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The effect of altitude on soil organic carbon content in semi-arid mediterranean climate

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Abstract
One of the most effective means in the combating climate change and desertification is soil organic carbon (SOC) management. However, land use puts a high pressure to fragile SOC pools particularly in semi-arid environments where SOC decomposition rate is high due to low soil moisture. Therefore, at higher elevations of Mediterranean Basin with cooler temperature SOC is higher than the coastal plains due to the better soil moisture contents. Agricultural pressure on highlands has increased in recent years because of the relatively low water requirement of crops. The purpose of this study is to analyze and determine the SOC dynamics in relation to the variations of soil physical and chemical characteristics from different elevations, ranging from 64 meters to 756 meters at semi-arid Mediterranean climate. SOC revealed decreases versus altitude increases that varied from 24.7 to 38.7 t ha^{-1} with a correlation coefficient of 0.527. The main driver of decreasing SOC by elevation is most probably displacing of fine particles from surface horizons by accelerated erosion at sloping and cultivated lands of higher altitudes. As a result, it is necessary to focus both on the plant pattern along with land management techniques for enhancing soil organic matter in agricultural production for enhancing SOC at higher elevations.
Keywords: Soil organic carbon, Altitude, Land use, Erosion

INTRODUCTION

Soil organic carbon is an effective tool in efforts to mitigate climate change and desertification that threaten the future of humanity on a global scale, thus enhancing knowledge on its management is crucial for the future of humanity. However, as soil carbon dynamics are driven by several factors such as climate, soil physical and chemical characteristics along with land management (Ramesh et al., 2019, Büyük et al., 2020) it is challenging to manifest all processes effect on it. Many studies have revealed the effect of climate on organic carbon by studying the interaction between climate and organic carbon (Jobbágy and Jackson, 2000). The effect of altitude on soil organic matter has been studied and it has been determined that there are differences in soil organic matter due to the altitudes effect on climate (Oechel et al., 2000). In general, soils in higher altitudes with cooler temperature in Mediterranean Basin have higher organic carbon content even in cultivated soils (GDCDE, 2018). However, the low irrigation requirement led to a farming pressure in high-altitude regions recently and that necessitates concerns about the sustainable management of soils (Sharma et al., 2006). Dieleman et al., (2013) reported that SOC stocks varied from 4.8 to 19.4 kg C m^{-2} at different altitudes and increased by 5.1 kg C m^{-2} for every 1000m increase. Aside from wider altitude changes, even a few meters make a difference in vegetation as determined by Yılmaz et al., (2020) in lagoonal areas adjacent to Mediterranean Sea in Southern Turkey. Microclimate effects of altitude on soil microbiology, C weathering and accumulation rates were studied by Matus et al., (2014). They stated that there is no single formula for the stabilization of soil organic matter at various altitudes because it is reliant on various parameters. However, although there is a positive relationship between altitude and organic matter increases in general to a certain height up to 1500 m in Garhwal Himalaya and Serbia (Manojlović et al., 2011; Sheikh et al., 2009), there are also opposite situations as Bangroo et al., (2017) determined a negative relation between soil organic carbon with increasing altitudes above 1800 m. Majority of previous studies focused on large variations in altitude and the soil organic carbon of coastal areas at sea level and mountainous lands over 2000 m (Akça et al., 2020). However, since only one crop is obtained per year in agriculture at altitudes above 1000 m in the Mediterranean, land use below 1000 m is more important in terms of agriculture and income of locals. Therefore, this study sought to determine the changes in soil's physical and chemical properties through six different altitudes varying from 64 m to 756 m within an extensively cultivated basin under Mediterranean climate. In conclusion, we suggest that the determination of the relationship between altitude and organic matter for each significant agricultural region is necessary in terms providing reference data in sustainable land management decisions.

