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Influences of slope aspects on soil properties of Anatolian black pine forests in the semiarid region of Turkey

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ABSTRACT

This study assessed the influences of slope aspect on soil physicochemical properties (soil quality indicators) on contiguous south-north facing slopes and hill plain (ridge crest) of the mid-mountain in Central Anatolia, having the same climate, vegetation and parent material. Anatolian black pine (*Pinus nigra* subsp. *Pallasiana* var. *Pallasiana* (Arnold)) was the dominant, and Cedar (*Cedrus libani* A. Richard), oak (*Quercus sp*.) were the co-dominant species in all aspects, whereas juniper (*Juniperus sp*.) was only recorded in north-facing forests. Some of the soil properties were determined on a grid with a 50 m sampling distance on the topsoil (0-15 cm depth). Accordingly, a total of 150 samples were taken from the three adjacent aspects. The data was analyzed using one-way ANOVA statistical methods. The investigated soil variables were soil organic matter (SOM), soil organic carbon (SOC), total nitrogen (TN), bulk density (BD), texture, lime ($CaCO_3$), and pH. The showed that differences between SOC, BD and soil texture were statistically significant at 0.05 levels. Topographic aspect induced microclimatic differences were found to be important factors for the significant variations in SOC stocks. The resulting analyses showed no significant variation ($p < 0.05$) across slope aspects for SOM, TN, lime, and pH. The differences may be attributed to topographic aspect induced microclimatic differences, which cause differences in the biotic soil component and organic matter trend and affect soil fertility. These results suggest that the slope aspect affects the soils of mountain forests through their direct influence on radiation, evaporation, biological activity, and soil moisture content.

Key Words: Aridity, aspect, decomposition, microclimate, slope, Turkey

Türkiye'nin yarı kurak bölgesi Anadolu karaçam ormanında bakının toprak özellikleri üzerine etkileri

ÖZ

Bu çalışmada, Orta Anadolu'da aynı iklim, bitki örtüsü ve ana materyale sahip Anadolu karaçam ormanında bakının toprak fiziko-kimyasal özellikleri (toprak kalitesi göstergeleri) üzerine etkileri araştırılmıştır. Tüm bakılarda Anadolu karaçamı ana türdür. Meşe ve sedir tüm bakılarda, ardıç ise sadece kuzey bakıda karışıma katılmıştır. Toprak özellikleri üst toprakta (0-15 cm) 50x50 m grid sistemi ile belirlenmiştir. Toplam 150 adet toprak örneğinde fiziksel ve kimyasal analizler yapılmıştır. Tek yönlü varyans analizi sonucuna göre, organik karbon, toplam azot, hacim ağırlığı, pH ve toprak tekstürü arasındaki farklılıklar istatistiksel olarak anlamlıdır. Elde edilen sonuçlar, bakının güneşlenme, buharlaşma, biyolojik aktivite ve toprak nem içeriği üzerindeki doğrudan etkileri nedeni ile orman topraklarını etkilediğini göstermektedir.

Anahtar Kelimeler: Kuraklık, bakı, ayrışma, mikro iklim, eğim, Türkiye

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1. Introduction

The regions of the world where average precipitation is between one-fifth and half of the potential plant water demand are termed ‘semi-arid’. They make up 15.2% of the global land surface, and the approximately 1.1 billion people who live there are among the world’s poorest (Scholes, 2020). Several semi-arid areas of the world are vulnerable to environmental changes and are degraded (UNEP, 1992; IPCC, 2007), partly due to a reduction in the permanent plant cover (Le Houe´rou, 1995). This degradation includes reduced SOC levels, lower soil nutrient content, lower water holding capacity, and increased risk of erosion (Batjes, 1999). These degraded areas have a large potential to sequester C in the soil, which may be preferable to storage in vegetation due to their longer residence times and less risk of a rapid release (Lal et al., 1999). In addition to the removal of atmospheric CO_2, increased soil organic matter (SOM) in semi-arid environments could be beneficial to food productivity and erosion control in poor and degraded areas (Ringius, 1999).

