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Determination of Changes in Soil Organic Carbon and Total Nitrogen Stocks under Different Stand Age of Kazdağı Fir (*Abies nordmanniana* subsp. *equi-trojani* (Steven) Spach)

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Abstract

Most of the carbon in forest ecosystems is stored in the forest litter and in the soil. Soil organic carbon (SOC) and total nitrogen (TN) stocks are, however, highly variable. Forest carbon stocks and fluxes vary with forest age, and relationships with forest age are often used to estimate fluxes for regional or national carbon inventories. Therefore, it is extremely important to determine the effect of stand age on SOC and TN stocks and the amount of tree species on the distribution. The objective of this study was to estimate SOC and TN stocks of Kazdağı fir (*A. nordmanniana* subsp. *equi-trojani* (Steven) Spach) in the northwest (Ilgaz) and northeast (Inebolu) of Kastamonu. Three sites of fir stand, aged 38, 57, 60, 66, 90, 100, 183, 250, 283 and 306 years were selected in pure fir forests. The results showed significant differences in the amounts of forest litter, SOC and TN stocks among the different stand ages. Kazdağı fir stands older than 100 years had much higher forest litter than the younger fir stands. The highest amount of forest litter was under the 306 years old fir stands (30.3 Mg ha^{-1}) while the lowest amount of forest litter was under the 100 years old fir stands (3.95 Mg ha^{-1}). When 0-30 cm soil depth was considered, the fir stands aged 100 and over generally showed higher SOC stocks than the fir stands younger than 100 years old, with the exception of 38 and 57 years old fir stands which had the highest SOC (166.7 Mg C ha^{-1}). Similarly, for TN stocks, it was also seen that the fir stands aged 100 or over had higher TN stocks than the fir stands younger than 100 years old. Our results have indicated that the forest litter, SOC and TN stocks of fir stands are more dependent on stand age.
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Keywords: Carbon and nitrogen sequestration, natural forest, stand age, soil depth, Kastamonu.

Farklı Yaşlardaki Kazdağı Göknar Meşçerelerinde (*Abies nordmanniana* subsp. *equi-trojani* (Steven) Spach) Toprak Organik Karbon ve Azot Stoklarındaki Değişimin Belirlenmesi

Öz

Orman ekosistemlerindeki karbonun çoğu toprak yüzeyi ölü örtüsünde ve toprakta depolanır. Toprak organik karbon (TOK), toplam azot (TA) stokları oldukça değişkendir. Özellikle orman karbon stokları ve havuzu orman yaşına göre değişir ve orman yaşına bağlı olarak genellikle bölgesel veya ulusal karbon envanterleri için tahmin edilebilmektedir. Bu nedenle, meşcere yaşının karbon ve azot stokları üzerindeki etkisinin, ağaç türü dağılımı üzerindeki miktarının belirlenmesi son derece önemlidir. Bu çalışmada, Kastamonu ilinin kuzeybatısı (Ilgaz) ve kuzeydoğusunda (İnebolu) yaygın olan Kazdağı göknarın (*Abies nordmanniana* subsp. *equi-trojani* (Steven) Spach) ölü örtü miktarı, toprak organik karbon (TOK) ve toplam azot (TA) stokları üzerinde meşcere yaşının etkisi araştırılmıştır. Meşceredeki ağaçların ortalama yaşları 38, 57, 60, 66, 90, 100, 183, 250, 283 ve 306 olan saf göknar meşcerelerinin her birinde üç tekrarlı deneme alanında çalışılmıştır. Sonuçlar, farklı meşcere yaşları arasında ölü örtü miktarı, TOK ve TA stokları arasında önemli farklılıklar olduğunu göstermiştir. 100 yaşından büyük göknar meşcerelerinin, genç göknar meşcerelerinden daha fazla ölü örtüye sahip olduğu tespit edilmiştir. Ölü örtü miktarı en yüksek 306 yaşındaki göknar (30.3 ton/ha), en düşük 100 yaşındaki göknar meşcerelerinde (3.95 ton/ha) belirlenmiştir. 0-30 cm derinlikte, 38 yaşındaki göknar meşceresi ile en yüksek TOK stokuna (166.7 ton/ha) sahip 57 yaşındaki göknar meşceresi hariç, 100 yaş ve üzerindeki göknar meşcerelerinde TOK ve TA stoku, daha genç olanlardan daha yüksek bulunmuştur. Sonuçlar, göknar meşcerelerinin ölü örtü miktarı, TOK ve TA stokları üzerinde meşcere yaşının önemli olduğunu göstermiş olup ilgili araştırmalarda meşcere yaşı dikkate alınmalıdır.
Anahtar Kelimeler: Karbon ve azot depolaması, doğal orman, meşcere yaşı, toprak derinliği, Kastamonu.

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1. Introduction

Forests are the largest carbon (C) reservoir in terrestrial ecosystems and they play an important role in mitigating elevated atmospheric CO_2 concentrations and preventing global warming (Schimel et al., 2001). Increasing nitrous oxide (N_2O) in the atmosphere is becoming a major global threat to global warming (Zhou et al., 2017) and nitrogen (N) deposition has also increased more than ten times since the last 150 years due to the intensification of human activities such as production and application of nitrogen fertilizer, and fossil fuel combustion (Hobbie, 2008), and the accumulation rate of N is expected to increase in the next few decades (Galloway et al., 2004). The increasing N availability would affect C and N cycles in terrestrial ecosystems (Tolunay and Çömez 2007; Jiang et al., 2010).

