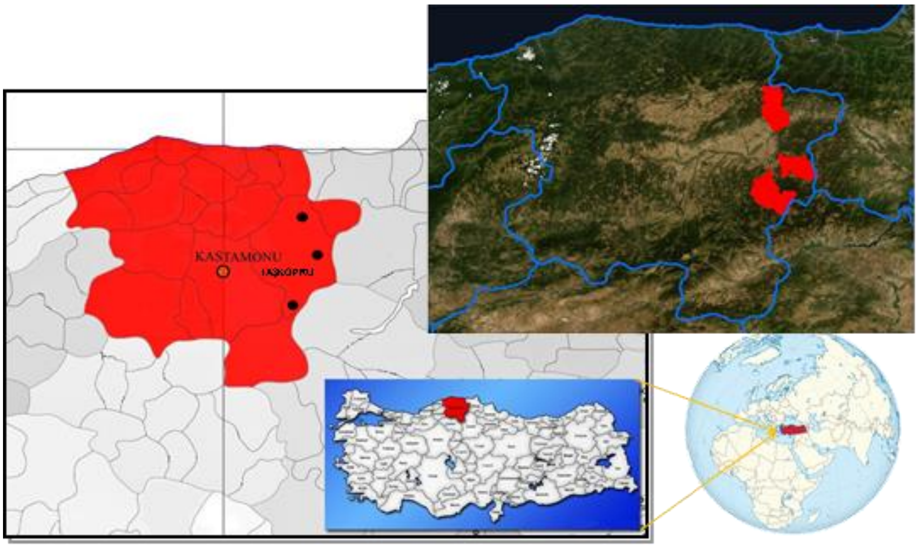

Figure 1. Location of the Study Areas on the Map of Türkiye

The main characteristics of the stands, geological, and soil properties are given in Table 1. Study areas were located on the west (W), south (S), northeast (NE), and north (N) aspects, and their altitudes varied from 1186 m to 1620 m. The average slope was between 0% and 35%. According to the stand canopy classification, the study areas are usually in the "very dense forest" (>70%). According to the 1:1.250.0000 scale geological map, the bedrock of the study areas is schists covered with clay (Akbaş et al., 2011). According to the FAO's soil classification system, soils are Eutric Cambisols (FAO and UNESCO, 1978). These soils contain eutric A horizons and have a base saturation of 50% or less at depths between 20 and 50 cm from the surface (Atalay, 2006). The humus layers of the Scots pine, Kazdağı fir, and black pine stands were mull. The mean annual temperature and rainfall were 12.9°C and 643 mm, respectively (DMİ, 2021).

Black pine, Scots pine, and Kazdağı fir are economically and ecologically important tree species in Turkey (Savacı et al., 2021). All trees are distributed over 4.199.623 hectares, 1.410.177 hectares, and 511.703 hectares, which account for 18.31%, 6.15%, and 2.23% of the overall forest coverage, respectively (OGM, 2020). Even-aged black pine, Scots pine, and Kazdağı fir stands were selected in 2020 for the four stages of stand development. These stands have been classified into the following stages of stand development classes according to tree diameters.

Reproduction stage (RS): Saplings are short in length, the number of lateral branches is low, and their length is short. This stage does not have a specific age and height range. Generally, the reproduction period continues until the saplings reach 100-150 cm. The age of density in the stands ended when the average breast height diameter of the individuals reached 8 cm (< 8 cm diameter). At the end of the density period, strong natural branch pruning and stem separation were observed in the stands.

Table 1. Geological and Stand Characteristics of the Study Areas at Four Different Stand Development Stages in Black Pine, Scots Pine, and Kazdağı Fir

