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Assessing the amount of soil organic matter and soil properties in high mountain forests in Central Anatolia and the effects of climate and altitude

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Abstract

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The objectives of this study were to determine the amounts of soil organic matter (SOM) stored within surface soils of high mountain forests and how the SOM amounts are affected by aridity and altitude in semi-arid regions of Central Anatolia. Various climate and altitude conditions of Central Anatolia were included in this study, and SOM amounts were found to be higher in the surface soils of northern Anatolia forests. Our results showed that altitude, climatic factors, and tree species were the most important factors affecting the amount of SOM and other soil properties. SOM, pH, bulk density and available water content differed significantly depending on the altitude and climatic factors in the study areas. As the altitude increased in semi-arid regions, the aridity decreased and the amount of SOM increased.

Keywords: forest soil; topographic conditions; climate model; semi-arid regions; Turkey

Mountain forests cover 9 million km^2 of the Earth's surface, and they constitute 23% of the Earth's forest cover. These forests are the most significant storage areas for soil organic matter (SOM) and carbon (Janzen 2004). SOM is an important terrestrial pool for carbon and nitrogen (Quan et al. 2014) and compared with the atmosphere, SOM stores twice as much carbon at present. Owing to the large amount of carbon stored in SOM, even small changes in the soil carbon storage may significantly affect the CO_2 concentration of the atmosphere (Liski, Westman 1997). This situation further increases the importance of SOM in forest soils.

In semi-arid and arid areas, precipitation, especially snowfall, increases with altitude above 1,500 m a.s.l., and regions of somewhat higher humidity can occur at high altitudes in these areas. These humid regions can support forests in arid and semi-arid areas. Such forests belong to the arid forest class, and they should be under absolute protection (FAO 2003). The mountainous areas of Anatolia contain a variety of forest types based on different climate types and rugged topography, resulting in the formation of local climates. Inner Anatolia features steppes below 1,200 m a.s.l., while dry forest zones are found at altitudes between 1,200 and 2,000 m a.s.l. Altitudinal forest belts occur in the high mountain ranges (Atalay et al. 2014). These forests have been degraded through grazing, illegal logging, erosion, aridity, and poor management over the course of centuries (Öztürk et al. 2010). High-altitude forests protect the sustainability of land resources in the mountains of Inner Anatolia; therefore, measures should be implemented to protect the high-altitude forest ecosystems. An

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assessment of soil organic matter and the physical properties of soil in high mountain forest ecosystems is an important part of this effort. Liski et al. (2002) and Nabuurs et al. (2003) suggested the use of models to determine the change of carbon storage in forest soils. These models include slow- and rapid-cycling SOM pools, with turnover rates that depend on climate properties. The objective of this study was to assess the SOM and other soil properties in semi-arid high mountain forest ecosystems of Turkey. In addition, the relationships between aridity and the SOM accumulated in forest soils of high mountains were investigated.

MATERIAL AND METHODS

The study areas lie within the semi-arid zone extending from north to south in Central Anatolia (Fig. 1). This zone includes high mountain forest areas at altitudes ranging between 1,300 and 1,700 m a.s.l. (Table 1). The mean annual precipitation of the study areas ranges from 444 to 1,034 mm. According to the United Nations Environment Programme Aridity Index – UNEP AI (Middleton, Thomas 1997) climate classification system, which evaluates precipitation and evaporation simultaneously, the study areas belong to the semi-arid climate class (0.5 < AI < 0.65) (Table 1). The UNEP AI is defined as the ratio of the mean annual precipitation (P, mm) to the mean annual potential evapotranspiration (E_p, mm) and quantifies rainfall availability relative to atmospheric evaporative demand. The tree species within the study areas, from the lowest to the highest altitude, were black pine: *Pinus nigra* Arnold subsp. *pallasiana* (Lambert) Holmboe var. *pallasiana*, Scots pine: *Pinus sylvestris* Linnaeus, cedar: *Cedrus libani* A. Richard, and fir: *Abies nordmanniana* subsp. *bornmulleriana* Mattfeld, (Table 1). The study areas were selected on the basis of their similarity to one another based on their properties and tree species.

The data in the present study were synthesized from seven studies previously conducted in the semi-arid and high mountain forests of Central Anatolia (Table 1). Seven different sample areas were selected from the forest areas in the transition regions, extending from north to south in Central Anatolia. The northern portion of Central Anatolia has a humid and mild climate due to its proximity to the Black Sea, whereas the southern one has a hot and humid Mediterranean climate. The soil data of forest areas from northern to southern Anatolia in order of appearance were used (Fig. 1). The majority of soils in the research areas were classified as Inceptisols and Entisols (Soil Survey Staff 1999).

