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Understanding relationship between physical quality indicators and organic carbon in soils affected by long-time continuous cultivation under sub-humid ecosystem

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Abstract

The objectives of this present study were to analyses soils and find out some soil quality properties and check relationship between soil compaction, crust formation and erodibility - K of the soils with the soil organic carbon (SOC) amount in the surface (0-20 cm) and subsurface (20-40 cm) soils affected by long-time continuous cultivation under sub-humid environmental condition. The research out comes showed that soil compaction, crust formation, erodibility K is highly significantly ($P < 0.001$) related to organic carbon, organic carbon stock, organic matter and between each other. The research also identifies that the study area generally, has clay texture, neutral pH, low amount of the CaCO3, high amount of OC and OM in top layer (0-20 cm) and moderate amount in bottom layer (20-40 cm). It was not identified significant differences between the soil properties in surface and subsurface soil layers.

Keywords: Soil organic carbon, compaction, crust formation, erodibility- K.

Introduction

In recent times the importance of soils organic carbon in the carbon cycle has been increasingly acknowledged as the CO_2 concentrations rising in the atmosphere and the increasing global warming (Rumpel et al., 2020). Soils organic carbon topic is researched in the scientific community not only for its imports for global warming butalso for its effect on soil quality and sustainable food production. The soil organic carbon (SOC) is one of the most crucial natural resource that is highly important to securing the soil quality. In addition to that, one of the essential non-renewable natural resources that all living things require is also soil (Schoonover and Crim, 2015). Therefore, one of the most major questions for scientist currently is finally to found efficient ways how increase SOC in soil and how to stop decrease CO_2 emission to the atmosphere.

The soil quality is much more complex when description of water quality and air quality (Bünemann et al., 2018). The easiest definition to define soil quality is "the capacity (of soil) to function". Soil quality must contain three main parts sustained biological productivity, plant and animal health and environmental quality. All these three parts mustfully function and be balanced between each other (Karlen et al., 1997). Here are no one definition who would define soil quality, because here no common agreement on it by scientific community. In addition, here are no one set of soil quality indicators recognized internationally by the scientists. However, here is common sense that the soil quality index must be made from the multiple physical, biological, and chemical attributes (Karlen et al., 2003).

The main goal of the present investigation is to determine relationship between some soil physical quality properties and soil organic carbon. The study area' soils have been cultivated for a long time period. Therefore, the motivation in the current research is to find out and understand some soil physical quality properties such as compaction, crust formation and soil erodibility-K factor of the study area' soils and check its relationship with the SOC amount in the soil.

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Material and Methods

Description of the study area

The study area is located at the 40th km on the Samsun-Bafra highway and is between 249000-254000 East and 4599200-4602400 North (WGS-84, Zone 37, UTM-m) coordinates (Figure 1). Total land asset is 923.9 ha. Bünyan Mountain in the south, and the Bafra Plain in the west and north, is adjacent to the western shore of Balık Lake in the Kızılırmak Delta.

