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Research Article / Araştırma Makalesi

# Determination of annual organic carbon sequestration in soil and forest floor of Scots pine forests on The Türkmen Mountain (Eskişehir, Kütahya)

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**Abstract:** This study was aimed to determine the annual organic carbon stocks in forest floor and soil in Scots pine (*Pinus sylvestris* L. subsp. *hamata* (Steven) Fomin.) forests. Research was conducted with two samplings in 2003 and 2013 on massive of Türkmen Mountains (Eskişehir, Kütahya) where located in West Central Anatolia Region in Turkey. Samplings were performed in 40 plots at pole (dbh=11.0-19.9 cm) and small tree (dbh=20.0-35.9 cm) development stages on different aspects, elevation, slope degree and slope positions. Data were evaluated with paired-samples t test. Soil organic carbon stocks show a significant (*P<0.001*) difference despite carbon stock in forest floor has not significant (*P>0.05*) difference between 2003 and 2013. Depending on these differences, accumulated carbon stocks were 2.88 Mg C $ha^{-1}$ $yr^{-1}$ in soil and 0.02 Mg C $ha^{-1}$ $yr^{-1}$ in forest floor.

**Keywords:** Scots pine, soil, forest floor, carbon sequestration

# Türkmen Dağı (Eskişehir, Kütahya) sarıçam ormanlarında toprak ve ölü örtüde biriken yıllık organik karbon miktarının belirlenmesi

**Özet:** Bu çalışma, sarıçam (*Pinus sylvestris* L. subsp. *hamata* (Steven) Fomin.) ormanlarında toprak ve ölü örtüde biriken yıllık karbon miktarının belirlenmesi amacıyla yapılmıştır. Araştırma, Batı İç Anadolu Bölgesi'nde yer alan Türkmen Dağı (Eskişehir, Kütahya) kütlesi üzerinde yürütülmüştür. Örneklemeler, direklik ($d_{1,3}$=11,0-19,9 cm) ve ince ağaçlık çağında ($d_{1,3}$=20,0-35,9 cm) bulunan, farklı bakı, yükselti, eğim ve yamaç konumu özelliğine sahip 40 alanda yapılmıştır. Veriler bağımlı iki örneklem t testi ile değerlendirilmiştir. 2003 ve 2013 yılları arasında toprak karbon stoğu bakımından önemli bir farklılık belirlenirken (*P<0,001*), ölü örtü karbon stoğu bakımından anlamlı bir farklılık (*P>0,05*) bulunamamıştır. Araştırma sonuçlarına göre toprakta 2,88 Mg C $ha^{-1}$ $yıl^{-1}$, ölü örtüde 0,02 Mg C $ha^{-1}$ $yıl^{-1}$ karbonun depolandığı belirlenmiştir.

**Anahtar Kelimeler:** Sarıçam, toprak, ölü örtü, karbon birikimi

## 1. INTRODUCTION

Forest ecosystems constitute the most important carbon sinks that can reduce atmospheric emissions via carbon sequestration in soil and plant biomass, at the same time, it can be caused to anthropogenic modifications (Çömez, 2012). In terrestrial ecosystems, more than 80% of the carbon accumulated in the soil, and more than 70% of all the soil organic carbon are sequestered by forest ecosystems (Jandl et al., 2007).

Under the Kyoto Protocol for the solution of the global climate change problem, countries prepare greenhouse gas emissions from the energy, transport, waste, agriculture and land-use-land use change and

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forestry sectors annually and they present their national inventory reports (NIR) on sequestered carbon from atmosphere to United Nations Secretariat of the Framework Convention on Climate Change (UNFCCC).

In forest ecosystems, there are two methods to determine the amount of carbon sequestered from the atmosphere. The first one is stock exchange and the second is gain-loss method. The first method is based on temporal change of carbon between two time periods, and the second method is based on the calculation of the amount of annual carbon accumulation (IPCC, 2003).

Carbon in forest ecosystems is accumulated in living plant mass (trees and ground cover), above and below ground biomass, dead plant mass (forest floor and dead wood) and in the soil. Numerous studies have been carried out to determine the carbon stocks stored in forest ecosystems in Turkey and other countries. However, the number of studies to determine the spatial changes of carbon sequestered in soil and forest floor is limited. Several studies exist on the determination of organic carbon stored in soil and forest floor of Scots pine forests (*Pinus sylvestris* L. subsp. Hamata (Steven) Fomin.) in Turkey (Çepel et al., 1977; Tolunay, 1997; Güner, 2006; Tolunay, 2009; Çömez, 2012). However, these studies were mostly aimed to determine available carbon stocks, and they do not submit annual carbon accumulations.