We took a total of 134 soil samples from the ground surface (0–20 cm depth, which is the effective depth of SOM accumulation in the research areas) on a 50 × 50 m systematic grid from 14 sampling points in the Sivas, Kardeşler (SK) Forest location, and 20 sampling points in other locations: Çankırı, Ilgaz Mountain (ÇI), Çankırı, Geçmiş Mountain (ÇG), Çankırı, Eldivan Mountain (ÇE),

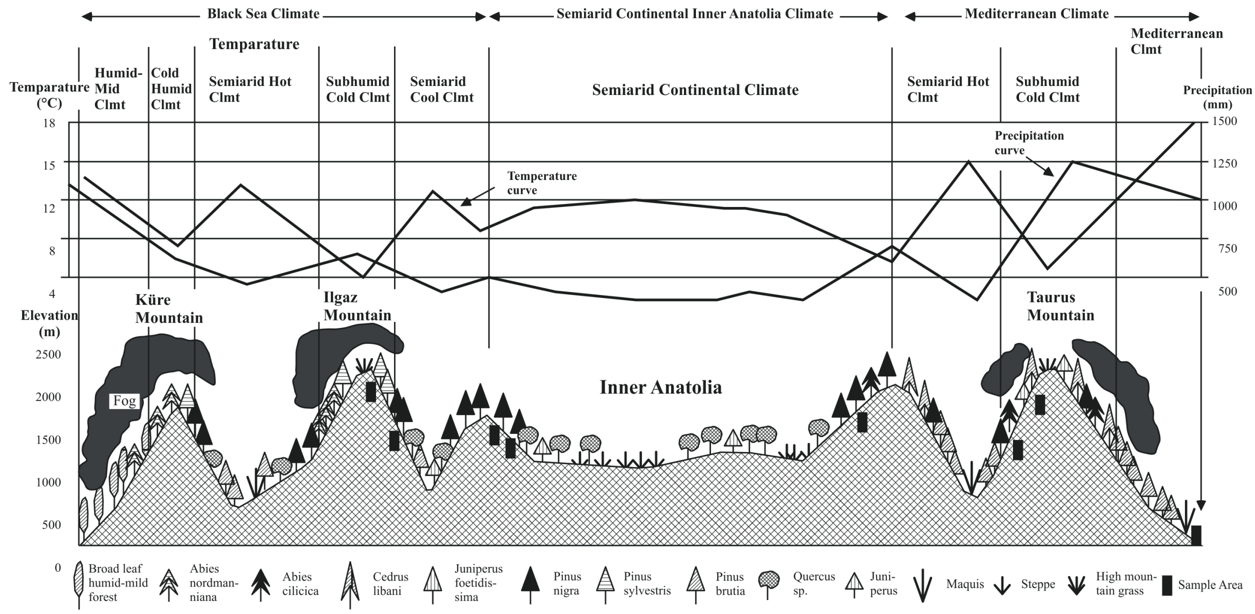

Fig. 1. Location of the study areas chosen within the climate and vegetation profiles of Central Anatolia in north-south direction from Black Sea to Mediterranean Sea (Atalay et al. 2014)

Table 1. Some topographic and climatic properties and the values of climate classification models for the study areas in Central Anatolia

Study area	Stand tree species	Coordinates	Mean altitude (m a.s.l.)	Mean slope (%)	Mean annual temperature (°C)	Mean annual precipitation (mm)	Mean annual humidity (%)	Potential evaporation (mm)	Aridity index	Thornthwaite climate classification	References
ÇI	BP-SP-F	33°45'19"E 41°01'34"N	1,650	30	7.8	1,034	70	640	1.6	26.8	Göl et al. (2010)
ÇG	SP-F	33°47'22"E 40°49'09"N	1,550	18	9.1	710	70	610	1.2	24.5	Göl and Çakir (2006)
ÇE	BP-SP	33°30'20"E 40°30'41"N	1,500	25	10.1	501	63	646	0.8	14.9	Göl (2002), Göl et al. (2004)
SK	BP-SP	37°03'22"E 39°47'60"N	1,300	20	9.0	444	64	614	0.7	18.4	Göl (2005)
ET	BP-SP	30°20'26"E 39°31'29"N	1,500	35	8.4	716	65	544	1.3	34.7	Göl et al. (2008)
KB	BP-SP-F	32°19'59"E 37°06'54"N	1,650	23	10.3	596	62	417	1.4	27.5	ÇEM (2015)
KK	BP-C	32°23'58"E 37°03'10"N	1,700	30	9.7	648	58	377	1.7	41.5	ÇEM (2015)