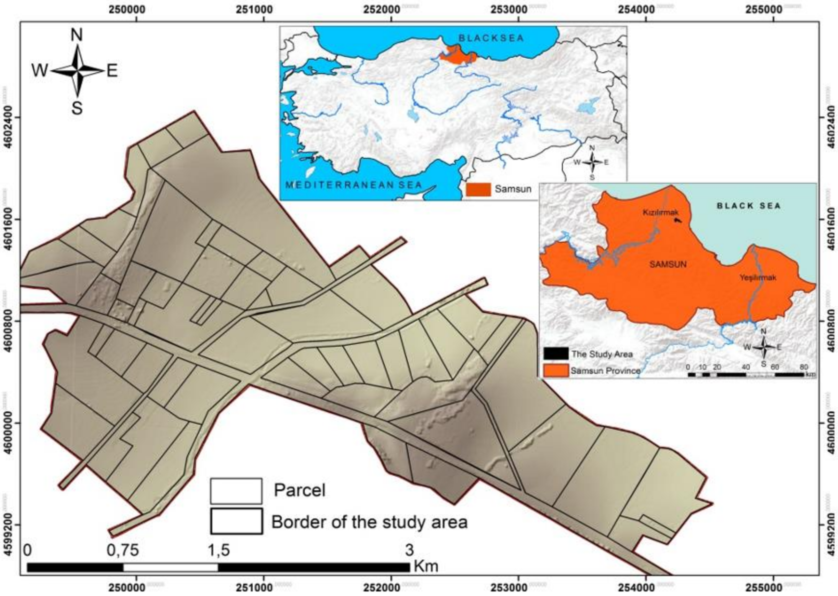

Figure 1. Location map of the study area

While the north-west and south-east parts of the land are areas where moderately steep and steep slopes are distributed in terms of slope, generally the middle and northwest parts of the land constitute areas with 0-4%, nearly flat and gently slopes (Figure. 2).

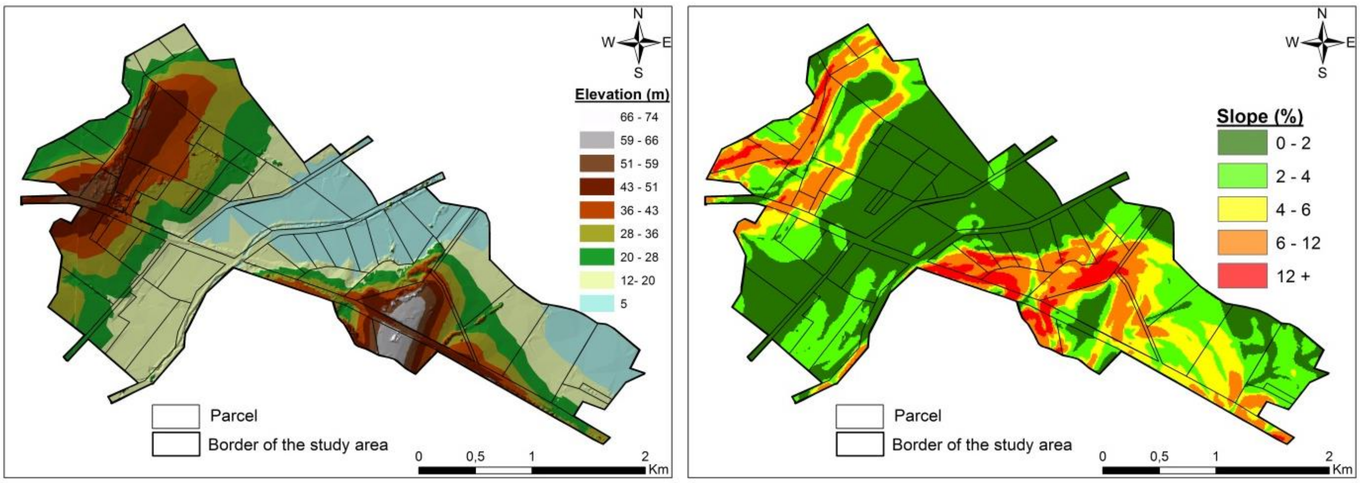

Figure 2. Elevation and slope map of the study area

The Black Sea climate, which is rainy in all seasons, cool in summers and warm in winters, is active on the coastline of the Black Sea Region. The annual average temperature of the study area was 14.3˚C, the highest average air temperature was 18˚C and the lowest average temperature was 10.7˚C. The average annual rainfall of the study area is around 710.0 mm. In addition, according to the Newhall model, soil temperature and moisture regimes (van Wambeke, 2000) were determined as mesic and ustic (wet tempustic in sub-class) (Turan et al., 2018).

Soil sampling and analysis

The grid-based soil sampling system was conducted with 89 sampling points located 300 m from each other (Figure 3). From each sample point was taken 2 soil samples; one from depth 0 to 20 cm and another from 20 to 40 cm. In totally 178 soil samples were collected from the study area. The collection of samples was done in 2021. After collection all samples were air dry and passed on a 2 mm sieve.