Mountain forests, occupy 23% of the Earth's forest cover (Price et al., 2011; Maren et al., 2015). Forest biomes are an important component of the global C budget. Globally, terrestrial ecosystems are currently a major net sink for atmospheric CO_2 (about 1 gigaton C per year); this sink mostly represents the difference between C accumulation in forests and CO_2 emissions from tropical deforestation (Canadell and Raupach, 2008). Consequently, sustainable management and conservation of mountain environments and their carbon storage capacity are important for maintaining the highland degraded forests. Several studies have been carried out to estimate differences in soil organic carbon (SOC) in relation to vegetation and soil properties, land uses, and climate (Rhoades et al., 2000; Li and Zhao, 2001; Lemenih and Itanna, 2004; Göl, 2009; Göl et al., 2010a; Göl et al., 2010b; Göl et al., 2017; Işık and Göl, 2021; Jiang et al., 2021; Novara et al., 2021). Spatial variation of soil properties is significantly influenced by numerous environmental factors such as landscape features, including position, topography, slope gradient and aspect, parent material, climate and vegetation (Tsui et al. 2004). Studies indicate some variations in soil properties related to the topographic position (Tsui et al., 2004; Yimer et al., 2006; Dengiz et al., 2007; Sidari et al., 2008). Topography influences local and regional microclimates by changing patterns of precipitation and temperature (Tsui et al., 2004). Topography strongly influences the compositional structure of tree communities and plays a fundamental role in classifying habitats (Shi et al., 2019). Aspect and slope control the movement of water (Daws et al., 2002) and materials in a hill slope and contribute to differences in soil properties. Cantlon (1953) and Pook and Moore (1966) revealed that opposing slopes vary in their microclimate; light intensity, soil and air temperature, humidity, soil moisture and evaporation, and duration of growing periods, and that these differences are closely associated with differences in vegetation composition and structure. In general, for the northern hemisphere, south-facing slopes receive more sunlight and become more xeric and warmer, supporting drought-resistant vegetation and less conducive for tree growth, while north-facing slopes retain moisture and are cold and humid, supporting moisture-loving plants (Maren et al., 2015).

Ecosystems of Turkey with the elevation of 1500 m and higher, and a slope range of 15-40% account for about 26 and 34% of the total land area of 759,978 km2, respectively (Atalay, 1997). Göl and Erşahin (2012) concluded that topographic attributes may be used to forecast the adequately likely impact of climate change on organic carbon emissions and soil properties from forest soils in mountainous regions of Central Anatolia. The understanding of the slope aspect is important for forest management and planning because of its influence on growth and forest productivity. Forest diversity, composition, and regeneration are affected by factors like climate, topography, aspect, the inclination of slope soil type and land use (Maren et al., 2015). Overgrazing, deforestation, and an increase in agricultural activity have intensified pressures on high-altitude fragile ecosystems. In high mountain ecosystems, the aspect reveals a local climate effect. This effect changes the vegetation and soil properties. The purpose of this study was to assess slope aspect influence on soil quality indicators (soil physical, chemical, and biological properties) in the middle mountains of North of Central Anatolia.

2. Material and Method

2.1 The location of the study area

The research area was located Eldivan district of Çankırı province found in the transition zone Black Sea climate to Inner Anatolia semiarid mesothermal climate. Coordinated of study area between 40º38'-40º20' N and 33º36'-33º25' E (Fig. 1). Due to the high slope degree and misuse and mismanagement of the fragile natural structure of the study area, severe soil erosion and landslides had occurred, which had led to economic and ecological destruction in agricultural areas and settlements until 1961. After this phenomenon, the catchment was rehabilitated and reforested from 1961 to the present (Anonymous, 1998; Göl et al., 2017).