ÇI – Çankırı, Ilgaz Mountain, ÇG – Çankırı, Geçmiş Mountain, ÇE – Çankırı, Eldivan Mountain, SK – Sivas, Kardeşler Forest, ET – Eskişehir, Türkmen Mountain, KB – Konya-Bozkır, Erenler Mountain, KK – Konya-Hadim, Köşker Mountain, BP – black pine (*Pinus nigra* Arnold subsp. *pallasiana* (Lambert) Holmboe var. *pallasiana*), SP – Scots pine (*Pinus sylvestris* Linnaeus), F – fir (*Abies nordmanniana* subsp. *bornmulleriana* Mattfeld), C – cedar (*Cedrus libani* A. Richard)

Eskişehir, Türkmen Mountain (ET), Konya-Bozkır, Erenler Mountain (KB), and Konya-Hadim, Köşker Mountain (KK) (Table 1). These soil samples were treated separately in all physical and chemical analyses. The sampling areas were chosen so that the factors other than temperature, altitude, and rainfall, such as land cover and forest stand properties were as similar as possible between the northern and southern study areas. Vanhala et al. (2008) found that the rate of SOM mineralization in their studied forest site types was equally dependent on temperature.

Soil samples were gathered from the surface soil (0–30 cm depth) for all of sampling areas because of the effective depth of soil organic matter (SOM) accumulation in the study areas. Undisturbed soil samples were collected with a steel cylinder (100 cm^3) for the bulk density analysis and disturbed soil samples were taken to investigate their physical and chemical properties in the laboratory. The fine soil fraction (< 2 mm in size) was used for the soil analysis. Particle size distribution in the soil was determined by the hydrometer method (Bouyoucous 1951); available water capacity (AWC) at 0.33 and 15 bar tension was determined using a pressure plate (Blake, Hartge 1986); bulk density was determined by the core method (Cassel, Nielsen 1986); soil pH (soil-to-deionized water, 1:5) and electrical conductivity were measured by an Orion Star A320 pH/electrical conductivity meter (Thermo Scientific, USA) (Rhoades 1996); carbonate ($CaCO_3$-lime) was determined by the pressure calcimeter method (Richard, Donald 1996), and SOM was determined by the Walkley-Black method (Nelson, Sommer 1996). Average annual rain and temperature records from 1980 to 2015 (Turkish State Meteorological Service 2015) were used for the UNEP AI, and the climate properties were identified. UNEP AI (UNEP 1997) and the Thornthwaite climate classification model – TCCM (Thornthwaite 1948) were used to determine the relationship between SOM and climate properties. All data were analysed using the SPSS® statistical software (Version 20.0, 2011). ANOVA used a two-factor randomized complete plot design. Significant *F*-values were obtained, and differences between individual means were tested using Duncan's test, with a significance level of $P < 0.05$.

RESULTS

The amounts of SOM measured in high mountain forest soils are given in Table 2. The SOM amounts in seven sampling areas in the transition zones of Central Anatolia were quite different from one another. Other soil properties in the sampling areas were also examined in this study. Fig. 2 shows SOM, soil properties, and the relationship between SOM and aridity corrected for all properties. All properties of surface soil differed significantly between study areas ($P < 0.05$), particularly the SOM

Table 2. Statistical comparison of some soil physical and chemical properties among the study areas