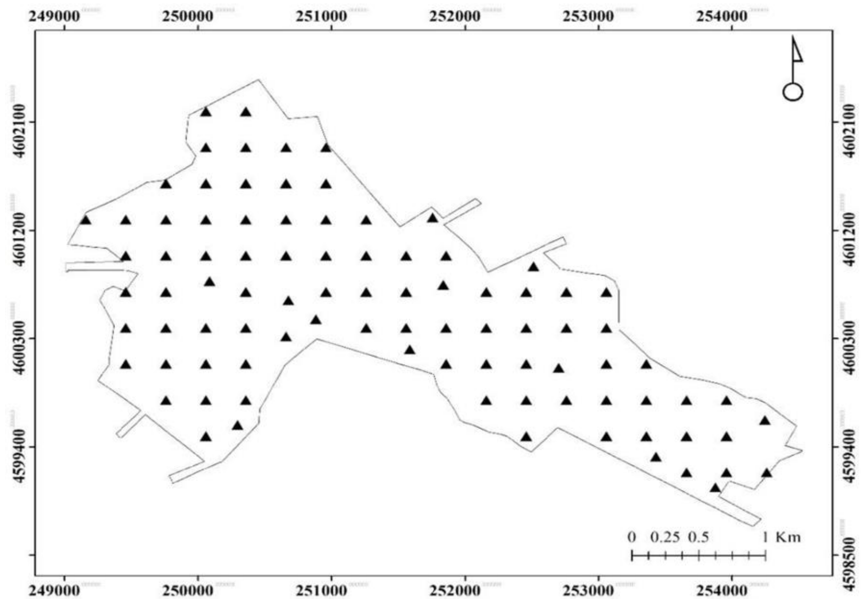

Figure 3. Soil sampling pattern

By using the Bouyoucos hydrometer method, the mechanical analysis of the soil (% sand, silt, and clay) was determined (Bouyoucos, 1962) and in a 1:1 soil-water suspension, electrical conductivity (EC) and soil reaction (pH) values were measured (Soil Survey Staff, 2014; Kacar, 2016). CaCO3 content was determined by volumetric calcimeter, and organic matter content was defined by considering the modified Walkley-Black method (Soil Survey Staff, 2014).

Determination of SOC stock

The SOC_{stock} of the surface layers (0–20 cm and 20-40 cm), described in kgm^{-2}, was estimated by the following equation (1) (IPCC, 2003):

$$\text{SOCstock} = \text{SOC} * \text{BD} * \text{H} * \frac{(100-\text{SK})}{100} \quad (1)$$

SOC: soil organic carbon content (%), BD: bulk density ($g\ cm^{-3}$), SK: skeleton content (% by weight), H: soil depth (2 dm)

Soil compaction susceptibility

For calculating the soil compaction susceptibility was used Vignozzi et al. (2007) index. This index is associated with the algorithm of Smith et al. (1997) with the equation for calculating the ρ100kPa Pellegrini et al. (2018). Soil compaction susceptibility index (CI) calculated based on the following equation (2):

$$\rho 100kPa = 1.04231 + \exp(-0.486474 - 0.464448186 * SOC) \quad (2)$$

$$CI = -0.09266 + 0.01576 * (Si + Cl) - 0.00012 * (Si + Cl)^2 + \rho 100kPa$$

SOC: soil organic carbon (%), Si: silt (2–50 μm) (%), Cl: clay (< 2 μm) (%)

Soil crusting susceptibility

For calculating soil crusting susceptibility, the FAO (1979) crust formation index (Ic, dimensionless) was used (Pellegrini et al., 2018). The soil crusting susceptibility estimated according to the following equation (3):

$$I_c = \frac{1.5*(Sif)+0.75*(Sic)}{Cl+5.8*SOC} \quad (3)$$

Sif: fine silt (2–20 μm) (%), Sic: coarse silt (20–50 μm) (%), SOC: soil organic carbon (%)

Cl: clay (< 2 μm) (%)

Soil erodibility K factor

The soil erodibility K-value based on the basic soil properties analyses results was indicated in calculation by Wischmeier and Simith (1978). The soil erodibility was calculated with formula wish is below (4):

$$\text{K-factor} = \{0.00021 \times M^{1.14} \times (12\text{-OM}) + 3.25 \times (\text{SSC-2}) + 2.5 \times (\text{PSHCC-3})\}/100 \quad (4)$$

OM: organic matter (%), SSC: soil structure code (1= very fine granular, 2 = fine granular, 3 = medium or coarse granular, or 4 = blocky, platy, or massive), PSHCC: profile saturated hydraulic conductivity code (1, 2, 3, 4, 5, or 6), M: textural factor, M = (silt 0.002-0.05mm (%) + fine sand 0.05-0.1mm (%)) × (100 - clay <0.002mm (%))