Site Factors	**Stand Development Stages**			
	Reproduction Stage (<8 cm diameter)	**Sapling & Pole Stage** (8 cm -19.9 cm)	**Large Pole Stage** (20 cm -35.9 cm)	**Medium Wood Stage** (36 cm-51.9 cm)
Black pine				
Latitude				
Longitude	41°25'25"	41°25'23"	41°24'08"	41°24'02"
Aspect	34°25'34"	34°24'33"	34°18'36"	34°18'35"
Altitude (m)	South	Northeast	West	West
Slope (%)	1228	1186	1207	1205
Bedrock type	10%	10%	30%	15%
Soil	Schist	Schist	Schist	Schist
Total soil samples	Eutric Cambisols	Eutric Cambisols	Eutric Cambisols	Eutric Cambisols
Tree number	18	18	18	18
Mean stand diameter (cm)	47	43	50	32
Stand density (%)	<8	19.1	27.3	38.7
	71%-100%	71%-100%	71%-100%	41%-70%
Scots pine				
Latitude	41°20'27"	41°19'28"	41°20'29"	41°19'12"
Longitude	34°13'41"	34°20'59"	34°13'42"	34°18'45"
Aspect	West	South	West	South
Altitude (m)	1270	1620	1253	1619
Slope (%)	20%	10%	15%	30%
Bedrock type	Schist	Schist	Schist	Schist
Soil	Eutric Cambisols	Eutric Cambisols	Eutric Cambisols	Eutric Cambisols
Total soil samples	18	18	18	18
Tree number	Planting area	83	65	30
Mean stand diameter(cm)	<8	16.2	25.2	38.5
Stand density (%)	71%-100%	71%-100%	71%-100%	71%-100%
Kazdağı Fir				
Latitude	41°19'03"	41°19'10"	41°19'00"	41°19'19"
Longitude	34°20'03"	34°21'42"	34°21'38"	34°19'54"
Aspect	South	Northeast	North	South
Altitude (m)	1619	1596	1614	1603
Slope (%)	5%	0%	35%	30%
Bedrock type	Schist	Schist	Schist	Schist
Soil	Eutric Cambisols	Eutric Cambisols	Eutric Cambisols	Eutric Cambisols
Total soil samples	18	18	18	18
Tree number	74	35	25	26
Mean stand height (m)	<8	19.9	35.9	39.5
Stand density (%)	71%-100%	71%-100%	71%-100%	71%-100%

Sapling or Pole Stage (SPS): These stages, which start with the natural pruning of branches and strong stem separation in the stands and continue until the increase in diameter as well as the height increase, are considered the sapling-pole stages (varied 8.1 cm to 19.9 cm diameter).

Large Pole Stage (LPS): The breast height diameters of trees are between 20 cm and 35.9 cm.

Medium Wood Stage (MWS): It is between 36 cm and 51.9 cm in the medium wood stage.

The stages of stand development were divided into four parts, as described above. Three subplots (20 m × 20 m = 400 m^2) were selected for each stage of stand development. The area measurements and sampling were carried out in September 2020. The canopy closure and diameter of trees for each subplot were determined. Diameter at breast height measurements of all trees at each stage of the stand development class were determined using a diameter taper.

A total of 216 soil samples (36 subplots × 3 soil depths × 2 replicates) were taken at different stand development stages, and soil samples were collected at 0-30 cm and randomly selected from black pine, Scots pine, and Kazdağı fir stands. A steel cylinder of 10 cm height and 100 cm^3 was used to take soil samples up to 30 cm depth. Soil samples were taken from three different soil depths (0-10 cm, 10-20 cm, and 20-30 cm) and passed through a 2 mm sieve for analysis. To determine the litter content of each tree, litter samples were taken from thirty-six subplots (3 replicates × 4 stages of stand development classes × 3 tree species = 36 subplots) on the forest floor. They were oven-dried at 65°C for 48 hours to determine the ratio of fresh weight to dry biomass.

Analysis of soils

The organic matter content in the soil was determined by an ash furnace method (Gülçür, 1974). Soil reaction was measured using a LaMotte-branded pH meter in a 1:2.5 mixture of distilled water and soil (Jackson, 1962). The maximum water holding capacity (MWHC) was calculated from the difference between the wet and dry weights of the cylinder samples (Özyuvacı, 1975). Bulk density was calculated by weight loss after drying the steel cylinder (Blake and Hartge, 1986). The concentrations of C and N were analyzed by a Eurovector (EA 3000) branded CHN-S elementary analyzer at Kastamonu University Central Laboratory. SOC and TN stocks were obtained by multiplying the bulk density, soil volume, and C or N contents (Lee et al., 2009; Sariyildiz et al., 2015). Soil mass was calculated as follows (equation 1):

$$M = BD \times T_i \times 10^4 \qquad (1)$$

where M: dry soil mass (Mg/ha), BD: bulk density (Mg m^{-3}), T_i: the thickness of the i^{th} soil layer (m), and 10^4: conversion factor (m^2 ha^{-1}). The SOC and TN stocks are calculated as follows (equation 2):

$$SOC \text{ or } TN = ([C\ \%] \text{ or } [N\ \%]) \times M \qquad (2)$$

where C: carbon content, N: nitrogen content.