Study area	Sample number	Texture (%)			Soil type	pH (1/5 DIW)	$CaCO_3$ (%)	EC ($dS \cdot m^{-1}$)	SOM (%)	BD ($g \cdot cm^{-3}$)	AWC (%)
		sand	silt	clay							
ÇI	20	41 ± 17.12^{a}	35 ± 16.69^{c}	24 ± 14.59^{a}	loam	5.79 ± 1.05^{a}	1.50 ± 2.22^{a}	0.78 ± 0.37^{b}	5.56 ± 3.76^{b}	1.14 ± 0.16^{a}	19.49 ± 6.09^{bc}
ÇG	20	48 ± 10.65^{a}	27 ± 5.29^{b}	25 ± 8.26^{a}	loam	6.55 ± 0.62^{b}	0.90 ± 1.41^{a}	1.55 ± 1.41^{cd}	4.59 ± 1.51^{b}	1.05 ± 0.21^{a}	17.07 ± 5.49^{ab}
ÇE	20	37 ± 13.15^{a}	33 ± 12.49^{bc}	30 ± 10.48^{a}	clay-loam	7.31 ± 0.35^{c}	4.91 ± 7.77^{b}	1.83 ± 0.78^{d}	2.32 ± 0.71^{a}	1.07 ± 0.13^{a}	24.42 ± 6.48^{d}
SK	14	44 ± 5.43^{ab}	34 ± 2.90^{c}	22 ± 6.07^{a}	loam	7.86 ± 0.28^{d}	17.74 ± 7.73^{c}	2.27 ± 0.48^{e}	2.05 ± 0.86^{a}	1.11 ± 0.26^{a}	13.78 ± 2.36^{a}
ET	20	43 ± 8.00^{ab}	27 ± 4.56^{b}	30 ± 6.73^{a}	clay-loam	5.79 ± 0.64^{a}	0.84 ± 0.30^{a}	1.27 ± 0.56^{c}	2.38 ± 0.83^{a}	1.09 ± 0.22^{a}	21.84 ± 4.26^{cd}
KB	20	54 ± 18.01^{b}	20 ± 7.35^{a}	26 ± 13.73^{a}	sandy-clay-loam	6.62 ± 0.37^{b}	1.87 ± 0.70^{a}	0.09 ± 0.06^{a}	3.11 ± 1.01^{a}	1.14 ± 0.07^{a}	16.86 ± 3.48^{ab}
KK	20	54 ± 18.01^{b}	20 ± 7.36^{a}	26 ± 13.73^{a}	sandy-clay-loam	6.63 ± 0.42^{b}	1.87 ± 0.59^{a}	0.09 ± 0.05^{a}	2.85 ± 0.63^{a}	1.15 ± 0.10^{a}	15.45 ± 3.11^{a}
F ratio		4.19	8.16	1.18		27.49	34.11	5.97	10.53	1.37	11.16
P		< 0.05	< 0.05	> 0.05		< 0.05	< 0.05	< 0.05	< 0.05	> 0.05	< 0.05

ÇI – Çankırı, Ilgaz Mountain, ÇG – Çankırı, Geçmiş Mountain, ÇE – Çankırı, Eldivan Mountain, SK – Sivas, Kardeşler Forest, ET – Eskişehir, Türkmen Mountain, KB – Konya-Bozkır, Erenler Mountain, KK – Konya-Hadim, Köşker Mountain, P – probability, the letters indicate statistically significant differences between soil properties affected in the study areas ($P < 0.05$), the same letter means that land use types are not statistically different, a < b < c < d < e, DIW – deionized water, EC – electrical conductivity, SOM – soil organic matter, BD – bulk density, AWC – available water content

($F = 10.53$, $P < 0.05$, Table 2). Similarities and differences existed among the tree species in the study areas. For example, the sampling areas of ÇI-ÇG and KE-KK have similar characteristics in terms of altitude, climate, and aridity, but the corresponding amounts of SOM were different (Table 1, Fig. 2). This difference is explained by the direct effect of evaporation and human activity on the accumulation of SOM in the KE and KK study areas. We found that SOM was significantly related to climate variables and altitude in our study areas (Fig. 2). Although the average altitudes of KB and KK study areas were the highest, the amounts of SOM were low. This situation was similar for the aridity-SOM relationship as well because, although the sampling areas of KB and KK in southern Anatolia were located at high altitudes, their average temperatures were high (9.7–10.3°C). Mean annual precipitation and SOM were correlated in our study (Fig. 2), and the similarity between the average amounts of SOM and the AI values is noteworthy (Fig. 2).

The relationship between the amount of SOM and aridity (Fig. 2) in seven sampling areas, based on the TCCM (Fig. 2) in Central Anatolia, is remarkable. The effect of aridity was lower and the amount of SOM accumulated in forest soils was higher in the sampling areas of ÇI and ÇG since they are located in the northern portion of Central Anatolia (i.e. under the effect of the humid Black Sea climate). The amount of SOM was lower in SK, ET, and ÇE sampling areas, where the effects of terrestrial arid climate were felt at higher levels. The KE and KK study areas are under the effect of the humid and hot Mediterranean climate, thus, the effect of aridity is high, causing the amounts of SOM to be low.