Geostatistical and statistical analysis

In the current study, Inverse Distance Weighting (IDW) method, the most common method used in geostatistical studies, was selected (Alaboz et al., 2021). The IDW approach predicts the values at the unsampled points using the linear combination of the values at the sampled points using the inverse distance functions of the distances. According to logic in IDW, the similarities get smaller the more away the target point is from the point where the assumption value is known (Li and Heap, 2008). The IDW can be calculated as follow (Equation 5):

$$Z = [\sum_{i=1}^{n}(Zi/di^{m}) \ / \sum_{i=1}^{n}(1/di^{m})] \quad (5)$$

Z: estimated value, *Zi*: the value at the known point (observed value), di: the distance between point i and the point whose value will be estimated, n: the number of observations, m: weighting power parameter (generally it can be used between 1 and 5 (Keshavarzi and Sarmadian, 2012; Dengiz, 2020). The weighting powers (1., 2., and 3.) commonly used in the estimation of IDW was considered in this study.

Results and Discussion

Descriptive statistics of soil physical and chemical properties

The descriptive statistic values of analysed soil physical and chemical properties for 0–20 cm and 20–40 cm depths in the study area is presented in the Table 1. In the present study, soils were in the fine and medium-fine texture group, and their texture classes were determined as C, CL, SiC and soil particle content is around 50 %, silt around 30 % and in sand around 20 % for both layers. The estimate bulk density in the farm is estimated around 1.3 g cm^3 in both layers. The pH values of the soil samples ranged between 5.68 - 7.98 at top 20 cm and 6.05 – 8.11 in down 20 cm while the mean of both layers is around 7.0 which indicate neutral soil reaction. The electrical conductivity has big range from 124. 2 µS m^{-1} to 1873 µS m^{-1} at 0-20 cm and 139.8 – 1094 µS m^{-1} in the 20 and 40 cm layer, while the average for both layers is around 400 µS m^{-1}. $CaCO_3$ mean is a little above 3 % in both layers. Therefore, the $CaCO_3$ content of the study area soils was classified as 'limey' and 'low limey', OM content varied from 'low' to 'high', soil reaction was also categorized as 'slightly acid and slightly alkaline', and the EC was 'non-saline', as per the methodologies of Doran and Jones (1996), Kacar (2016) and Hazelton and Murphy (2016). OC and OM are higher in top layer with mean 2.0 % and 3.45 % respectively and in down layer OC is 1.48 % and OM 2.55 %.

Table 1. Descriptive statistics of soil properties in soils

Parameters	Mean	SD	CV	Variance	Min.	Max.	Skewness	Kurtosis
Surface (0–20 cm depth)								
pH	7.21	0.52	7.27	0.27	5.68	7.96	-0.83	0.20
EC	433.71	304.87	70.29	92946.80	124.20	1873.00	2.39	6.51
CaCO3	3.22	2.91	90.43	8.48	0.38	18.87	3.08	12.28
OM	3.45	1.43	41.38	2.04	1.02	7.96	0.60	0.22
Sand	20.29	7.58	37.37	57.52	8.25	55.41	2.06	7.40
Silt	31.78	4.84	15.23	23.42	16.70	44.61	-0.23	1.39
Clay	47.93	7.00	14.61	49.04	27.90	68.90	-0.44	1.19
BD	1.28	0.05	4.27	0.00	1.17	1.50	1.09	2.38
SOC_{stock}	5.10	1.99	39.12	3.98	1.60	10.81	0.43	-0.12
Compaction	1.70	0.09	5.22	0.01	1.52	1.92	0.23	-0.55
CF	0.49	0.17	34.56	0.03	0.04	1.11	0.93	3.07
Ero.-K	0.19	0.04	21.54	0.00	0.13	0.37	1.67	3.74
Sub-surface (20–40 cm depth)								
pH	7.28	0.50	6.81	0.25	6.05	8.11	-0.54	-0.45
EC	413.00	210.60	51.00	44377.90	139.80	1094.00	1.31	1.51
CaCO3	3.46	4.52	130.57	20.41	0.37	37.07	5.34	35.97
OM	2.55	1.11	43.67	1.24	0.23	4.92	-0.02	-0.60
Sand	20.31	9.76	48.08	95.32	7.36	74.56	3.23	13.69
Silt	30.72	6.19	20.14	38.26	8.10	43.75	-0.90	1.70
Clay	48.98	7.62	15.55	58.00	17.34	62.01	-1.40	3.19
BD	1.30	0.07	5.43	0.005	1.19	1.58	1.74	3.66
SOC_{stock}	3.81	1.60	42.00	2.56	0.37	7.11	-0.08	-0.58
Compaction	1.76	0.10	5.57	0.01	1.59	2.02	0.54	-0.11
CF	0.50	0.20	39.25	0.04	0.17	1.45	1.67	5.70
Ero.-K	0.20	0.06	31.04	0.00	0.13	0.59	3.54	18.22