The climatic type of the region was determined by using the data from the Eldivan Meteorology Station (Anonymous, 2016) according to the Thornthwaite method. The climate type in the research area was “arid-subhumid, mesothermal, moderately excessive water during winters, close marine” climate type. The North and South Anatolia Mountain ranges block the moist airflow from the sea (Fig. 2). Therefore, Central Anatolia receives the least rainfall in Turkey and is one of the semiarid regions. The forests in this region are generally located above 1000m altitude. These forests are under the pressure of aridity, shallow and unproductive soil characteristics, human activities, and grazing. This situation results in a fragile ecosystem of high mountain forests in Central Anatolia.

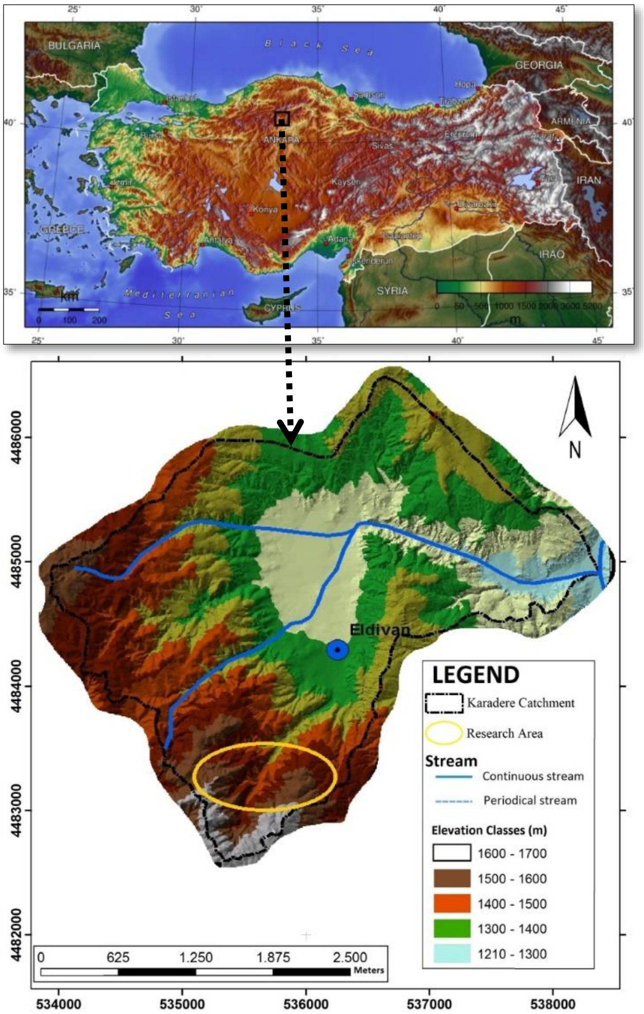

Fig. 1. Location of research area in karadere catchment on the physical map of Turkey

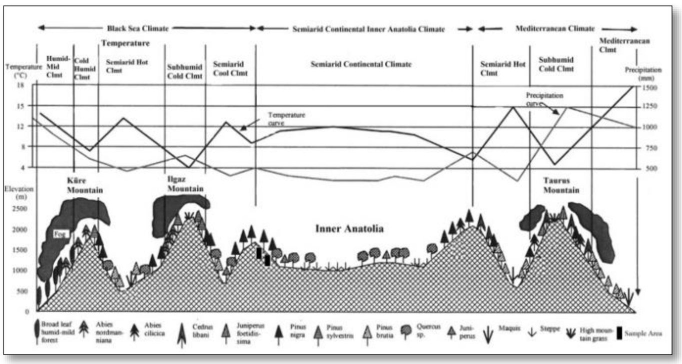

Fig. 2. Climatic and vegetation profiles in N-S direction from The Black Sea to The Mediterranean Sea, and Study Areas (Adapted From: Atalay, 2014)

The research area was formed of the Tertiary Oligo-Miocene gypsum series. That formation starts with thick and red bottom conglomeras followed by light color clay and marl, stratified with gypsum. Top strata of the gypsum series may include Miocene at many locations. This sequence implies marine regression and replacement of desert climate (Ketin, 1962). Catchment soils were classified as Entisols and Inceptisols according to Soil Survey Staff (1999), (Göl and Dengiz, 2007).