In many countries, inventory-based approaches are widely used worldwide forests to estimate C storage capacity of aboveground biomass (Terakunpisut et al., 2007; Ahmad et al., 2016). Even though soils represent the most important long-term organic C reservoir in terrestrial ecosystems, as they contain more C than plant biomass and atmosphere (Tarnocai et al., 2009), less attention is given to estimate SOC (Richards et al., 2007; Vesterdal et al., 2013) and also TN stocks, which are closely related to global climate change. Studies have shown that more than 650 billion tons of C are stored by forests, with 56% stored in forest litter and soil (FAO, 2010). SOC accumulation rate is largely dependent on plant net primary productivity (Jobbágy and Jackson, 2000), which is mainly limited by N in most ecosystems (Vitousek and Howarth, 1991). Therefore, soil N pool has been considered as an indicator of C sequestration potential (Vesterdal et al., 2008). The inputs of soil organic matter (SOM) through forest litter can also affect SOC stocks (Bonan, 2008). Forest litter is the most important component of C and N accumulation in forest soil and the largest inflow of organic matter (OM) and nutrients to the forest litter (Sariyildiz, 2008; Asplund et al., 2018).

Another factor that affect SOC stock is stand age (Sariyildiz et al., 2008; Ali et al., 2019). Stand age is a main contributor to SOC change dynamics. However, the relationship between stand age and SOC stock is not necessarily linear. A number of study have shown that quantity and quality of forest litter vary with tree species, geographical position and stand age (Albrektson, 1988; Berg et al., 1995). Others have found that forests in the latter stages of stand development could either be C neutral (Dangal et al., 2017; Seedre et al., 2015), sequester a small quantity of C (Jonard et al., 2017), or exhibit a declining C pool (Liu et al., 2013). This indicates that the dependent relationship between total forest ecosystem C storage and stand age may be species and site-specific (Sariyildiz et al., 2005; Jia et al., 2017). Some studies have shown that the soil N stock increases with increasing stand age in the upper soil layer because of cumulative biological fixation, litterfall, recycling from deeper mineral soil via root mortality and even atmospheric N deposition (Hume et al., 2016). However, the changes in SOC and TN stocks at different stand ages are rarely quantified and poorly understood.

In this study, we aimed at investigating the effects of stand age on the amounts of forest litter and SOC and TN stocks of Kazdağı fir species. For this, three sites of fir stand, aged 38, 57, 60, 66, 90, 100, 183, 250, 283 and 306 years were selected in Kazdağı fir forest and mineral soil samples were taken from 0-5 cm, 5-10 cm, 10-15 cm, 15-20 cm and 20-30 cm soil depths and analyzed for pH, soil texture, bulk density, soil organic carbon and total nitrogen.

2. Materaial and Method

2.1. Study Site Description and Sampling

The study was carried out in Kastamonu, northwest of Turkey. Forest litter samples (L+F+H) and soil samples were taken from two study areas, Inebolu (41º 51' 23" N - 33º 45' 36" E) and Ilgaz (41º 04' 08" N - 33º 46' 12" E) (Figure 1). Inebolu area is located 80 km away from the North Kastamonu city and Ilgaz is located 50 km away from the South Kastamonu city. The altitudes of the studied areas were 1030 m a.s.l. for Inebolu and 1250 m a.s.l. for Ilgaz. The aspects of all studied sites were North (N). At the site, fir was dominant tree species in stands. The fir is represented with species and four sub-taxa in Turkey. It is an important tree species in Turkey. As an endemic taxon, Kazdağı fir (*A. nordmanniana* subsp. *equi-trojani* (Steven) Spach) is distributed in the Central and Western Black Sea Region and South Marmara Region in Turkey (Mataracı 2012). The fir taxa in Turkey are distributed on a surface area of 584 781 hectares, which accounts for 2.62% of the overall forest coverage. The aspect was northeast (NE) and medium slopes (range from 20% to 30%). In the areas, winters are long, cold and snowy, whereas summers are short and warm. According to the weather data collected from Inebolu and Ilgaz Meteorology Station between 1960 and 2015 (55 years). According to Thornthwaite method (Thornthwaite, 1948), Inebolu area is very humid, moderate temperature (Mesothermal), with or without water deficiency, near-marine climate type

(AB'1rb'3) while Ilgaz area is very humid, low temperature (Microthermal), with or without water deficiency, near-terrestrial climate type (B1C'2rb'1).

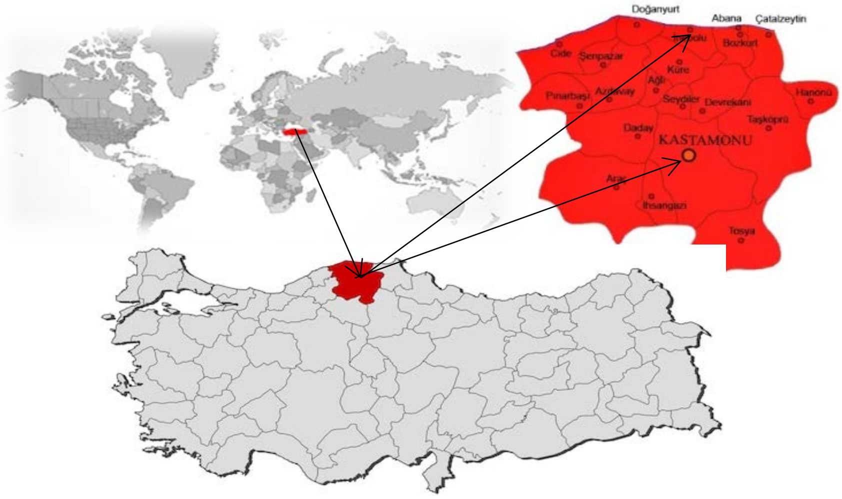


Figure 1. Location of the study areas.