SD: standard deviation, Min: minimum, Max: maximum, CV: coefficient of variation, BD: Bulk Density, OM, Organic matter, SOC: Soil organic carbon, EC: Electrical conductivity, Ero.-K: Erodibility K factor, CF: Crust formation

The organic carbon stock is higher in top layer where the mean is 5.10 kg m^{-2} when down layer has mean of 3.81 kg m^{-2}. The compaction is mostly the same in both layers with mean around 1.70 and the range around 1.5-2.0. The crust formation in both layers is generally same with a mean around 0.5. In addition, the erodibility-K is also most same in both layers with a mean of 0.19 in top and 0.20 in bottom. According to Table 1, mostly all soil parameters were found in unsymmetrical position called as skewness. It can be noted that the analysed soil properties generally exhibit moderate to high variations when the changes in physical and chemical soil properties in both soil depths of the research area are examined in terms of coefficient of variation (CV). The CV can be classified in 3 groups accordingto Wilding (1985): low (<15%), medium (15% and 35%) and high (>35%). In comparison to dynamic soil parameters like water content, hydraulic conductivity, bulk density, compaction and organic matter, static soil characteristics including mineralogy, soil texture and soil thickness have a lower amount of variation, according to Salam et al. (2015). In the current study, the pH, bulk density and compaction of soils were classified as 'low' CV, the silt, clay and erodibility-K at top layer amounts were medium, and the values for the other properties were 'high' CV.

Spatial Distribution of the physical soil quality parameters

The surface soil later has more organic carbon stock when compared to bottom layer. Previous study done in Ethiopia also states that SOC stock was significantly higher in the top layer (0 to 15 cm) compared with bottom layer (15 to 30 cm) (Mohammed et al., 2017). The distribution in the field is identical in both layers. The study area can be separated in 2 parts northwest and southeast (Figure 4). The highest concentration of soil organic carbon is in the northwest part and the lowest in the southeast part.