Statistical analysis

A two-way ANOVA test (SPSS program Version 22.0) was used to analyze the impacts of stand development stages and soil depths on SOC and TN stocks. Tukey's honestly significant difference test was used for multiple comparisons (α=0.05).

RESULTS AND DISCUSSION

Soils

Some soil properties of the black pine, Scots pine, and Kazdağı fir stand development stage classes are shown in Table 2. In general, the sapling or pole stage of black pine stands (BP_{SPS}) had the lowest organic matter content (2.8%), maximum water holding capacity (4.2%), N concentration (0.14%), C concentration (1.65%), and SOC stock (24.86 Mg/ha), while it had the highest bulk density (1.03 g cm^{-3}). The reproduction stage of Kazdağı fir stands (Fir_{RS}) had the highest organic matter content (8.2%), C concentration (4.97%), and SOC stock (52.44 Mg/ha) compared to the other stands. The N concentration was similar in all stages of stand development in black pine stands (Table 2).

Organic matter in soils, especially in Scots pine and Kazdağı fir stands, was the highest in the reproduction stages, and the sapling or pole stage decreased by approximately 50% and increased approximately 2.5 times in the large pole stages and decreased approximately 1.8 times in the medium wood stages. The pH range of soils under the 3 tree species varied. Scots pine soils in the reproduction stages were strongly alkaline, and Kazdağı fir stands were neutral. In other stand development stages, they were generally light or moderately acidic soils (Table 2). The bulk density in the soils of the tree species in each stand development quite low values (Table 2). There was a statistically significant difference in the water-holding capacity of the three tree species at different stand development stages. However, no statistically significant difference was observed in the different stand development of black pine (Table 2).

Table 2. Soil Properties of Four Different Stages of Stand Development in Black Pine, Scots Pine, and Kazdağı Fir

Tree species & Stand development stages	Organic matter (%)	pH	Bulk density (g cm^{-3})	MWHC (%)	N (%)	C (%)	TN stock (Mg/ha)	SOC stock (Mg/ha)
Black pine (BP)								
RS	4^{c}±1.8	5.6^{a}±0.8	0.88^{h}±0.13	9.5^{d}±7.16	0.21^{a}±0.05	2.33^{d}±1.3	2.7^{g}±0.22	29.86^{e}±4.41
SPS	2.8^{a}±1.2	5.9^{d}±0.4	1.03^{k}±0.17	4.2^{a}±1.5	0.14^{a}±0.05	1.65^{a}±1.2	2.15^{b}±0.26	24.86^{a}±3.75
LPS	6.4^{g}±1.5	6.7^{g}±0.3	0.70^{b}±0.15	16.0^{j}±4.9	0.17^{a}±0.07	3.75^{h}±2.1	1.66^{a}±0.22	36.3^{g}±4.39
MWS	5.5^{f}±0.9	6.6^{f}±0.2	0.84^{g}±0.18	14.4^{h}±4.9	0.21^{a}±0.02	3.22^{g}±0.9	2.59^{e}±0.18	39.92^{h}±2.8
Scots pine (SP)								
RS	3.6^{b}±0.9	8.4^{i}±0.08	0.9^{i}±0.11	10.3^{f}±4.7	0.21^{a}±0.04	2.06^{b}±0.6	2.93^{i}±0.2	27.94^{c}±2.85
SPS	6.9^{i}±2.2	5.8^{c}±0.1	0.65^{a}±0.11	14.4^{h}±3.1	0.58^{cd}±0.28	4.03^{j}±1.5	6.46^{k}±1.07	37.71^{g}±3.33
LPS	6.5^{h}±1.0	5.9^{d}±0.5	0.84^{g}±0.1	10.3^{f}±3.2	0.23^{a}±0.04	3.79^{i}±1.2	2.86^{h}±0.15	44.94^{i}±2.78
MWS	3.6^{b}±0.4	6.2^{e}±0.07	0.96^{j}±0.20	10.7^{g}±2.9	0.17^{a}±0.03	2.11^{c}±0.6	2.43^{d}±0.22	30.17^{f}±2.12
Kazdağı fir (Fir)								
RS	8.2^{k}±2.4	7.0^{h}±0.2	0.75^{d}±0.11	9.0^{c}+4.6	0.49^{bc}±0.3	4.97^{l}±1.9	5.48^{j}±1.09	52.44^{k}±5.60
SPS	4.7^{e}±1.3	5.6^{a}±0.3	0.73^{c}±0.17	10.2^{e}±2.2	0.22^{a}±0.06	2.68^{f}±1.2	2.31^{c}±0.21	27.18^{b}±2.62
LPS	7.2^{j}±1.9	5.8^{c}±0.1	0.77^{e}±0.19	15.1^{i}±4.3	0.23^{a}±0.07	4.2^{k}±1.2	2.62^{f}±0.26	46.73^{j}±4.73
MWS	4.2^{d}±1.5	5.7^{b}±0.1	0.80^{f}±0.13	7.7^{b}±2.6	0.25^{a}±0.02	2.42^{e}±1.0	2.92^{i}±0.16	28.2^{d}±3.24