It is provided that the two different study sites, where show the most widespread of the fir species, are the same in terms of site characteristics (aspect, slope, elevation etc.). A total of 30 forest stands (10 stand age x 3 replicate=30) were selected to represent 10 stand age-classes: 38, 57, 60, 66, 90, 100, 183, 250, 283 and 306 years stands. The average stand age was selected to include the least three trees from each area (total $n_1+n_2+n_3=10$). The bedrock of the study area is usually neritic limestone and schists covered with a sandy loam and clay (Akbaş et al. 2015). The soil type is an acrisol soil according to the World Reference Base for Soil Resources & Brown Forest Soil Type according to FAO (Anonymous, 1999). Organic layer of the humus is mull type.

In the study sites, three subplots (20 m × 20 m) were chosen for each stand age-class and total 30 forest litter samples (L+F+H) were collected from three randomly selected 50 cm x 50 cm locations, and the litter (L) fragmented debris (F) and humus (H) on the mineral soil were completely taken. In each subplot, some stand characteristics were also measured. The measurements of diameter at breast height (DBH) and height were made on three sample trees for each stand age-class. DBH was measured using a diameter tape. Tree age was determined by dendrochronological approach, coring trees at breast height. Tree heights were measured with a Blume-Leiss clinometer.

Total 250 soil samples were also collected in early October 2014 under the different aged fir stands from which total 30 forest litter samples were taken. The soil samples were collected from randomly selected under the stands. Degreaded soil samples were taken from a depth of between 0 and 30 cm to analyze soil texture. A soil core device with an inner diameter of 5 cm was used for soil sampling to a depth of 30 cm. Mineral soil sample cores were taken from 0-5 cm, 5-10 cm, 10-15 cm, 15-20 cm and 20-30 cm soil depth, and passed through a 2 mm sieve to remove stones and gravel to analyze in soil.

2.2. Analysis of Forest Litter Samples and Soils

The forest litter samples were air-dried and then oven-dried at 70 ˚C for 48 h (Sariyildiz 2000). Using the moisture values, the dry weights of the forest litter samples were obtained by the difference between the wet and dry weights of the forest litter samples, and multiplied by the conversion coefficient (25) to hectares (Makineci, 1999).

Soil pH (H_2O) was measured in a 1:2.5 mixture of deionized water and soil using a glass calomel electrode (LaMotte pH meter 5 series) after equilibration for 1 h in solution (Jackson, 1962). Soil moisture content on fresh soil samples was calculated by weight loss after drying approximately 10 g of soil for 24 h at 105ºC (Allen, 1989). Bulk density was determined by weight loss after drying the undisturbed soil cores (Blake and Hartge, 1986). Soil texture (sand, silt and clay) was determined using the hydrometer method of Bouyoucos (1962). Determination of total organic carbon and nitrogen was determined in the Eurovector EA3000 Single CHN-S elementary analyzer according to dry combustion method in Kastamonu University Central Laboratory. All analyses were carried out in triplicate. The SOC and TN stocks were calculated by multiplying soil volume, soil bulk density, and SOC or TN content and expressed as Mg ha^{-1} (Lee et al., 2009). Soil mass was calculated as follows (eqn. 1):

$$M_i = BD_i * T_i * 10^4$$

where M_i is dry soil mass (Mg ha^{-1}), 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^{-1}). The fixed depth (FD) determination of areal SOC or TN stock is calculated as follows (eqn. 2):

$$SOC_{i-fixed} \text{ or } TN_{i-fixed} = ([SOC_i] \text{ or } [TN_i]) * M_i$$

where $SOC_{i\text{-}fixed}$ is the C (or $TN_{i\text{-}fixed}$ is the N) mass to a fixed depth (Mg C ha^{-1} or Mg N ha^{-1}) and $[SOC_i]$ or $[TN_i]$ is the C or N content (Mg C ha^{-1} or Mg N ha^{-1}) (Sariyildiz et al., 2015).

2.3. Statistical Analysis

A two-way ANOVA (analyses of variance) was applied for analyzing the effects of stand age and soil depths on SOC and TN stocks using the SPSS program (Version 22.0 for Windows). Following the results of ANOVAs, Tukey's Honestly Significant Difference (HSD) test (α=0.05) was used for multiple comparisons of SOC and mass TN stocks in relation to stand age and soil depths.

3. Results

3.1. Stand and Soil Characteristics

Stand and soil characteristics of the study sites are given in Table 1 and Table 2 respectively. In general, mean tree diameter and height showed an increase with increasing stand age (Table 1). Canopy closure of 57 and 66 years old stands was 11-40%, while 90 and 100 years old were 71-100%. The others had 41-70% canopy closure (Table 1).

Table 1. Stand characteristic of the study sites (n=100).

Stand age (year)	Study area	n	DBH ± SE (cm)	Height ± SE (m)	Canopy closure (%)	Stand type
38	İnebolu	10	31^{a}±1.75	24^{a}±0.75	41-70	Gbc2
57	Ilgaz	10	35^{ab}±1.68	32^{b}±1.42	11-40	Gcd1
60	İnebolu	10	42^{ab}±2.84	35^{bc}±1.63	41-70	Gbc2
66	Ilgaz	10	44^{ab}±2.80	36^{bc}±0.99	11-40	Gcd1
90	İnebolu	10	47^{b}±3.67	41^{d}±1.05	71-100	Gcd3
100	İnebolu	10	48^{b}±2.42	41^{d}±0.56	71-100	Gcd3
183	Ilgaz	10	97^{c}±3.40	35^{bc}±0.98	41-70	GÇsA
250	Ilgaz	10	109^{c}±2.78	38^{cd}±0.32	41-70	GÇsA
283	Ilgaz	10	127^{d}±4.73	39^{cd}±0.43	41-70	GÇsA
306	Ilgaz	10	133^{d}±5.33	40^{d}±0.47	41-70	GÇsA

Values indicate the range (age) or the mean ± standard error (SE), n: number of sampled trees, DBH: diameter at breast height. Where letters in superscript differ, data are significantly different ($p < 0.05$).