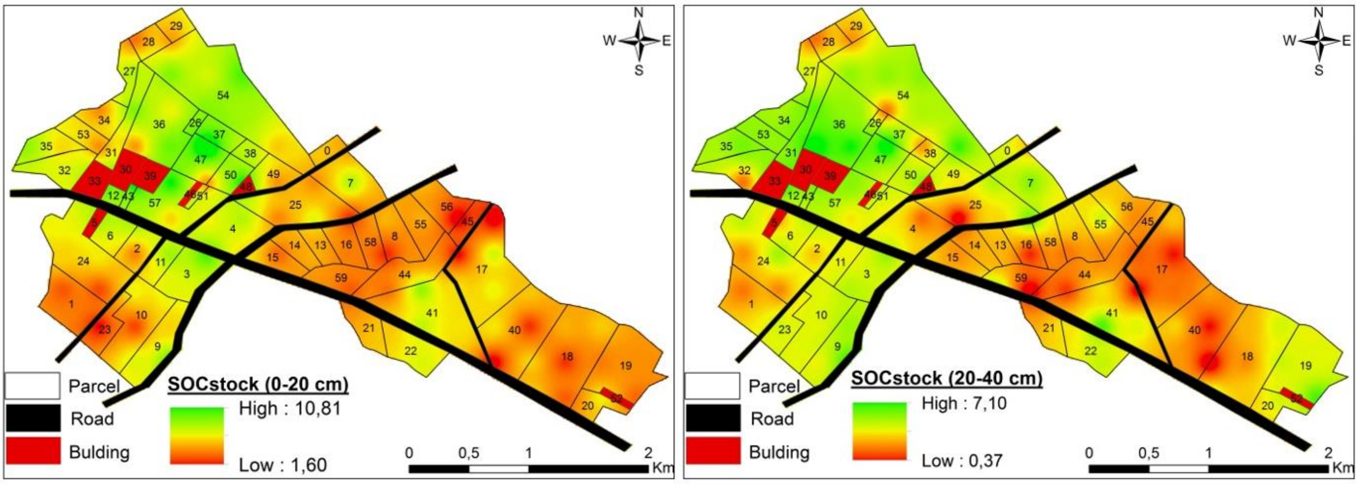

Figure 4. Soil Organic Carbon Stock (kg m^{-2}) maps

It is possible to characterize soil compaction as a densification procedure where porosity is reduced, leading to major changes in the soil's structural characteristics, behaviour, and temperature and moisture regimes. In the study area, the soil compaction is higher in the bottom layer. However, the effected locations are mostly identical between both layers. Moreover, Stone and Lorson (1980) indicated that compressibility, which is the ease with which a soil experiences a reduction in volume when subjected to pressure, determines a soil's susceptibility to compaction. The most compacted area is the centre place of the research area where is pasture, forest, and some rice fields (parcels no: 13-17, 44, 45, 55, 56, 58, 59). Also, the most compacted place has lower amount of soil organic carbon, higher bulk density and the highest amount of sand and clay particles in the soil (Figure 5). On the other hand, the other cultivated areas are compacted less.

As for crust formation, between the most frequent physical deterioration processes of cultivated soils are surface sealing and crusting, which involve the mechanical degradation of surface aggregates by the impact of raindrops and the subsequent drying process. The crust formation of the study area is much more visual in the surface soil layer of the research area. Demirağ Turan and Dengiz (2021) stated that surface sealing or crusting, which include the mechanical destruction of top soil structure by the effect of raindrops and the subsequent drying process, are two of the most frequent physical deterioration processes of cultivated soils. In the top layer most, vulnerable location is in the centre location where is high amount of silt and sand, the lowest amount of soil organic carbon (parcels no 4, 25, 14, 15) and sub soil layer crusting is disperse in some regional parts in the parcels; 8, 40, 41 and 58 (Figure 6).