This present study is aimed to determine the amount of annual organic carbon sequestered in soil and forest floor. It is believed that obtained data will contribute to the Turkish national greenhouse gas inventory.

## 2. MATERIALS AND METHODS

### 2.1. Study area

The research area is located on the Turkmen Mountain between 39º16'-39º38 'north latitudes and 30º06'-30º36' east longitudes (Figure / Şekil 1).

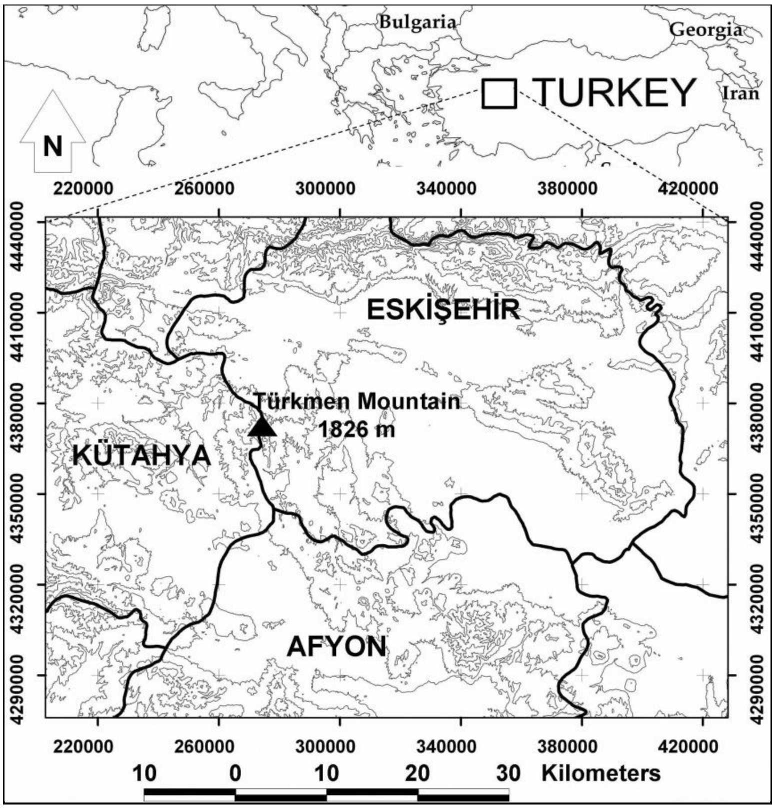


Figure 1. Location of the study area
Şekil 1. Araştırma alanının konumu

The dominant geological parent materials of research area are rhyolite and dacite. In addition, basalt, claystone and limestone parent materials exist (URL, 2015). The main soil type is "grey brown and podsolic grey brown forest soils" (Güner, 2006).

According to the data of Eskişehir, Kütahya and Afyonkarahisar meteorological stations, the average annual temperature ranges from 10.6 °C to11.1 °C, and annual precipitation is between 374 and 562 mm. The climate type of the study area varies between semi-humid and humid in Thornthwaite water balance system (Güner, 2006).

The study area is dominated by Scots pine. The other main plant species spreading in the study area are Anatolian black pine (*Pinus nigra* Arnold. subsp. *pallasiana* Lamb. (Holmboe), trembling poplar (*Populus tremula* L.) and oriental beech (*Fagus orientalis* Lipsky.). Dominant species of understory are laurel leaved cistus (*Cistus laurifolius* L.), tinctory oak (*Quercus infectoria* Oliv.), downy oak (*Quercus pubescens* Willd.), Turkish oak (*Quercus cerris* L.), common oak (*Quercus robur* L.), prickly juniper (*Juniperus oxycedrus* L.), wild service (*Sorbus torminalis* (L.) Crantz.), dog rose (*Rosa canina* L.), and hawthorn (*Crataegus pentagyna* Willd.) (Güner, 2006).

Some site and stand characteristics of sample plots were given on Table / Tablo 1 (Güner, 2006). Thus, stand development stages of sample plots are between pole stage (dbh=11.0-19.9 cm) and small tree stage (dbh=20.0-35.9 cm).