MATERIALS AND METHODS

Site Characteristics

The study area, covering 327990 ha, is located between 35° 52′- 36° 42′E and 36° 57′- 37°45′N is located in the east of the Mediterranean Region of S. Turkey. The altitude of the basin ranges from 64 m to 756 m above sea level. Long term average monthly climate data of the lowest and highest locations are given in Table 1 (1986-2019).

Soils were sampled from six sites located between 64 m to 756 m (Toprakkale 64 m, Kadirli 95 m, Osmaniye 121 m; Düziçi 389m; Bahçe 582 m and Hasanbeyli 756m). A total of 165 (Toprakkale 10, Kadirli 83, Osmaniye 40, Düziçi 25, Bahçe 1, Hasanbeyli 6) disturbed and undisturbed samples were taken from 0-20 cm in 2018-2019.

Laboratory Analysis

Soil samples were air-dried and sieved through a 2 mm sieve for analysis. Undisturbed soil samples were collected with 100 cm^3 steel cylinders. Soil texture, bulk density, electrical conductivity and pH (saturated paste) organic matter (wet digestion), soil organic carbon (Total Organic Carbonizer), $CaCO_3$, P, Zn, Fe, Cu and Mn were determined according to methods defined in Soil Survey Staff (2014). For each site, soil C content was calculated on a hectare basis (Lee et al., 2009).

Data Analyses

Analysis of variance was performed to evaluate the data obtained from soil samples taken from regions at different heights and points representing the lands to determine the differences in the physical and chemical properties of the soil. Data analyses were done to investigate the relationship between soil bulk density, organic matter, soil organic carbon, $CaCO_3$, pH, EC, Silt, Sand, Clay, P, K, Ca, Mg, Na, B, Fe, Cu, Zn and Mn from the six different altitudes. Correlation and regression analyses were performed.

RESULTS AND DISCUSSION

In the study area, with the change of altitude, there was also a differentiation in soil properties. The texture of the soils was silty clay loam and silty loam at higher altitudes, and clay or clay-loam in lower altitudes (Table 2). The most significant effect of altitude on soil texture seems to be erosion as it most probably washed-out fine particles from surface in sloping higher elevations (Table 2 and Figure 1).

In general, as altitude increases, there was a decrease in silt and clay content while sand revealed an increase. The sand content is negatively correlated to the low altitude with -0.736 (Table 3). The lowest $CaCO_3$ was determined at 582 m by 1.67 % while the highest was determined at 95 m. These high values are most probably due to the carbonate-rich alluvial sediment deposition in Kadirli (95 m) and Toprakkale (64 m) along with exposure of eroded C horizon at 756 m. Soil pH also showed similarities with $CaCO_3$, with 6.45 at 582 m and 7.98, 7.60 and 7.44 at 64 m, 95 m and 756 m respectively.

Table 1. Long term average monthly climate data of the lowest and highest locations

	Toprakkale (64 m)	Hasanbeyli (756 m)
Average temp. (°C)	18.5	9
Aver. high temp (°C)	24.8	20.8
Aver. low temp (°C)	12.7	1
The highest temp. (°C)	43.6	32
The lowest temp. (°C)	12.7	17
Average Rainy Days	78	66.4
Average Precipitation (mm)	854.9	424

Table 2. Altitudinal variation in physical and chemical properties (means±SD) across six different sites

Parameters	Locations (m)					
	Toprakkale 64	Kadirli 95	Osmaniye 121	Düziçi 389	Bahçe 582	Hasanbeyli 756
$CaCO_3$ (%)	14.1±5.80	41.7±10.4	26.6±9.27	22.4±10.32	1.67±0.59	14.3±7.89
pH	7.98±0.09	7.60±0.20	7.91±0.19	7.49±0.37	6.45±0.28	7.44±0.47
EC (dSm^{-1})	0.74±0.14	0.91±0.35	0.85±0.41	0.63±0.26	0.94±0.08	0.67±0.13
Silt (%)	23.4±5.32	26.7±8.02	23.8±20.4	18.7±4.66	20.4±2.50	21.4±7.87
Sand (%)	42.1±9.86	36.8±12.0	36.4±13.3	51.9±13.9	66.1±8.50	52.1±18.46
Clay (%)	34.5±7.38	36.5±11.2	39.9±10.54	29.4±10.7	13.5±2.29	26.5±11.78
Texture Class	SCL	CL	C	SCL	SL	SCL