Mean soil pH ranged from 5.00 (100 years old stands) to 6.11 (183 and 283 years old stands), while soil bulk density varied from 0.60 g cm^{-3} (57 years old stands) to 1.49 g cm^{-3} (90 years old stands). 60 years old stands had the lowest sand content (8%), whereas they had the highest clay (54%) and silt (38%) contents. 90 years old stands showed the highest sand content (84%), whereas they showed the lowest clay (8 %) and silt (8%) contents (Table 2).

Table 2. Soil characteristics of the study sites (mean 0-30 cm soil depth).

Stand age (year)	n	pH±SE	Soil bulk density±SE (g cm^{-3})	Sand±SE (%)	Silt±SE (%)	Clay±SE (%)	Soil texture classes
38	25	5.16^{ab}±0.022	1.12^{bc}±0.046	32^{b}±0.719	26^{f}±0.289	42^{d}±0.447	C
57	25	5.79^{de}±0.095	0.60^{a}±0.042	65^{d}±0.742	23^{e}±0.408	12^{b}±0.465	SL
60	25	5.15^{ab}±0.058	1.16^{bc}±0.053	8^{a}±0.683	38^{g}±0.447	54^{e}±0.577	C
66	25	5.58^{cd}±0.04	0.66^{a}±0.045	57^{c}±0.365	22de±0.289	21^{c}±0.500	SL
90	25	5.99^{ef}±0.069	1.49^{e}±0.081	84^{h}±0.683	8^{a}±0.447	8^{a}±0.577	LS
100	25	5.00^{a}±0.039	1.40^{de}±0.067	76^{g}±0.342	15^{b}±0.695	9^{a}±0.387	SL
183	25	6.11^{f}±0.11	0.95^{b}±0.05	72^{f}±0.975	20^{cd}±0.785	8^{a}±0.365	SL
250	25	5.78^{de}±0.069	0.61^{a}±0.056	66de±0.342	26^{f}±0.577	8^{a}±0.500	SL
283	25	6.11^{f}±0.042	0.95^{b}±0.031	64^{d}±1.057	22de±0.671	14^{b}±0.577	SL
306	25	5.33^{bc}±0.042	0.67^{a}±0.04	69^{ef}±0.224	18^{c}±0.289	13^{b}±0.465	SL

Values indicate the range (age) or the mean ± standard error (SE), n: number of sampled trees, C: clay, SL: sandy loam, LS: loamy sand. Where letters in superscript differ, data are significantly different ($p < 0.05$).

3.2. Variation in Forest Litter Samples

Variations in mean amounts of forest litter samples with stand age are shown in Figure 2. In general, the fir stands older than 100 years seemed to have much higher forest litter than the younger fir stands (Figure 2). The highest amount of forest litter sample was under the 306 years old fir stands (30.3 Mg ha^{-1}) while the lowest amount was under the 100 years old fir stands (3.95 Mg ha^{-1}).

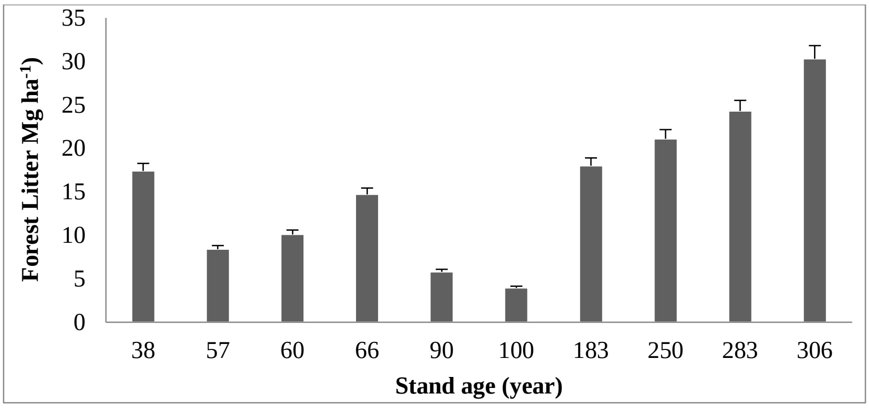


Figure 2. Variation in forest litter of fir between the different stand ages.

3.3. Variation in Soil Organic Carbon and Total Nitrogen Contents

Mean SOC and TN contents of the ten different stand ages and five different soil depths are given in Table 3. At the depths of 0-5 cm, the 57 years old fir stands had the highest SOC contents (20.4%), while the 250 years old had the lowest SOC contents (4.30%). The 57 years old fir stands also showed the highest SOC contents at the depths of 5-10 cm and 15-20 cm (19.2 % and 10.2 % respectively), while the 250 years old fir stands had the highest SOC contents at the depths of 10-15 cm (14.7%). Mean SOC content (0-30 cm) was also the highest for the 57 years old fir stands (12.3%). The 90 years old fir stands had the lowest SOC content at the depths of 5-10 cm (3.01%), 10-15 cm (1.43%), 15-20 cm (1.74%), and 0-30 cm (3.43%) while the 183 years old fir stands had the lowest SOC content at the depths of 20-30 cm (1.30%).