Table 1. Some site and stand characteristics of sample plots
Tablo 1. Örnek alanların meşcere ve bazı yetişme ortamı özellikleri

| | Units | Mean | Minimum | Maximum |
|---|---|---|---|---|
| ***Stand properties*** | | | | |
| Stand volume | $m^3 ha^{-1}$ | 411.3 | 218.7 | 683.2 |
| Stand density | tree $ha^{-1}$ | 1035 | 500 | 2000 |
| Stand age | year | 87 | 67 | 108 |
| Diameter at breast height | cm | 23.2 | 16.8 | 31.1 |
| Height | m | 17.9 | 10.3 | 26.8 |
| ***Physiographic factors*** | | | | |
| Elevation | m | 1492 | 1222 | 1708 |
| Inclination | % | 20 | 3 | 40 |
| Slope position | % | 51 | 13 | 83 |
| Radiation index | | 0.516 | 0.004 | 0.983 |
| ***Climatic properties*** | | | | |
| Mean annual temperature | °C | 7.8 | 6.3 | 8.9 |
| Annual rainfall | mm | 727 | 609 | 854 |
| Actual evapotranspiration | mm | 412 | 399 | 425 |
| Water deficit | mm | 157 | 119 | 183 |
| Water surplus | mm | 286 | 206 | 394 |
| Rainfall of the most drought month | mm | 17 | 13 | 22 |
| Rainfall from June to September | mm | 145 | 119 | 167 |

### 2.2. Field sampling and laboratory methods

Sampling were performed on 40 plots, each plots has different aspect, altitude, slope position and slope characteristics. One soil pit was dug in each sample plot and mineral soil horizons were determined. Soil samples were taken from determined soil horizons (Ah, Ael, Bst, BC, Cv) with soil corers in one litter volume after description of soil profile and site characteristics. Forest floor samples were collected from one square meter representing and settled in the center of plot. Each forest floor sample was separated to layers as litter (L), fermentation (F) and humus (H). Sampling of soil and forest floor was repeated twice in both 2003 and 2013 for temporal comparison.

Total 400 soil samples were air dried, sieved with 2 mm mesh size and weighed. Soil moisture was determined by weighing of fresh and dried soil samples (dried at 105 ºC for 24 hours), soil texture (sand, silt and clay ratio) was analyzed by hydrometer method and organic carbon ratio was determined by Walkey and Black wet digestion method (Carter and Gregorich, 2008). 240 forest floor samples were dried at 65 ºC for 48 hours, weighed and ground for analysis. The carbon concentrations of the subsamples of forest floor were measured using a LECO TruSpec 2000 Analyzer (Leco, 2000).

### 2.3. Data evaluation

Unit volume values were used to determine the soil carbon stocks of sample plots. For this purpose, the organic carbon concentration which was determined by analysis for each soil horizon was multiplied by fine soil volume weight (< 2 mm) and converted to values in unit volume. Carbon content in a square meter for each soil horizon was calculated multiplying horizon thickness (mm) by determined volume values. The total carbon content of the soil pedon was determined by summing the carbon contents of all of the soil horizon depths. Then, soil carbon stocks in an area basis were calculated by using conversion coefficient for unit area in hectare.

To determine the carbon stocks of forest floor, forest floor amounts were multiplied by carbon concentrations of litter, fermentation and humus layers in a square meter. Calculated values were converted to hectare basis by using conversion coefficient. The change of carbon content of soil and forest floor in a decade between 2003 and 2013 were statistically compared with paired samples t test (Özdamar, 2002).

## 3. RESULTS AND DISCUSSION

Soil and forest floor properties were given on Table / Tablo 2. Forest floor masses were determined as 29.8 Mg ha$^{-1}$ in 2003 and 32.5 Mg ha$^{-1}$ in 2013. Çömez (2012) found as 28.7-46.4 Mg ha$^{-1}$ and Janssens et al. (1999) reported as 73.1 Mg ha$^{-1}$ forest floor mass for Scots pine stands at the similar development stages. Tolunay and Çömez (2008), reviewed that forest floor masses of Scots pine forests in Turkey, reported as ranged from 4.4 to 111.0 Mg ha$^{-1}$. Our results in the ranges of forest floor masses of Scots pine forests in Turkey.