The natural tree species of the sample area are Anatolian black pine (*Pinus nigra* subsp. *Pallasiana* var. *Pallasiana* (Arnold)), cedar (*Cedrus libani* A. Richard), oak (*Quercus* sp.), juniper (*Juniperus* sp.), hornbeam (*Carpinus* sp.), and willow (*Salix* sp.), linden (*Tilia* sp) (Anşin, 1983; Göl et al., 2010b).

2.2 Soil sampling and analysis

The study area consists of various topographic features. Soil sampling areas were categorized into three wind directions (N, E, flat), according to their geographic location and followed a gradient of increasing sunbathing from north to south in the study region. The sampling method was systematic with equal distances between soil samples in this study. On the 50×50 grid sites, 150 soil samples were gathered from 0-15 cm depth for three slope aspects (north-sought facing slope and hill flat).

Prior to analysis, samples were dried (24 h at 75 oC), crushed with a rubber-pestle and sieved (2 mm grid) to separate the coarse fragments from the fine earth. Soil samples were taken only from the topsoil and analyzed for particle size distribution (Bouyoucous, 1951), Bulk Density (BD) (Blake and Hartge, 1986) and soil pH and electrical conductivity (EC) (Rhoades, 1996), Carbonate (CaCO3-Lime) (Richard and Donald, 1996), soil organic matter (Nelson and Sommer, 1996). Total nitrogen (TN) was determined by Kjeldahl (Bremner, 1996)

Soil organic carbon concentration (SOCc %) and for practical purposes, only that in the fine-soil fraction (<2 mm) was considered. The average value of the SOCc (%) concentration and soil BD by layer was used in this study. We used the following equation to calculate soil organic C stock (SOCst) ($Mg.ha^{-1}$):

SOCc (%) = 0.58 x SOM (%) (Eq. 1)

and

SOCst ($Mg.ha^{-1}$) = BD x SOCc (%) x D (Eq. 2)

where SOM (%) is soil organic matter as a percentage of soil dry mass, BD is soil bulk density ($g.cm^{-3}$), and D is the thickness of the sampled soil layer (cm). The former equation assumes that soil SOM is 58% SOCc (Eq. 1 - 2), (Mg: megagram, ha: hectare) (Mann, 1986).

2.3 Statistical analysis

The descriptive statistics (mean, max., min., standard deviation (SD), coefficient of variation (Cv), skewness, kurtosis coefficient) for SOC in terms of slope aspects were calculated using the SPSS® 20.0 (IBM corporation software). Before geostatistical analyze, abnormality test with Kolmogorov-Smirnov analysis was implemented using SPSS® 20.0 software. The log-transformation was made for providing constant variance because SOC values in our data set showed a non-normal distribution, and the spatial analysis of SOC content was made based on log-transformed values in this study (Webster, 2001). The mean differences between soil organic carbon values of land use types were compared using one-way ANOVA followed by the LSD test (P<0.05).

3. Results

The amount of SOC was analyzed in different adjacent slope aspects. Accordingly, the highest amount of SOC sequestration (80.96 g $C.kg^{-1}$) was measured in the north-facing slope (NFS) topsoils of forests (Table 1). It was followed by forest lands on the south-facing slope (SFS) and on hill flat areas (HFAs), respectively. The variation of SOC content in the soils of NFS is much higher (0.94-80.96 g $C.kg^{-1}$). The lowest SOC content (0.40 g $C.kg^{-1}$) in all three slope aspects is in the forest soils of the HFAs. According to the average carbon storage amounts, South facing slope, North facing slope, HFAs were determined respectively (13.58, 11.96, and 6.93).