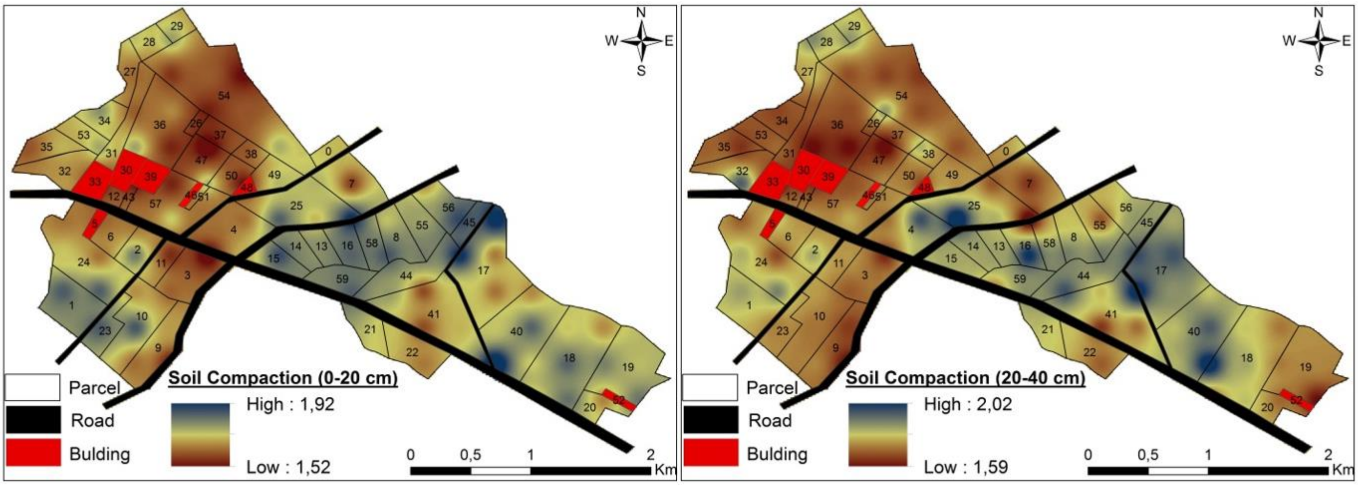

Figure 5. Soil compaction maps

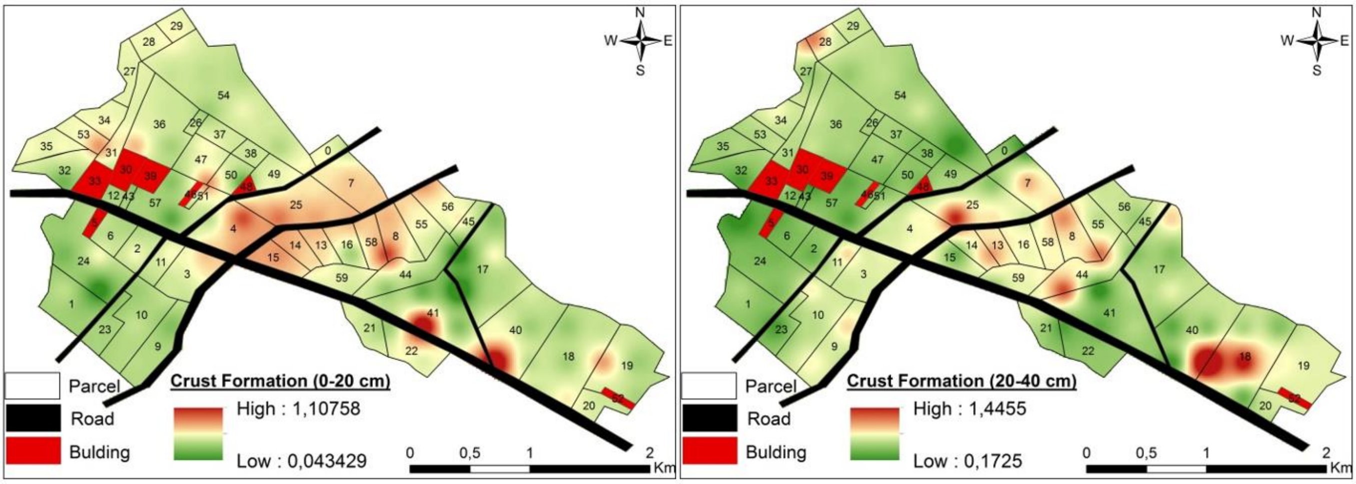

Figure 6. Soil crusting formation maps

The soil erodibility maps of the top and bottom layers of the study area's soils are mostly identical. The most areas at risk for soil erosion is the centre location of the study area with the lowest soil organic carbon amount, the highest amount sand and silt particles in the soil (parcels no: 4, 13- 16, 25, 44, 58, 59), the other territory where high amount of clay particles is in soil is less vulnerable for soil erosion risk (Figure 7). The land use for most vulnerable location is pasture area which was chosen as prevention against erosion. It is well known that cover crops prevent soil erosion and improve soil condition (Ruiz-Colmenero et al., 2013). Moreover, vegetation coverage has a big effect on erosion prevention and reducing loss ratio of nutrients and fine particles fine particles (Yan et al., 2013).