Table 2. Soil and forest floor properties of sample plots
Tablo 2. Örnek alanların toprak ve ölü örtü özellikleri

| | Units | Mean | Minimum | Maximum |
|---|---|---|---|---|
| ***Soil properties*** | | | | |
| Bulk density | g cm$^{-3}$ | 1.14 | 0.52 | 1.33 |
| Fine soil | Mg ha$^{-1}$ | 6323.2 | 1690.0 | 9105.3 |
| Sand | Mg ha$^{-1}$ | 3891.6 | 883.0 | 6176.8 |
| Silt | Mg ha$^{-1}$ | 1108.2 | 457.7 | 1710.1 |
| Clay | Mg ha$^{-1}$ | 1323.3 | 349.3 | 2242.7 |
| ***Forest floor properties*** | | | | |
| 2003 Forest floor (L+F+H) | Mg ha$^{-1}$ | 29.883 | 16.304 | 56.061 |
| 2013 Forest floor (L+F+H) | Mg ha$^{-1}$ | 32.592 | 15.477 | 69.218 |

Soil carbon concentrations in descending trend with soil depth (Table / Tablo 3). Carbon concentrations of soil were changed 0.21-4.36% in 2003, and 0.65-4.94% in 2013. Similar results were obtained in a research on oak forests, and it was determined that the mean soil carbon concentration decreased with soil depth and changed between 0.6% and 6.1% (Makineci et al., 2015). Carbon concentrations of forest floor decreased from the litter layer to the humus layer and were found to be 42.8-52.8% in 2003 and 38.7-51.6% in 2013 (Table / Tablo 3). Çömez (2012) found that the carbon concentrations of forest floor were 31.5-52.5% for Scots pine stands, which are the same as the development ages in this study. Carbon concentration of forest floor in beech forests was found between 35% and 52% in West Black Sea Region (Yildiz and Eşen, 2006; Yildiz et al., 2007; Yildiz et al., 2009). The carbon concentration of the forest floor determined in this study also in the range of the values found for beech forests. The element content of forest floor varies according to the plant species, as well as the site fertility and the decay rate. In addition, forest floor dynamics of the young stands over development may differ from the dynamics of forest floor in the older stages (Yildiz et al., 2011). For this reason, it can be expected that the characteristics of forest floor in the stands under development will be different after 10 years. On the other hand, considering the decomposition period of forest floor, measurement of carbon in pools corresponds only a comparison between the pools at a certain time because some of the carbon pool of forest floor is transferred to the soil pool over ten years. However, the carbon dynamics of these ecosystems could not be explained clearly with the comparison of carbon pools alone. For this reason, it is possible to give a more accurate analysis to take account the dynamics on inputs and outputs of these carbon pools (fast and slow growing). Yildiz (2000) compared the systems of weed clearing treatments and top soil degradation in the plantations of the Douglas-fir on the coastal and inland parts of the Oregon, USA. Despite plantations led to a decline in the total carbon and nutrient pools of ecosystem in early years due to severe degradations, total carbon accumulation (biomass+soil+forest floor) of ecosystem on the plots in which tree growth facilitated with the intensive treatments was more compared to the lesser degraded plots at the 15. years of experiments.

The organic carbon content in the soil was calculated as 37 Mg ha$^{-1}$ in 2003, 66 Mg ha$^{-1}$ in 2013, and annual organic carbon accumulation was 2.88 Mg ha$^{-1}$ (Table / Tablo 4). Soil organic carbon stocks in 2003 and 2013 showed a statistically significant ($P < 0.001$) difference. The soil organic carbon content in a meter soil depth was found in the range of 92-100 Mg ha-1 in Scots pine forests having similar characteristics (Çömez, 2012). In the temperate zone forests in Northeast China, the soil carbon stock was determined as 70 Mg ha$^{-1}$ (35-113 Mg ha$^{-1}$) (Zhu et al., 2010). In Turkey, it was reported that the soil organic carbon contents of Scots pine forests change between 18 and 448 Mg ha-1, with an average of 78 Mg C ha$^{-1}$ (Tolunay and Çömez, 2008). The soil organic carbon stocks in our study among the ranges determined for the Turkish Scots pine forests. However, the soil carbon contents of present study are lower than those of the study which was conducted on Scots pine forest on Sündiken Mountain (Çömez, 2012). The reason of this pattern is likely lesser fine soils in the unit volume.