According to the results of statistical test, SOC (g $C.kg^{-1}$, F: 2.958, p: 0.057), in the samples taken from different perspectives, there was statistical difference with 95% confidence (Table 2). The SOC contents on the SFC and HFAs were significantly (p<0.05) higher than those on the NFS (Fig. 1). On the other hand, according to the SOC content NFS, showed similar features with SFS and HFAs, and there was no statistically significant difference between them.

The analyzed soil physicochemical properties did show significant differences between slope aspects, except for CaCO3, SOM, and pH (Table 2). The sand and clay contents differed between slope aspects; sand content was higher in north-facing slope (NFS) while clay content was higher in sought facing slope (SFS), whereas the soil type did not vary.

Table 1. Descriptive statistics of soil properties sampled to a depth of 15 cm in adjacent different slope aspects (Nt = 150)

Slope Aspect	Soil Properties		N	Min.	Max.	Mean.	SD	Skewness	Kurtosis
South facing slope	SOC	mg $C.cm^{-3}$	30	0.89	13.03	4.0	3.08	1.15	0.80
	SOC	g $C.kg^{-1}$	30	2.45	46.43	13.58	10.57	1.28	1.45
	CaCO3	%	30	0.28	29.97	2.87	5.21	5.18	27.71
	EC	$dS.m^{-1}$	30	0.06	0.25	0.13	0.05	0.49	-0.74
	Bulk Density	%	30	0.60	1.23	1.01	0.16	-0.55	0.14
	Clay	%	30	3.01	49.0	22.37	16.53	0.13	-1.80
	Sand	%	30	34.00	85.0	58.37	15.26	0.01	-1.36
	Total Nitrogen	%	30	0.02	0.40	0.12	0.09	1.28	1.45
	SOM	%	30	0.42	8.01	2.34	1.82	1.28	1.45
	pH		30	6.23	7.74	7.09	0.34	-0.49	0.59
	Salt	%	30	0.00	0.01	0.01	0.01	0.96	0.65
North facing slope	SOC	mg $C.cm^{-3}$	30	0.25	9.59	2.90	2.52	1.27	0.49
	SOC	g $C.kg^{-1}$	30	0.94	80.96	11.96	15.29	3.45	14.47
	CaCO3	%	30	0.14	2.43	1.16	0.65	-0.07	-1.09
	EC	$dS.m^{-1}$	30	0.12	0.32	0.23	0.05	-0.69	0.24
	Bulk Density	%	30	0.39	1.26	0.92	0.16	-0.89	3.72
	Clay	%	30	4.01	20.01	8.93	3.43	1.39	2.72
	Sand	%	30	55.0	78.01	68.07	5.41	-0.47	0.47
	Total Nitrogen	%	30	0.01	0.70	0.10	0.13	3.46	14.48
	SOM	%	30	0.16	13.96	2.06	2.64	3.45	14.47
	pH		30	6.20	7.15	6.91	0.23	-1.71	2.41
	Salt	%	30	0.01	0.02	0.01	0.01	-0.43	-0.50
Hill flat areas (Ridge crest)	SOC	mg $C.cm^{-3}$	30	0.12	6.47	2.16	1.42	1.28	2.18
	SOC	g $C.kg^{-1}$	30	0.40	22.18	6.93	4.45	1.64	4.11
	CaCO3	%	30	0.85	14.27	2.01	2.39	4.98	25.98
	EC	$dS.m^{-1}$	30	0.08	0.30	0.17	0.06	0.15	-1.02
	Bulk Density	%	30	0.80	1.38	1.01	1.13	0.70	0.68
	Clay	%	30	3.01	49.01	15.43	15.59	1.17	-0.47
	Sand	%	30	38.0	78.01	65.17	13.04	-1.03	-0.53
	Total Nitrogen	%	30	0.00	0.19	0.06	0.04	1.63	4.05
	SOM	%	30	0.07	3.82	1.19	0.77	1.64	4.11
	pH		30	6.28	7.65	6.93	0.37	-0.12	-0.38
	Salt	%	30	0.00	0.01	0.01	0.0	0.07	-0.92