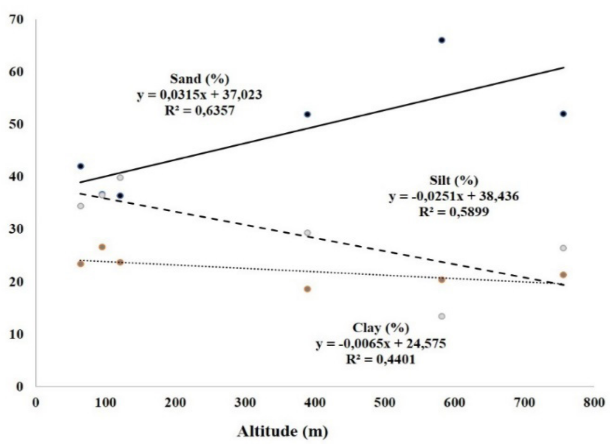

Figure 1. Effect of altitude on soil texture

Table 3. Correlation coefficient of physico-chemical properties of soil with altitude

Parameters	Correlation coefficient (r)
$CaCO_3$ (%)	0.441
pH	0.653
EC (dSm^{-1})	0.229
Silt (%)	0.757
Sand (%)	-0.736
Clay (%)	0.665
SOC (t C ha^{-1})	0.527
OM (%)	0.543

The clay content of the soils varied from 13.5 to 39.9 %. The clay in the agricultural lands located in low altitude areas is higher than that in the high-altitude areas due to deposition of clay-rich alluvial sediments (Table 2). Bulk density changed from 1.30 at Hasanbeyli at 756 m to 1.43 g cm^3 at Toprakkale at 64 m (Table 4). This variability is closely related to the organic matter and texture change (Reichert et al., 2018). Bulk density also decreased with increased altitude due to erosion of fine particles. The organic matter of the soils is decreased with the increase in altitude which varied from 1.42 to 2.21 % (Table 4) with the highest mean value of 2.21±0.80 at 64 m followed by 2.10±0.09 at 95 m, 1.95±0.7 at 121 m, 1.88±0.91 at 389 m, 1.56±0.11 at 582 m and 1.4±0.15 at 756 m (Table 4). This may be attributed to a lack of clay at higher altitudes, which holds more water and enhances aggregation that both have positive effect on soil carbon sequestration (Oades 1988; Wagner 2007). Moreover, the decreasing precipitation with altitude seems to be another parameter effective on the SOC content of the studied soils.

Climate characteristics along with altitude affect soil organic matter dynamics. Göl (2017) and Yao et al., (2019) reported that altitude changes in the ecosystem led to changes in both the quantity and quality of soil organic matter. The organic matter content is positively correlated to the decreasing altitude with 0.543 in the study site. However, while Kidanemariam et al., (2012) found increasing SOC with elevation, Bangroo et al., (2017) discussed the negative affect of decreasing

Table 4. Soil Bulk Density, OM, Carbon and SOC (means±SD) stock (0-20 cm) of six sampling sites

Site	Altitude	Bulk density	Organic matter	C	SOC
		g/cm^3	%	%	t ha^{-1}
Toprakkale	64	1.41±0.10	2.21±0.80	1.27±0.46	38.4±12.8
Kadirli	95	1.38±0.10	2.10±0.09	1.19±0.46	36.5±12.0
Osmaniye	121	1.37±0.11	1.95±0.7	1.10±0.41	33.0±11.8
Düziçi	389	1.43±0.08	1.88±0.91	1.13±0.53	32.7±14.9
Bahçe	582	1.30±0.02	1.56±0.11	0.84±0.07	27.1±1.20
Hasanbeyli	756	1.30±0.15	1.42±1.01	0.77±0.58	24.7±14.7

altitude on SOC sequestration. Thus, altitude does not seem to be the sole parameter effecting SOC dynamics.