At the depths of 0-5 cm, the 57 years old fir stands had the highest TN contents (0.78%), while the 250 years old had the lowest TN contents (0.25%). The 250 years old fir stands showed the highest TN contents at the depths of 5-10 cm (0.74 %) and the lowest TN contents (0.20%) under the 66 years old fir stands. The 66 years old fir stands had the lowest TN contents at the depths of 10-15 cm, 15-20 cm and 20-30 cm and also 0-30 cm (Table 3). The highest TN contents (0.66%) at the depth of 10-15 cm was found under the 250 years old fir stands, while the 57 years old fir stands had the highest TN contents (0.46%) at the depths of 15-20 cm. The 283 years old fir stands showed the highest TN contents at the depths of 20-30 cm (0.35 %). Mean TN content (0-30 cm) was the lowest for the 57 years old fir stands (0.23%)

Table 3. Soil organic carbon and total nitrogen (%) of the different stand ages and soil depths (cm).

Stand Age (year)	Soil Organic Carbon (%)						Soil Total Nitrogen (%)					
	0-5 cm	5-10 cm	10-15 cm	15-20 cm	20-30 cm	Mean	0-5 cm	5-10 cm	10-15 cm	15-20 cm	20-30 cm	Mean
38	5.23[a]	4.69[b]	4.10[b]	4.63[b]	3.81[c]	4.49[a]	0.26[a]	0.23[a]	0.22[b]	0.24[b]	0.21[a]	0.23[a]
57	20.4[c]	19.2[e]	7.35[c]	10.2[d]	4.51[d]	12.3[d]	0.78[d]	0.72[c]	0.35[c]	0.46[d]	0.26[b]	0.51[d]
60	10.8[b]	3.33[a]	2.18[a]	2.44[a]	2.21[b]	4.19[a]	0.51[c]	0.19[a]	0.14[a]	0.16[a]	0.16[a]	0.23[a]
66	10.0[b]	1.74[a]	9.18[d]	3.12[b]	1.65[a]	5.14[b]	0.44[b]	0.20[a]	0.39[c]	0.25[b]	0.23[a]	0.30[b]
90	9.12[b]	3.01[a]	1.43[a]	1.74[a]	1.83[ab]	3.43[a]	0.39[b]	0.26[a]	0.20[b]	0.21[b]	0.23[a]	0.26[a]
100	6.16[a]	4.61[b]	3.64[b]	1.87[a]	5.69[d]	4.39[a]	0.36[b]	0.27[a]	0.24[b]	0.20[b]	0.23[a]	0.26[a]
183	12.3[b]	7.72[c]	6.60[c]	4.47[b]	1.30[a]	6.48[b]	0.50[c]	0.42[b]	0.36[c]	0.22[b]	0.18[a]	0.34[b]
250	4.30[a]	16.8[e]	14.7[e]	8.97[c]	3.46[c]	9.64[c]	0.25[a]	0.74[c]	0.66[d]	0.40[d]	0.23[a]	0.46[c]
283	6.95[a]	6.72[c]	4.01[b]	5.63[c]	4.22[d]	5.51[b]	0.38[b]	0.34[b]	0.27[b]	0.32[c]	0.35[c]	0.33[b]
306	11.6[b]	13.8[d]	9.09[d]	7.81[c]	2.58[b]	8.97[c]	052[c]	0.58[c]	0.45[c]	0.41[d]	0.22[a]	0.44[c]

Where letters in superscript differ (abcde), data are significantly different ($p < 0.05$).

3.4. Variation in Soil Organic Carbon and Total Nitrogen Stocks

Mean SOC and TN stocks of the different stand ages are given in Figures 3 and 4, respectively. The single effects and interactions of stand ages and soil depths are listed in Table 4.

Table 4. ANOVA results of soil organic carbon and total nitrogen stocks.

	Sources	SS	df	MS	F	Eta squared
SOC_{stock}	Stand Age (SA)	4721.281	10	524.587	4.592***	.292
	Soil Depth (SD)	1142.876	4	285.719	2.501*	.091
	Sa x Sd	20340.565	40	565.016	4.945***	.640
	Error	11425.072	100	114.251		
TN_{stock}	Stand age (SA)	4.512	10	.501	4.938***	.308
	Soil depth (SD)	9.302	4	2.326	22.907***	.478
	Sa x Sd	23.024	40	.640	6.300***	.694
	Error	10.152	100	.102		

Asterisks refers the level of significance : *P<0.05; **P<0.01; ***P<0.001. SOC_{stock}: Soil Organic Carbon Stock, TN_{stock}: Total Nitrogen Stock, SS: Sum-of-squares, df: degrees of freedom, MS: Mean squares.

There were significant differences ($P < 0.001$) in SOC stocks among the different stands ages Figure 3). Interactions of stand ages and soil depths were also significant on the SOC and TN stocks. That means that the SOC and TN stocks behave in different ways according to the five different soil depths on ten different stand ages are given in Figures 3 and 4.