Notes: SOC- soil organic carbon, EC- electrical conductivity, SOM- soil organic matter, SD- standard deviation

Simple Analysis of Variance was performed to compare soil properties from different perspectives (Table 2). LSD homogeneity test was used in order to determine the difference between the groups. According to the results of this test, $CaCO_3$ (F: 1979, p: 0.144), SOC (g $C.kg^{-1}$, F: 2.958, p: 0.057), total nitrogen (F: 2.945, p: 0.058), pH (F: 2.866 p: 0.062) and SOM (F: 2.960, p: 0.057) in the samples taken from different perspectives, there was no statistical difference with 95% confidence. Salt (F: 27.792, p: 0.001), sand (F: 5.162, p: 0.008), clay (F: 7.691, p: 0.05), bulk density (F: 3.354) , p: 0.040), SOC (mg $C.cm^{-3}$, F: 4.336, p: 0.016) and EC (F:

23.641, p: 000) were statistically different in samples taken from different perspectives with 95% confidence.

Table 2. Comparison of types of slope aspect of soil properties according to one-way ANOVA by followed LSD (p<0.05)

Soil Properties		N	North Facing slope	South Facing Slope	Hill Flat Areas
			M ± Std. Error	M ± Std. Error	M ± Std. Error
CaCO3	%	50	1.161±0.651NF	2.872±5.210 NF	1.997±2.394 NF
EC	dS.m^{-1}	50	0.228±0.522ab	0.129±0.521c	0.171±0.646b
Bulk Density	%	50	0.921±0.157b	0.997±0.157ab	1.015±0.132a
SOC	mg C.cm^{-3}	50	0.899±2.515ab	4.002±3.083a	2.160±1.420b
Clay	%	50	8.930±433b	22.370±16.531a	15.430±15.589b
Sand	%	50	68.07±5.407a	58.37±15.262b	65.170±13.041a
Total Nitrogen	%	50	0.103±1.132 NF	0.117±0.091 NF	0.059±0.038 NF
SOM	%	50	2.062±2.639 NF	2.341±1.822 NF	1.194±0.767 NF
pH		50	6.910±0.231 NF	7.089±0.344 NF	6.929±0.366 NF
Salt	%	50	0.010±0.003a	0.005±0.002c	0.007±0.003b

NF- nonsignificant, Significant at $p \leq 0.05$, a > b > c

4. Discussion and Conclusion

The main finding of our research is that the soil properties between the ridge plain and the slope aspects differ. The main influence on forest soils was internal variability within both ridge crest and slope forests. Topography and slope were important factors in the distribution of soil properties along the semi-arid region forest in the Anatolian mountains. Many Studies indicate some variations in soil properties related to the topographic position (Tsui et al., 2004; Yimer et al., 2006; Sidari et al., 2008). But the influence of the slope aspect on forest stand characteristics and soil physico-chemical properties in the semiarid Anatolian mountains are still lacking. Many studies (Cantlon, 1953; Olivero and Hix, 1998; Begum et al., 2010; Paudel and Vetaas, 2014) suggested that understanding the perspective is important for forest management and planning because of its impact on growth and forest productivity. Daws, et al. (2002) found that topography could result in the differences in spatial patterns of environmental conditions, especially soil water availability. Although the relationships between topography and soil properties were inconsistent in different studies, we found that a relationship between the slope and soil properties in our studied forest. Herwitz and Young (1994) found greater growth and turnover on the ridge crest than on the slopes in a tropical lower montane rain forest in Queensland. Furthermore, Lozano-García et al. (2016) highlighted that north-facing slopes had higher SOC content than other topographic aspects. Beaty and Taylor (2001) reported that slope aspect and position induced considerable variation in forest composition. Fissore et al. (2017) recorded that slope aspect and landslide occurrence were closely linked to the C cycle, and Jasińska et al. (2019) found that slope aspect significantly affected litter decomposition rate, leading to a changed SOC content. Significant differences among slope aspects were found for most of the parameters studied. North-facing slopes had higher soil moisture and greater SOC and SOM as compared to south-facing soils