SOC decreased as altitude increases that varied from 24.7 to 38.7 t ha^{-1} (Table 4) with a correlation coefficient of 0.527 (Table 3).

Along with effect of lowerclay, higher altitudes are known to decrease leaf surface area, number of stomas along with low shoot development, which all cause reduced biomass development and this in turn negatively affect soil organic matter (Pirlak et al., 2003; Aslantaş and Karakurt, 2007).

Micro-macro nutrient of soils revealed some significant correlation with the altitude. There was a positive correlation between soil P (0.667), K (0.3798), Ca (0.292), B (0.215), Cu (0.675), Zn (0.441) and altitude, while Mg (-0.266), Na (-0.374), Fe (-0.484) and Mn (-0.579) revealed a negative correlation (Table 5). Smectite has been reported (Akça et al., 2009) as the most common clay type in the region, it is likely that the decrease in Mg and Fe content with height is related to the decrease in clay content. Thus, decreases in micro-macro element after 582 m is another indicator of transported surface clayey soil rich in plant nutrients.

Table 5. Correlation coefficient and concentration of some macro and micro nutrients

Parameters	Altitude (m)						Correlation coefficient (r)
	64	95	121	389	582	756	
P (mg kg^{-1})	6.95	12.1	15.2	20.2	15.6	17.9	0.667
K (mg kg^{-1})	492	221	364.2	461.8	475.7	418.9	0.379
Ca (mg kg^{-1})	7287.8	410	5052.2	5010.2	7171	5115.3	0.292
Mg (mg kg^{-1})	1266.2	95	1666.8	778.3	815.7	637.8	-0.266
Na (mg kg^{-1})	370.7	277.8	362	175.7	441.6	147.6	-0.374
B (mg kg^{-1})	1.6	0.9	1.2	1.4	1.3	1.4	0.215
Fe (mg kg^{-1})	1.15	11.8	2.1	0.9	0.6	0.7	-0.484
Cu (mg kg^{-1})	0.56	0.2	0.8	1.1	1.1	0.9	0.675
Zn (mg kg^{-1})	1.16	0.3	0.9	0.9	0.8	1.3	0.441
Mn (mg kg^{-1})	26.6	10.9	44.9	13.8	10.7	10.4	-0.579

CONCLUSION

Organic matter is expected to increase as altitude increases in the Mediterranean Basin, according to common findings. As there is less evaporation at high altitudes, there is more available water in the soil profile, which leads to more biomass development in cultivation. In the case of natural regions, this is a sound argument. And it was investigated in this research whether the same judgment could be applied to agricultural areas. One of the major findings was the negative relationship between increased altitude and organic matter in sloping cultivated areas. Along with organic matter, the clay content also decreased with the increased altitude. The change in clay content is most probably due to the transport of fine material by erosion at high altitudes from sloping cultivated lands as in sampling points C horizon were exposed to the surface. Although shifting crops to higher altitudes to prevent rising temperature and drought induced by climate change can be a type of climate adaptation strategy. However, at high elevations with sloping topography erosion is severe risk at cultivated lands which is one of driver of soil degradation, So, this study revealed that priority should be given to combating erosion in land-use to increase soil organic matter at altitudes from 60 m to 1000 m in a semi-arid Mediterranean climate. The necessity to focus on the plant pattern for increasing the soil organic matter as well as combating erosion in highlands of Mediterranean basin is crucial as no land for cultivation is available beyond higher altitudes.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest

The authors declared that for this research article, they have no actual, potential or perceived conflict of interest.

Author contribution

The contribution of the authors to the present study is equal. All the authors read and approved the final manuscript. All the authors verify that the Text, Figures, and Tables are original and that they have not been published before.

Ethical approval

Ethics committee approval is not required.

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Data availability

Not applicable.

Consent for publication

Not applicable.

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