At the top 5 cm soil depths, SOC stocks showed higher contents at the first three youngest fir stands than those at the last oldest fir stands than lower contents in 90 years old stands (44.2 Mg C ha^{-1}). For example, SOC content was the lowest in 250 years old stands (9.8 Mg C ha^{-1}) while it was the highest in all other mature fir stands (Fig. 3a). At the soil depths of 5-10 cm, the increase in SOC stocks from the stand age of 100 was higher than young fir stands (except for 57 years old stands). 306 years old stands showed the greatest SOC stocks (46.8 Mg C ha^{-1}), whereas 66 years old stands showed the lowest SOC stocks (4.9 Mg C ha^{-1}) (Fig. 3b). At the soil depths of 10-15 cm, SOC stocks varied from 11.3 Mg C ha^{-1} in 60 years old stands to 44.5 Mg C ha^{-1} in 66 years old stands. In mature fir stands, the increase in SOC stocks was higher than young fir stands (except for 66 years old stands) (Fig. 3c). At the soil depths of 15-20 cm, this time the middle age fir stands (66, 90 and 100 years old) showed the lowest SOC stocks (Fig. 3d). At the soil depth of 20-30 cm, the 38 and 100 years old stands (had the highest SOC stocks, while the 66 years old stands had the lowest (Fig. 3e). When all data (0-30 cm) was compared, it was generally seen that the fir stands aged 100 and over had higher SOC stocks than the younger fir stands (Fig. 3f).

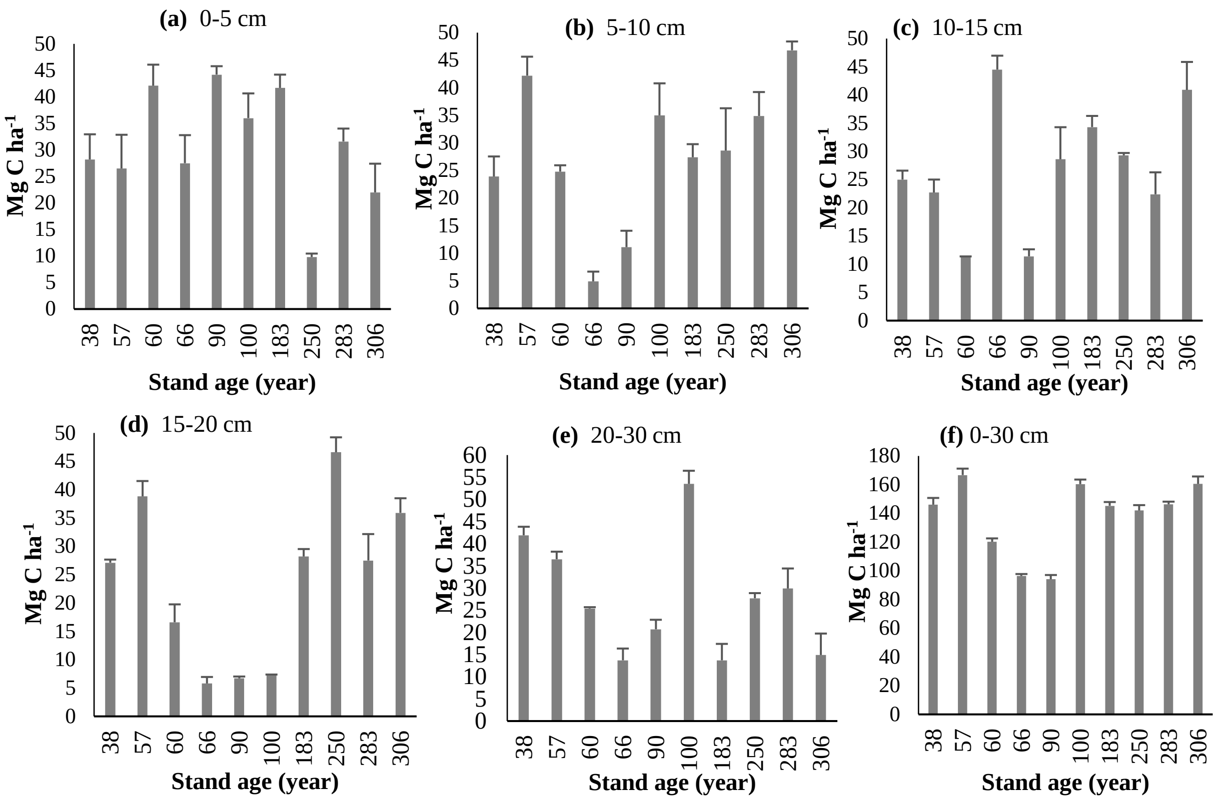
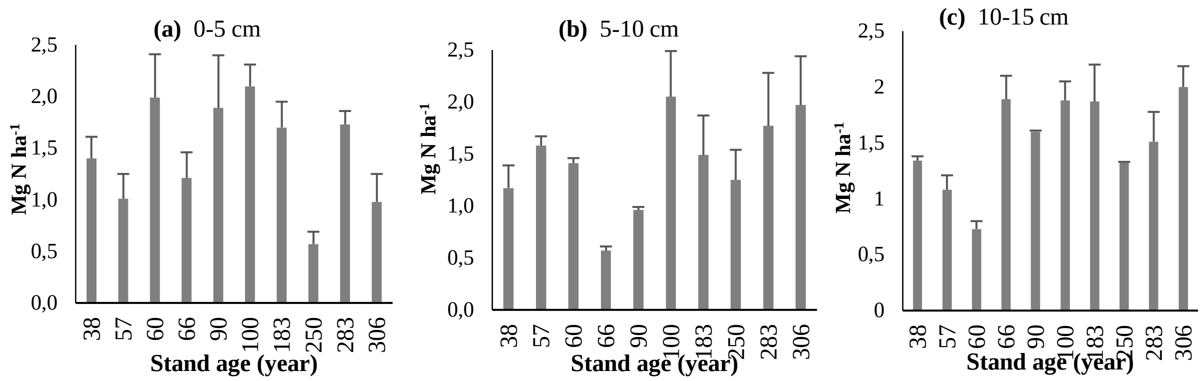


Figure 3. Variation in soil organic carbon stocks of fir between the different stand ages according to soil depths, 0-5 cm (a), 5-10 cm (b), 10-15 cm (c), 15-20 cm (d), 20-30 cm (e) and 0-30 cm (f).