Among the study areas, the highest amount of SOM (6.18%) was measured in forest soils of ÇI with black pine and Scots pine. The lowest amount of SOM (1.80%) was measured in the forest soils of SK with black pine and Scots pine. The amounts of SOM being similar for ÇG, ÇE and ET, which also have similar altitude, climate and AI conditions, confirm the strong relationship between climate, aridity and SOM (Table 2, Fig. 2). Soils in all study areas were determined between weakly alkaline and weakly acidic. The amount of lime in the soils collected from the SK sampling point was high (Table 2, Fig. 2). The AWC in forest soils of ÇE and SK was higher than in soils from the other sampling areas ($F = 11.16$, $P < 0.05$). The amount of clay in soils from these sampling areas affected the AWC (Fig. 2). The average bulk densities of the soils collected from all sampling points were low (Fig. 2).

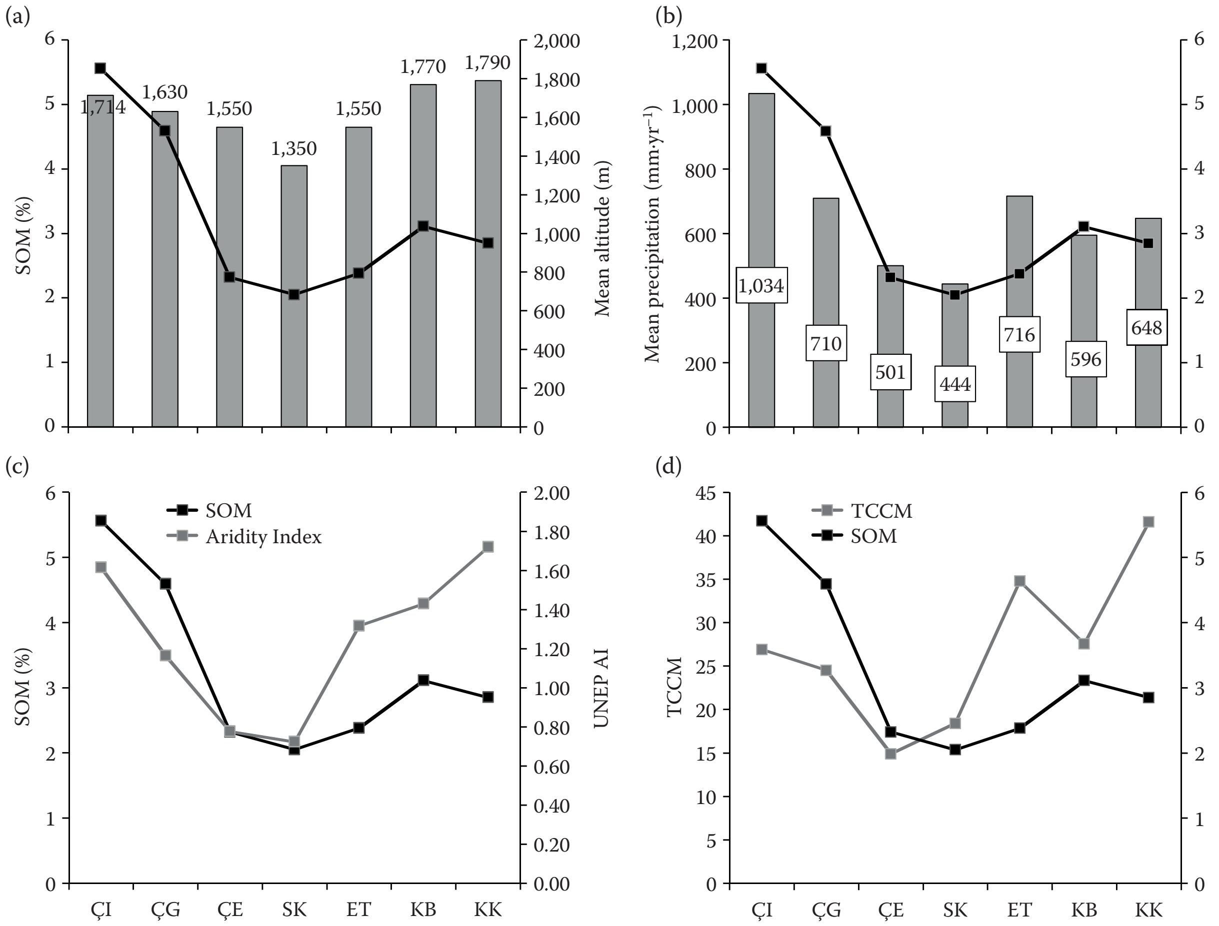

Fig. 2. The relationship between soil organic matter (SOM) and mean altitude (a), mean annual precipitation (b), United Nations Environment Programme Aridity Index – UNEP AI (c), Thornthwaite climate classification model – TCCM (d) in the study areas