Values represent the mean ± standard error (SE). *In cases where the letters in the superscript are different, the data differ significantly ($P < 0.001$).
RS: Reproduction Stage, SPS: Sapling & Pole Stage, LPS: Large Pole Stage, MWS: Medium Wood Stage

The sapling or pole stages of Scots pine stands (SP_{SPS}) had the highest N concentration (0.58%), and TN stock (6.46 Mg/ha) and the lowest bulk density (0.65 g cm^{-3}) compared to the other three stand development stage classes (Table 2). The reproduction stages of Scots pine stands (SP_{RS}) had the highest pH (8.4), and the lowest pH values were in the Fir_{SPS} (5.6) and BP_{RS} (5.6) stands. The highest water holding capacity was 15.1% in the Fir_{LPS} stands (Table 2). For black pine stands, the distribution of SOC for different stages of stand development of the trees was in the order of medium wood stage (39.92 Mg/ha) > large pole stage (36.3 Mg/ha) > reproduction stage (26.86 Mg/ha) > saplings or pole stage (24.86 Mg/ha).

TN stocks in the topsoil (0–10 cm) varied among stand development stages ($P < 0.001$) and between the Fir_{RS}, SP_{SPS}, and other stages (Fig. 2). In general, the highest TN stock was observed in SP_{SPS} stands (6.46 Mg/ha), with significantly lower values in thick-diameter trees (SP_{MWS}-Table 2). In black pine, Scots pine, and Kazdağı fir stands at 4 different stand development stages, the TN stock at 0-10 cm was the highest in Fir_{RS} (2.16 Mg/ha), followed by Fir_{MWS} (0.92 Mg/ha), Fir_{LPS} (0.86 Mg/ha), and Fir_{SPS} (0.77 Mg/ha), respectively. TN stocks at the 0-10 cm soil depth were the highest in SP_{SPS} (2.26 Mg/ha), followed by SP_{RS} and SP_{LPS} (0.75 Mg/ha) and SP_{MWS} (0.73 Mg/ha). The highest TN stocks of black pine were observed in BP_{RP} (0.97 Mg/ha), and the lowest were observed in BP_{LPS} (0.68 Mg/ha). TN stocks of black pine at 4 different development stages in soils from 10-20 to 20-30 cm tended to increase and decrease (BP_{LPS} and BP_{RS}) or to decrease and increase (BP_{MWS} and BP_{SPS}). The TN stock increased as the depth increased in all stand development stages of Scots pine. For TN stocks of Kazdağı fir stands, Fir_{LPS} and Fir_{MWS} tended to increase and decrease according to soil depth (Figure 2). The TN stock at 0-30 cm ranged from 1.66 to 6.46 Mg/ha. The highest TN stock was observed in the SP_{SPS} (6.46 Mg/ha) and Fir_{RS} (5.48 Mg/ha) stands, and the lowest was observed in the BP_{LPS} (1.66 Mg/ha) stands (Figure 2).