Our results showed a tendency increase and decrease of TN stocks of Kazdağı fir stands at the top 5 cm (Fig. 4a). At the soil depths of 5-10 cm, the increase in TN stocks from the stand age of 100 and over (except for 250 years old stands) was higher than young fir stands (Fig. 4b). It was higher in young and mature fir stands and was lower in middle-aged stands (66, 90 and 100 years old) at the 15-20 cm (Fig. 4d), while lower in young and mature fir stands and higher in middle-age stands at the 10-15 cm (Fig. 4c). At all stand ages, TN stocks tended to increase and decrease (Fig. 4e). When all data (0-30 cm) was compared, it was generally seen that the fir stands aged 100 or over had higher TN stocks than the fir stands younger than 100 years old (Fig. 4f).



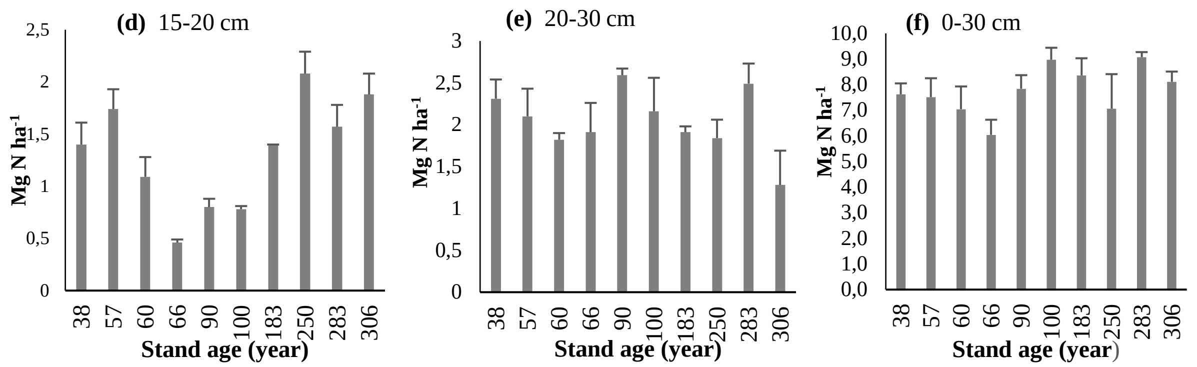


Figure 4. Variation in soil total nitrogen stocks of fir between the different stand ages according to soil depths, 0-5 cm (a), 5-10 cm (b), 10-15 cm (c), 15-20 cm (d), 20-30 cm (e) and 0-30 cm (f).

4. Discussion

The present study has shown that stand age and soil depth can have significant effects on forest litter and SOC and TN stocks of fir species (*A. nordmanniana* subsp. *equi-trojani* (Steven) Spach). In general, the results showed that the fir stands older than 100 years had much higher forest litter than the younger fir stands. Amount of forest litter in fir stands ranged from 30.3 Mg ha^{-1} (306 years old fir stands) to 3.95 Mg ha^{-1} (100 years old fir stands). It can be explained that the forest litter at the middle slope on the south-facing aspect is moister, owing to the lower amounts of net radiation reaching the ground. A study by Duyar et al. (2014) showed that annual mean forest litter was 46.64 Mg ha^{-1} for *A. nordmanniana* subsp. *bornmulleriana* **(**Mattf.). They also found that this amount was 58.7 Mg ha^{-1} in winter season and 50.3 Mg ha^{-1} at the altitude of 1550 m a.s.l. For 170 years old *A. borisii-regis* (Mattf.) stands, Kavvadias et al. (2001) found that the forest litter was 47.8 Mg ha^{-1}. Our findings for the amounts of forest litter of fir species were lower than the findings of those researchers. This could be attributed to the site differences among the studies. Forest litter thickness generally increases with decreasing temperature; the reduction of the biomass efficiency decreases at higher altitudes (Çepel et al., 1977). This may be due to shadowing impact of other stand parameters on age effect on litterfall. Therefore, stand growth (m^3 ha^{-1}), which is the main influential factor on litterfall (Clarke et al., 2018) is under the control of substantially crown closure, growing stock and site index. Studies on the factors influencing the differences in the amounts of forest litter between or within tree species have shown that many factors could be responsible. Those include (1) short- or long-term climatic deviations, such as temperature, precipitation, storm, frost etc. (Hennessey et al. 1992), (2) chronic or extreme changes in environmental factors, for example, crashing air pollutants or sea water on trees (Pedersen and Bille-Hansen, 1999), (3) differences due to site factors (aspect, altitute, soil characteristics) (Albrektson, 1988), (4) management practices and stand status (silvicultural interventions, thinning, cleaning, age, disease, etc.) (Hennessey et al., 1992) (5) species diversity (Bonnevie-Svendsen and Gjems, 1957).

Albrektson (1988) (for *P. sempervirens*) and Ranger et al. (2003) (for *P. menziesii* Franco) found that needle litter decreased with increasing stand age. On the other hand, Çepel et al. (1988) (for *P. brutia*) and Köhler et al. (2008) (for *Q. copeyensis*) reported that forest litter was highest in the middle stand age. Albrektson (1988) was reported that the needle litterfall decreased with increasing stand age. In our study, there was no clear increase or decrease in the forest litter with the stand age. However, the younger stands (less than 100 years old) had lower forest litter than the older fir stands (Fig. 2). The reason for the difference in the amount of forest litter on the soil surface between the old and young stands could be attributed to the variation in litterfall material as shown a number of studies. For example, Binkley (1986) reported that most of the amount of litterfall found on the soil surface at early ages in the stand was effective in needle cast and later branches and shoots were more dominant.