ÇI – Çankırı, Ilgaz Mountain, ÇG – Çankırı, Geçmiş Mountain, ÇE – Çankırı, Eldivan Mountain, SK – Sivas, Kardeşler Forest, ET – Eskişehir, Türkmen Mountain, KB – Konya-Bozkır, Erenler Mountain, KK – Konya-Hadim, Köşker Mountain

DISCUSSION

Changes in mean annual precipitation, altitude, and aridity had a significant effect on soil properties and SOM accumulation in our study. The results demonstrate the important role of site specific factors, such as climate, altitude and aridity, in influencing the amounts of SOM. Both altitude and climatic factors had significant effects on the accumulation of SOM. Vanhala et al. (2008) indicated that the temperature sensitivity of SOM decomposition decreases at lower temperatures at high altitudes. Our results also showed a significant negative relationship between the amount of SOM and aridity. Moreover, habitat characteristics had complex effects on SOM accumulation through differences in temperature, precipitation, altitude, and aridity. The amount of SOM increased significantly with increasing altitude. Our findings demonstrate the combined effects of altitude and aridity on SOM accumulation and reveal that they can influence the SOM amount.

The local population in the mountain range of the southern region in Central Anatolia uses forest areas for grazing. Grazing has a negative impact on forest ecosystem and SOM accumulation (Franzluebbers et al. 2000). In addition, evaporation losses are high because of the average annual temperatures of this region.

When altitude and AI were low, the amounts of SOM were also found to be low in study areas. The effects of altitude, climate and land use type/land cover (LUTLC) on SOM accumulation have been demonstrated in many studies (Stergiadi et al. 2016). Janssens et al. (2005) found that current land use, geographic position, climate and peat disturbance were dominant determinants for the net carbon balance of the terrestrial biosphere of European terrestrial ecosystems. We found a significant relationship between SOM and climate variables and altitude in our study areas, similar to that found by Townsend et al. (1995).

Precipitation/evaporation ratio was higher in sampling areas of southern Anatolia because of the temperature. The temperature dependence of SOM accumulation can be affected by different climatic properties based on the geographic area. Vanhala et al. (2008) found that the land cover, temperature and soil properties affected SOM decomposition in northern and southern Finland. Moreover, animal husbandry and transhumance activities are quite common in this region. Grazing in the forest affects SOM accumulation negatively, and this effect was also observed in sampling areas less strongly.

When altitude, aridity and average annual rainfall are analysed together, strong relationships between these factors become apparent. A decrease is observed in the amount of SOM of the surface soils of high mountain forests from northern to southern areas in Central Anatolia. From north to south, evaporation increases with the high temperatures in Central Anatolia. Thus the effect of aridity is stronger.

A correlation analysis indicates that the surface SOM concentration is, in general, negatively correlated with aridity and positively correlated with mean annual precipitation and altitude. Dai and Huang (2005) also reported that SOM content in the top soil layer is positively correlated with the precipitation/temperature ratio in the soils.

Management of forests and other mountain resources in Central Anatolia drives the need for new research on soil properties. Mountain forest dynamics is sensitive to the spatial and temporal variability of soil properties, especially the variability in SOM (Nambiar 1997). SOM is strongly related to soil type, landscape morphology, climate, and LUTLC management. In this research, different SOM of surface soils in the high mountain forests in different climate zones in Central Anatolia has been assessed and evaluated.

The amounts of SOM in surface soils vary widely in the transition zone in the high mountain forests in Central Anatolia. We found that the amounts of SOM generally decrease with aridity, and it is positively correlated with increasing precipitation associated with altitude. The linear relationships between UNEP AI and SOM, altitude and SOM, and precipitation and SOM are shown. These results explain the climate, SOM, and altitude relationships in the high mountain forests of Central Anatolia. Sensitivity analyses should be conducted on the aridity and SOM relationship in different ecosystems in order to increase the reliability of the estimates about the effects of climate change and aridity. This research points out significant relationships for the current estimates of the effects of aridity on SOM. Aridity has a negative effect on vegetation and accumulation of SOM in semi-arid climate zones in Central Anatolia.

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