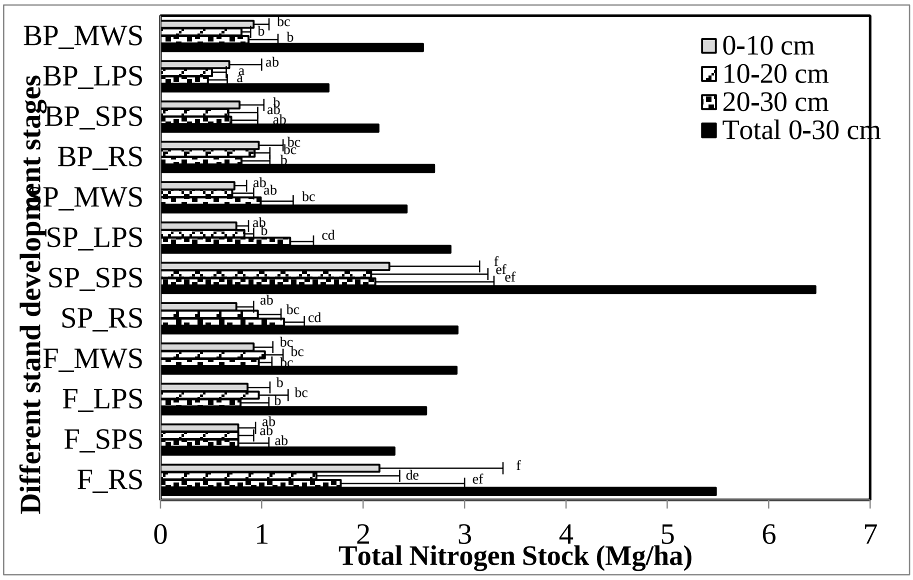

Figure 2. Total Nitrogen (TN) Stock at Different Soil Depths in Four Stages of Stand Development of Black Pine, Scots Pine, and Kazdağı Fir. The Differences between Tree Species at Different Development Stages and Soil Depths are Expressed in Different Lowercase Letters (*P* < 0.05)

The SOC stock at 0-10 cm for the three tree species varied between 7.83 Mg/ha and 23.4 Mg/ha. The highest stock of SOC was in Fir_{RS} (23.4 Mg/ha), followed by Fir_{LPS} (17.22 Mg/ha), Fir_{SPS} (11.36 Mg/ha), and Fir_{MWS} (10.51 Mg/ha). The reproduction stage of the Scots pine and black pine stands at 0-10 cm had the lowest SOC stock, followed by the trees in the order of $SP_{(MWS)} < BP_{(SPS)} < SP_{(SPS)} < SP_{(LPS)} < BP_{(LPS)} < BP_{(MWS)}$ (Figure 3).

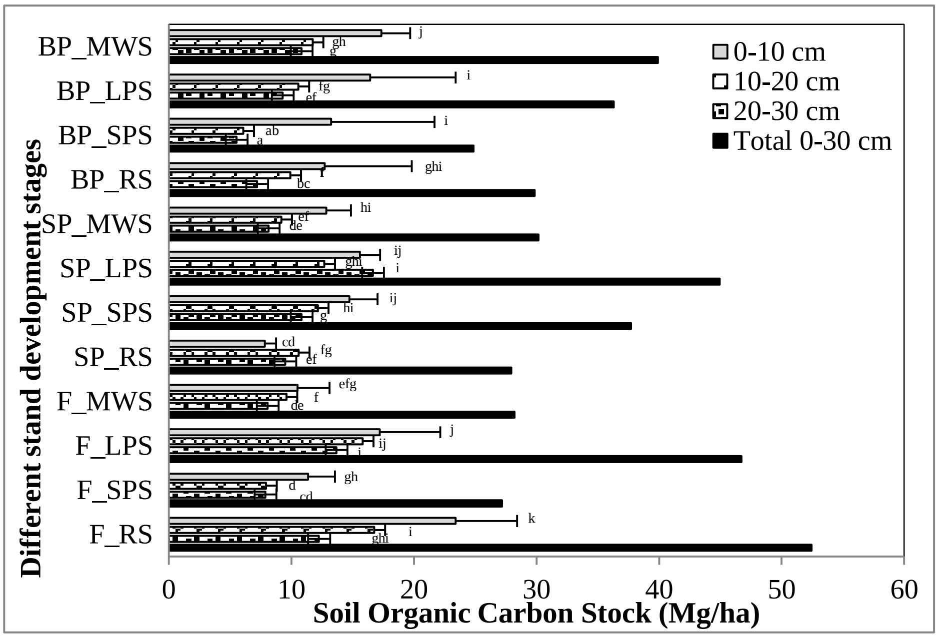

Figure 3. Soil Organic Carbon (SOC) Stock at Different Soil Depths in Four Stages of Stand Development of Black Pine, Scots Pine, and Kazdağı Fir. The Differences between Tree Species at Different Development Stages and Soil Depths are Expressed in Different Lowercase Letters (*P* < 0.05)

At 10-20 and 20-30 cm, SOC stocks for Scots pine stands were the highest SP_{LPS} stands according to the stand development stage, and SP_{SPS}, SP_{RS}, and SP_{MWS} were ranked from highest to lowest. At 0-30 cm, SOC stocks for black pine stands were the highest BP_{MWS} stands according to the stand development stage, and BP_{LPS}, BP_{RS}, and BP_{SPS} were ranked from highest to lowest (Figure 3).