Table 3. Carbon concentration of soil and forest floor (%)
Tablo 3. Toprak ve ölü örtü karbon oranları (%)

| | 2003 | | | 2013 | | |
|---|---|---|---|---|---|---|
| | **Mean** | **Minimum** | **Maximum** | **Mean** | **Minimum** | **Maximum** |
| ***Soil horizons*** | | | | | | |
| Ah | 4.36 | 1.67 | 8.44 | 4.94 | 2.70 | 9.30 |
| Ael | 1.98 | 0.42 | 3.78 | 2.14 | 0.81 | 4.09 |
| Bst | 0.85 | 0.10 | 2.16 | 1.34 | 0.57 | 2.47 |
| BC | 0.36 | 0.07 | 0.97 | 0.91 | 0.41 | 1.63 |
| Cv | 0.21 | 0.03 | 0.52 | 0.65 | 0.25 | 1.57 |
| ***Forest floor layers*** | | | | | | |
| L | 52.87 | 51.89 | 54.10 | 51.66 | 43.83 | 56.90 |
| F | 48.71 | 44.79 | 50.99 | 46.38 | 28.56 | 53.69 |
| H | 42.84 | 24.70 | 49.02 | 38.77 | 21.16 | 49.43 |

Table 4. Carbon stocks in soil and forest floor
Tablo 4. Toprak ve ölü örtü karbon stokları

| **Carbon stocks** | **Units** | **2003 Mean (Min.-Max.)** | **2013 Mean (Min.-Max.)** | **Annual sequestration Mean (Min.-Max.)** |
|---|---|---|---|---|
| Soil | Mg C ha$^{-1}$ | 37.161 (18.308-73.515) | 65.939 (35.524-109.006) | 2.877 (0.646-5.695) |
| Forest floor | Mg C ha$^{-1}$ | 14.582 (6.16-27.35) | 14.775 (7.340-31.707) | 0.019 (-0.934-0.932) |

Many studies have been carried out on annual carbon accumulation in the soil. It has been found that carbon accumulation in the soil were as 0.21 and 0.40 Mg ha$^{-1}$ year$^{-1}$ in two different Scots pine ecosystems in Germany (Prietzel et al., 2006). Annual carbon accumulation in soil with litter fall was 2.7 Mg ha$^{-1}$ in the alder plantations in South Korea (Kim et al., 2009). Lettens et al. (2005) stated that 1.0 Mg $ha^{-1}$ soil carbon accumulation per year was estimated in the conifer forests in Belgium. Annually 2.2-2.5 Mg $ha^{-1}$ carbon accumulation was determined in the top of 30 cm soil depth under Sitka spruce forest (Black et al., 2009). It was determined that 1.0-1.4 Mg $ha^{-1}$ carbon was deposited per year at 50 cm soil depth in spruce-fir forests in Southeast America (Miegroet et al., 2007). Present results on annual organic carbon accumulation in soil are generally similar to other research findings. However, organic carbon accumulation in the soil can vary widely. For example, as a result of cutting treatments in the forest, the soil organic carbon stock increases with cutting residuals in the first stage, then decreases depending on the reduction on litterfall and fine roots. Furthermore, the carbon stocks of soil and forest floor increase until reaching to the full canopy cover and a balance in the stand, and the annual carbon accumulation decreases in the maturing stands. The sample plots in present study were in the pole and young tree stages, and no silvicultural treatments have been operated during ten years between 2003 and 2013 when the sampling was carried out.

The average carbon stock of forest floor was 14.5 Mg C $ha^{-1}$ in 2003, 14.7 Mg C $ha^{-1}$ in 2013, and annual carbon accumulation in forest floor was 0.02 Mg C $ha^{-1}$ (Table / Tablo 4). Differences on carbon stocks of forest floor between 2003 and 2013 were not statistically significant ($P>0.05$). Berg et al. (2007), determined that annual carbon accumulation in forest floor on average 0.18 Mg C $ha^{-1}$ (0.04-0.41 Mg C $ha^{-1}$ $year^{-1}$) for soils of Swedish forests. Furthermore, lower carbon accumulation in forest floor can be interpreted that decomposition rate of forest floor in optimum level.

## 4. CONCLUSIONS

In conclusion, significant organic carbon accumulation in soil (2.88 Mg C $ha^{-1}$ $year^{-1}$) was determined in sampling period with ten years' interval under Scots pine forests in Türkmen Mountains. Forest floor constitutes the main source of soil organic carbon accumulation and nutrient cycle in forest ecosystems. For this reason, protection of forest floor has special importance in terms of ensuring the soil fertility and ecological sustainability. In this context, further researches should be conducted on carbon budgets, stock changes and effects of forestry operations on carbon management in forest ecosystems.

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