Forest soil's properties are affected by climate, topography, soil water content, and litter and canopy cover. In the soil on the sought-facing slope, a lower content of SOM and SOC and a higher bulk density related to soil water content were observed. The differences may be attributed to topographic aspect-induced microclimatic differences, which causing differences in the biotic factors. Kutiel (1992) also found that topographic factors affect soil properties. Shi et al., (2019) found strong evidence that topographic variables, especially elevation, convexity, and slope constrained the distribution of tree species in the Qinling Mountains of north-central China. Variation of soil properties within a relatively uniform climatic region may also result from topographic heterogeneity (Brubaker et al., 1993). Topography combines soil type. Topography has been associated with drainage regimes and soil properties are correlated with tree species distribution in a forest (Bourgeron, 1983; Johnston, 1992). The slope aspect led to changes in some of the physical, chemical, and hydrophysical properties of soils especially. An understanding of the differences in soil characteristics between slope aspects in high altitude semiarid environments is fundamentally important for the efficient management of these semi-natural systems. Here, we analyzed some soil properties of north- and south-facing slopes and hill flat in trans-Anatolian semiarid regions. We found the absolute and clear relationships between opposing slope aspects and soil characteristics as seen in many other studies. We conclude that the combined effects of topographical variability and slope aspect determine the soil characteristics, along with organic material and carbon stock in this semiarid region. Bellingham and Tanner (2000) concluded that soil pH and disturbance effects were variable within forests on ridge crests versus slopes. Soil organic carbon accumulation in forests is linked to soil parent material, topography, climate, vegetation, and time factors (Yüksek et al., 2009; Karahan and Erşahin, 2018). Jeyanny et al. (2013) quantified the spatial variability of soil C, C:N, and forest soil depth at varying topographic conditions in tropical and lowland forests.

Soil chemical and physical properties were greatly affected by soil moisture. Wang et al. (2007) investigated the spatial data for soil moisture as related to topography to understand their mutual effect on N forms in a subtropical forest in China. They reported that the soil NH4+ and NO3 content were similar under different forest conditions. Their results further showed that N mineralization and nitrification showed a negative correlation with the topographic position. Spatial variation in organic soil carbon stock has been related to physical, biological, and chemical processes such as climate, soil type, tree species composition, stand age, and topography in forest ecosystems (Kristensen et al., 2015). Jeyanny et al. (2013) concluded that the spatial structure of soil C showed differences in forest with different topography. Beaty and Taylor (2001) reported that slope aspect and position induced considerable variation in forest composition. The spatial arrangement of forest suggests that slope aspect and elevation are primary determinants of the local vegetation patterns (Eisenlohr et al., 2013). It is suggested that plant community, soil properties and environmental factors all made contribution to the microbial diversity between sunny and shady slope, among which temperature was the main factor that can explain most of the variations in mountain forest ecosystems.

Overall, information on the soil properties of forests is important in developing strategies for forest management (Karahan and Erşahin, 2018). Additional research is needed to investigate if similar findings between slope aspects can be observed at larger scales in semi-arid regions (Bellingham and Tanner, 2000). Our results demonstrate that the slope aspect could provide an important reference for high mountains forests management strategies in light of sustainable development. Future research should jointly evaluate the relationship between changing geological, forest stand, climate, and slope aspect characteristics. In this regard, studies should be conducted to evaluate multiple interactions and feedback among components of forest ecosystems across different scales of time and space (Akhavan et al., 2010).

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