The distribution of SOC at different mineral soil depths is shown in Fig. 4. Approximately 83% of the SOC was deposited in topsoil in Kazdağı fir and black pine trees, indicating that a higher SOC stock was sequestered in the upper layer. The percentage of SOC at 0-10 cm was the highest in the sapling or pole stages of the black pine stands (48.27%). The highest SOC percentages at three different soil depths were determined in the stages of stand development of black pine. For the reproduction stage of black pine stands, the percentages of SOC at different soil depths were 38.15%, 29.73%, and 21.61%, respectively, and decreased with increasing soil depth. Similarly, it was observed that the C content decreased as soil depth increased under Kazdağı fir and Scots pine (only SP_{SPS} and SP_{MWS}) at different stand development stages (Figure 4).

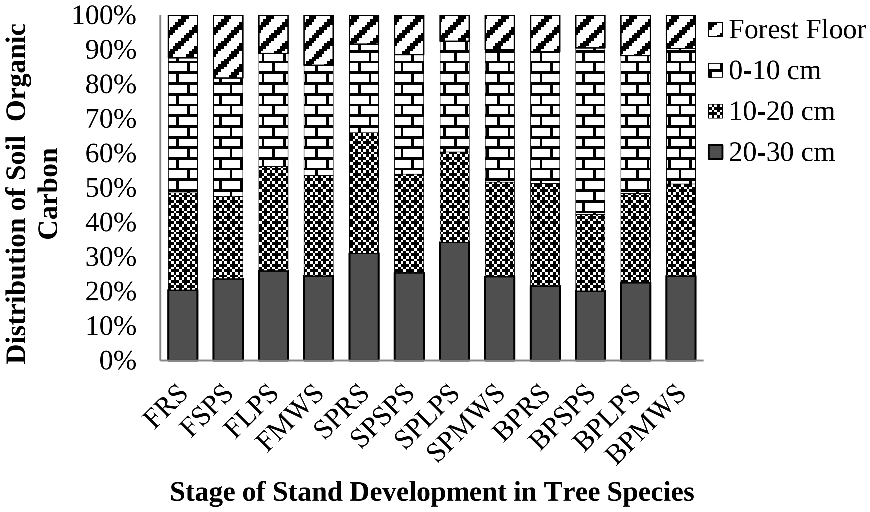

Figure 4. Percentage Contribution of the Carbon Pool in the Forest Floor and Different Mineral Soil Depths in Four Stand Development Stages (RS, SPS, LPS, MWS)in Black Pine (BP), Scots Pine (SP), and Kazdağı Fir (Fir)

Litter on the forest floor

The C concentration of litter samples ranged from 2.56 Mg/ha in the reproduction stage of Scots pine stands to 7.04 Mg/ha in the reproduction stage of Kazdağı fir stands. While the C concentration of the litter samples of Kazdağı fir stands decreased according to the stage of stand development, it showed an increasing and decreasing trend in other stands. The percentage of C within different stages of stand development is shown in Fig. 4. Litter on the forest floor was predominant, representing 18.18 % of SOC stocks in the sapling or pole stage of fir stands. Additionally, the percentage of C in the litter was the highest in the sapling or pole stage of fir (18.18%) and Scots pine stands (11.46 %), and the lowest in the large pole stage of fir (11.0%) and Scots pine (7.51%) stands, whereas the percentage of C was the lowest in the sapling or pole stage of black pine stands (9.44%) and the highest in the large pole stage of black pine stands (Figure 4). For Kazdağı fir, Scots pine, and black pine stands, the percentages of C for different stages of stand development were in the order of $Fir_{SPS} > Fir_{MWS} > Fir_{RS} > BP_{LPS} > SP_{SPS} > Fir_{LPS} > BP_{RS} > SP_{MWS} > BP_{MWS} > BP_{SPS} > SP_{RS} > SP_{LPS}$ (Figure 4).