In our study, with the exception of 38 and 57 years old fir stands (for only SOC stocks but not total TN stocks), the stands aged 100 and over showed higher SOC and TN stocks than the fir stands younger than 100 years old. These results have indicated that variation in SOC and TN contents and stocks with the stand age are not always in a linear increase or decrease way. Studies have shown that crown cover, stand density, litter accumulation, topography of the species, sea distance and microclimate site characteristics of any tree stand may show fluctuations due to the differences in the environment. In our study, mean total SOC stock (0-30 cm soil depth) in the fir stands ranged from 166.7 Mg C ha^{-1} (57 years old fir stands) to 94.1 Mg ha^{-1} (90 years old fir stands). Our findings are within the values shown by the other studies. For example, Kantarcı (1979) showed for *A.bornmuelleriana* that mean SOC stock ranged from 65.5 Mg C ha^{-1} to 196.2 Mg C ha^{-1}. Sevgi et al. (2011) reported for *A.bornmuelleriana* that mean SOC stocks (0-30 cm soil depth) was 79 Mg C ha^{-1}. The differences in the values for similar fir species could be attributed to the differences in SOC analysis methods as well as different study sites. As a result, it should be considered that the analysis instruments used may also change the determination of SOC.In many studies, it was shown that the amount of organic C stored in the soil increased linearly with the age of the stand. Tian et al. (2015) for the different ages of shrub plantations (3-, 12-, 27- and 37-year-old) in China found that SOC stock capacity increased with increasing stand age and the average SOC stocks of 0-100 cm soil depth were 12.715 Mg C ha^{-1}, 20.793 Mg C ha^{-1}, 23.111 Mg C ha^{-1} and 27.652 Mg C ha^{-1}, respectively. Likewise, Sariyildiz et al. (2015) found for *A.bornmuelleriana* that mean SOC stocks (0-20 cm soil depths) was 61.3 Mg C ha^{-1} for the 45 years old stand and 70.9 Mg C ha^{-1} for the 82 years old stand. On the other hand, some studies have shown a fluctuation in SOC stock with increasing stand age. For example, McGrath et al. (2001) reported for three different stand age (5-18 years, 12-15 years and 100 years) that SOC stocks (0-20 cm soil depth) were 22.2±2.0 Mg C ha^{-1}, 20.5±8.5 Mg C ha^{-1} and 26.6±2.7 Mg C ha^{-1} respectively. Marin-Spiotta et al. (2009) showed that SOC stocks of 0-10 cm soil depth from 4 different stand ages (10-, 20-, 30- and 80-year-old) were fluctuating with the stand age (26.7 ±2.8 g g^{-1}, 28.7±3.5 g g^{-1}, 25.2±2.1 g g^{-1} and 30.4±2.9 g g^{-1}, respectively). Chen and Shrestha (2012) found that the SOC stocks increased from 2- and 10-year-old stands to 29-, 85- and 140-year-old stands, and then decreased in 203-year-old post-fire stands. Mao et al. (2010) reported that the amount of SOC contributed to the total ecosystem C storage firstly increased and then decreased with increasing stand age, and that upper soil layers had higher levels of SOC than the lower soil layers. Some researchers have found no relationship between stand age and SOC stocks (Marin- Spiotta et al., 2009; Neumann-Cosel et al., 2011). They have argued that land use patterns, clay content, topography, climatic conditions, land use/land cover change, forestry management practices, selected sampling areas were effective on organic C stocks in soil (Jobbágy and Jackson, 2000; De Koning et al., 2003; Desjerdans et al., 2004).

In our study, mean TN stock (0-30 cm soil depth) in the fir stands ranged from 9.07 Mg N ha^{-1} (283 years old fir stands) to 6.04 Mg N ha^{-1} (66 years old fir stands). Similar to the results for the SOC stocks, mean TN stocks also showed a fluctuation with increasing stand age. Similar results were also reported by a number of researchers (McGrath et al., 2001; Marin-Spiotta et al., 2009). For example, Klopatek (2002) found for 20-, 40- and 450-550 years Duglas fir (*P. menziesii* (Mirb.) Franco) that the TN storages of 0-20 cm soil depth were 3.5 Mg N ha^{-1}, 7.5 Mg N ha^{-1} and 3.8 Mg N ha^{-1} respectively. Hume et al. (2016) discussed that TN content may be lower than C because N is progressively locked up in live biomass, which is likely the explanation for why the TN stock altered less significantly with stand ages and between different stand types compared with soil OC stocks here.

5. Conclusion

In conclusion, the results of this study have shown that stand age has significant effects on SOC stock and TN dynamics. But the effects can vary with the soil depths. On the other hand, stand age has significant effects on the amounts of forest litter and there is a strong relationship between the amounts of forest litter and the SOC and TN stocks. This indicates to the importance in considering the effect of stand age in moderating effect of forest composition on forest litter processes and chemistry. Our results demonstrate that taking stand age and soil depths into consideration are highly beneficial for ecosystem SOC and TN stock estimation and underline the potential of *A. nordmanniana* subsp. *equi-trojani* for SOC and TN stocks in natural forest ecosystems. According to the Paris Agreement, which has been signed recently, priority should be given to the studies on this subject in order to evaluate the C values that forests have kept underground and above ground, to present the necessary formulas and equations in estimating them economically, and to reveal the opportunities to benefit from C markets. Stand age, soil sampling depth and also the methods used to quantify SOC and TN stocks should be considered for accurate assessments of changes in SOC and TN stocks potential in the future studies.

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