Effects of different stand development stages on soil organic carbon stocks

The study showed that tree species, different stages of stand development, and soil depth changes can have significant effects on SOC stocks. In our study, SOC stocks at 0-30 cm increased significantly due to the increase in the diameter of black pine trees (except for BP_{SPS}). That is, the highest SOC storage capacity was observed in soils under medium wood stages and large pole stages of stand development (Table 2). These results are in line with the findings of previous studies. That is, SOC stocks in mature stands were higher than those in young stands (Cao et al., 2012; Miao et al., 2014; Li et al., 2015a; Sariyildiz et al., 2015). Similarly, Davis et al. (2003) found that the SOC stock varied with the stage of *Nothofagus* stand development in New Zealand. The high SOC storage capacity of middle-aged and extremely mature trees can be explained by the interactions between factors such as canopy, stand density, soil characteristics (Miao et al., 2014; Li et al., 2015a), and thinning interventions (Jandl et al., 2007). However, our results for Scots pine and fir stands showed no increase in SOC stocks from the reproduction stage to the medium wood stage but a tendency of increase-decrease or decrease-increase. SOC stocks in all stand development stages peaked in large pole stands (44.94 Mg/ha) and declined as sapling or pole stands (37.71 Mg/ha) were replaced with medium wood stands (30.17 Mg/ha) and reached a low point (27.94 Mg/ha) in the reproduction stages of stand development for Scots pine stands (Table 2 and Fig. 3). Growth and yield charts of even-aged trees can often be the effect of a significant reduction in stand productivity in mature trees (Jandl et al., 2007; Chen et al., 2013). Our study reported that litterfall in the medium wood stage for Kazdağı fir and Scots pine stands was lower than that in young-old trees. Decreases in forest floor litter accumulation in medium-aged stands might cause a decrease in total SOC. However, the results of our study have been opposed to the results of Harmon et al. (1990) and Zimmermann et al. (2000), who reported that mature and old-year-old Scots pine stands in the USA transferred a higher portion of C to the soil than in the early stages of stand development and that SOC accumulated in the soil. Savacı and Sarıyıldız (2020) found that the SOC stock (0-30 cm) in Kazdağı fir stands ranged from 166.7 Mg/ha (57-year-old fir stands) to 94.1 Mg/ha (90-year-old fir stands) in Turkey. Peichl and Arain (2006) stated in their study that C accumulation in the soil for *Pinus strobus* trees between 2 and 65 years old ranged from 30.1 to 37.2 Mg/ha, which is consistent with Scots pine and black pine stands in our study. Sariyildiz et al. (2015) found that the SOC stock was lower in young fir stands (61.3 Mg/ha) than in mature fir stands (70.9 Mg/ha) at 0-20 cm. On the other hand, Makineci et al. (2015) stated in their study in Turkey that SOC stock increased due to the increase in stand development ages. Mao et al. (2010) stated that SOC stock contributes to total C storage in the ecosystem, first increasing and then decreasing with increasing stand age. Additionally, the upper soil layers had higher SOC than the lower soil layers. In addition, plant biomass gradually increases with stand age, but soil carbon may indicate different trends (Du et al., 2015).

Effects of different stand development stages on total nitrogen stocks

TN stocks in mineral soil varied widely because we obtained several stand development stages of three tree species from the reproduction to medium wood stages. The TN stock at 0-30 cm ranged from 1.66 to 6.46 Mg/ha. The highest TN stock was observed in the reproduction stages of black pine (2.7±0.22 Mg/ha) and Kazdağı fir (5.48±1.09 Mg/ha) stands, whereas the highest TN stock was in the sapling or pole stages of Scots pine (16.46±1.07 Mg/ha) stands (Table 2). However, TN stocks in each tree species reached the lowest and highest values at different stand development stages. Differences in TN stocks between tree species in this study could be attributed to differences in litter quality and quantity of tree species (Sariyildiz et al., 2015). This might be due to the low organic matter input during the early stage of stand development (Peichl and Arain, 2006). Similarly, Savacı and Sarıyıldız (2020) found that TN stocks also fluctuated due to increased stand age. These results showed that the change in TN stocks at stand development stages (stand age) was not always linearly increasing or decreasing. This study has demonstrated that the reproduction stages of fir stand development had higher TN stocks (5.48±1.09 Mg/ha) than the other stages of fir stand development (Table 2). Similarly, Sariyildiz et al. (2015) indicated that a young fir stand had a higher TN stock (6.82 Mg/ha) than a mature fir stand (5.93 Mg/ha) at 0-20 cm. However, Yuan and Chen (2010) observed in their study that there was an increase in TN stock in the soil with stand development for *Populus tremuloides*. They stated that the amount of N increased in the soil with stand development, as well as the biological inputs of N fixation and accumulated atmospheric N. Yan et al. (2018) determined in their study that larch stands (*Larix kaempferi*) under an increase in soil TN stock were observed across the stand age.

Changes in different stand development stages on the forest floor

The amount of litter decreased in stages from reproduction to medium wood for Kazdağı fir stands. The reproduction stage of fir stands had approximately two times more litterfall than the medium wood stages of fir stands, indicating that litterfall decreases with stand age. The carbon content of litter was higher at the reproduction stage (7.40 Mg/ha) than at the sapling-pole stage (6.04 Mg/ha), larger pole stage (5.78 Mg/ha), and medium wood stage (4.77 Mg/ha) (Fig. 4). Similarly, Clinton et al. (2002) and Davis et al. (2003) assumed that the C accumulation of *N. solandri* var. *cliffortioides* litter was higher at the seedling stage than at other stages. This increase may be because the amount of litterfall was high on the forest floor. Çepel et al. (1988) (for *P. brutia*) and Köhler et al. (2008) (for *Q. copeyensis*) stated that litter was the highest in moderate-aged stands. Savacı and Sarıyıldız (2020) found that *A. nordmanniana* subsp. *equi-trojani* stands (> 100 years old) had higher litter than young fir stands in Turkey. However, in Scots pine stands, the lowest carbon content of litter was observed at the reproduction stage (2.56 Mg/ha) and medium wood stage (3.36 Mg/ha), whereas the highest carbon content of litter was at the sapling or pole stage (4.88 Mg/ha). Çömez et al. (2019) found that the lowest litterfall occurred in young stands, while the highest litterfall occurred in pole Scots pine stands in Turkey. With similar results to our study, Blanco et al. (2006) stated a total litterfall of 3.99 Mg ha^{-1} for the pole stage of Scots pine stands in Spain. Güner and Özkan (2019) reported that the amount of N was between 23.6 and 188.0 kg ha^{-1} in the litter of *Pinus nigra* at different stand development stages. Davis et al. (2003) stated that the carbon inputs from coarse woody debris decaying up to the polar stage may be higher. However, there may be a decrease in the carbon inputs due to less or limited material to decompose under the mature stage. Our study showed that the amount of litter carbon in the black pine stands under the forest floor decreased from the reproductive stage to the sapling & pole stage and then increased and decreased again during the medium mature stages. The C concentration of black pine litter samples ranged from 2.59 Mg/ha in the sapling and pole stage to 4.81 Mg/ha in the larger pole stage. Li et al. (2015a) reported that the amount of dead branches and fallen leaves increased with stand age. Depending on stand development, there is C accumulation in the litter and forest floor. C input to the soil is provided by the ingestion of organic matter by microfauna or the leaching of dissolved organic carbon (Yang et al., 2011). Differences in forest floor litter between stand development stages in this study could be attributed to differences in tree species. The reason for the difference in the amount of litter accumulated under old and young stands may affect the variability of the litter material (Savacı and Sarıyıldız, 2020). In addition, Binkley (1986) stated that the amount of litterfall in young stands was mainly composed of needle casts, while the old stand was composed of branches and shoots.

CONCLUSION

Our results indicate that the stages of stand development affected the SOC and TN stocks. However, TN and SOC stocks increased at different stages in Scots pine, black pine, and fir stands at different stand development stages. We concluded that these tree species have considerable C stock potential at different stand development stages. The results showed that litter decreased in stages from reproduction to medium wood for Kazdağı fir stands. Litter on the forest floor and soil were the two main contributors to the total C stock for all tree species and showed the greatest variation in C stocks throughout the stand development stages. Litter quantity on the forest floor, SOC, and TN stocks in the soil can be used strategically in new afforestation processes and management practices. SOC and TN stocks have high values for the studied stand, making these results very important for C and N cycles. The information provided by our study may be used to apply C budget management, and different stand development ages should be considered when calculating C stocks and dynamics in forests. More comprehensive studies on the effects on C and N stocks will be needed by studying other tree species with different stand development stages.

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Conflict of Interest

The article authors declare that there is no conflict of interest between them.

Author’s Contributions

The authors declare that they have contributed equally to the article

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