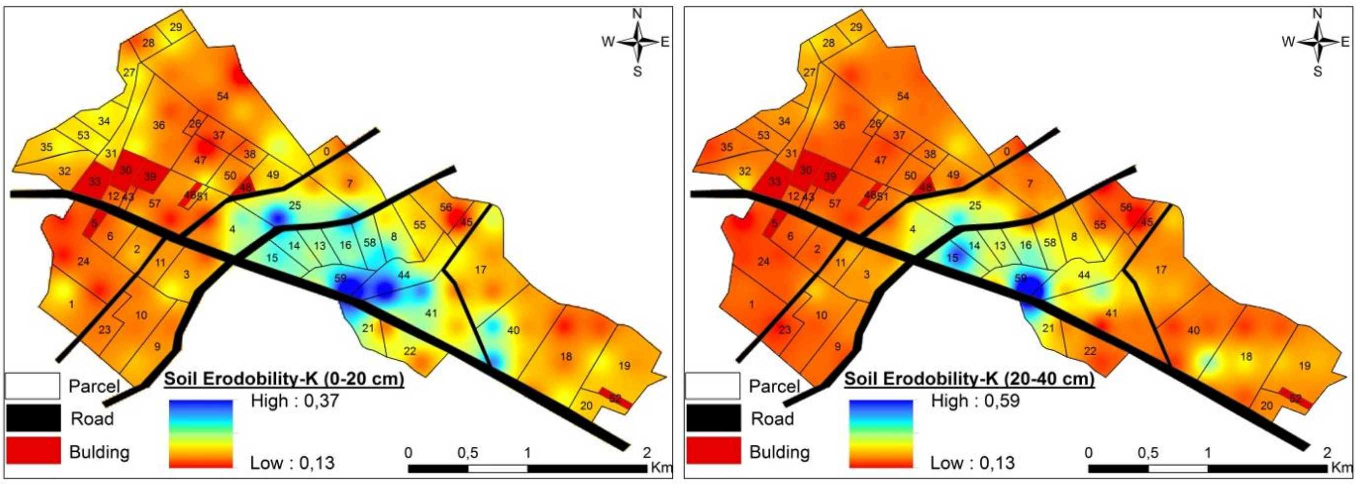

Figure 7. Soil erodibility Factor (K) maps

Correlation between soil characteristics and physical quality parameters

Correlations between soil properties and physical soil quality parameters are given in Table 2. The soil properties were examined for checking statistically significant relationships between soil organic carbon and soil physical properties such as soil compaction, crust formation, erodibility K. The correlation analysis showed that erodibility-K is highly significantly ($P<0.001$) related to soil organic carbon, soil organic carbon stock, organic matter and between each other. Moreover, the erodibility-K factor has relationship ($P<0.001$) with pH, sand, clay, bulk density. Many previous studies of soil erosion confirmed that erodibility is strongly related to soil organic matter, soil texture and structure (Wang et al., 2013). Dikinya's study results have shown that erodibility K factor significantly correlates with organic matter amount, clay fractions percentage, slope length, bulk density, structural properties, and soil porosity (Dikinya, 2013). In addition, the Radziuk study says that decrease in soil organic carbon increases the erodibility (Radziuk and Switoniak, 2021).

The compaction has a relationship ($P<0.001$) with to organic carbon, organic carbon stock, organic matter, clay, bulk density, and lesser relationship ($P<0.005$) with sand. The previous studies confirm the findings. For example, Kumar reported that compaction of soil highly related with its texture (Kumar et al., 2009). Also, many other scientists' studies confirmed the significant relationship between organic matter and soil compaction and stated that an increase in soil organic matter reduces the compactability (Kumar et al., 2009; Shahgholi and Jnatkhah, 2018).

The crust formation has a relationship ($P<0.001$) with soil organic carbon, SOC stock, organic matter, silt, and clay. It is well known in previous studies that the soil crusting not only depends on the external factors but also on soil factors such as organic matter content, soil texture, clay mineralogy, exchangeable cations, sesquioxide content, soil water content (Pagliai et al., 2004). Maïga-Yaleu et al. (2013) pointed out that there is a significant relationship between soils crusting and SOC. In addition, Négyesi et al. (2021) states that the surface crusts differentiate depending on the soil texture and silty loamy soils resulted in harder and more solid crusts in comparison with other textures. Also in the current study, soil compaction, crust formation and erodibility K have strong relationships ($P<0.001$) between each other.

The soil quality parameters that, on the whole, indicate small differences, both in soil layers, are erodibility-K and susceptibility to compaction and crusting. On the other hand, since erodibility-K can change by a rate of up to about six times, it must be taken into account that even small differences in erodibility-K might have an impact on the eventual erosion rate from a specific storm (0.13 to 0.59, Murphy, 2014).

Table 2. Pearson correlation between soil properties and physical quality parameters

Parameters	SOC_{stock}	Compaction	CF	Erodibility-K
pH	-0.348**	0.355**	0.101	0.338**
EC	0.109	-0.180	0.187	-0.132
CaCO3	-0.067	0.099	0.195	0.064
OM	0.996**	-0.961**	-0.290**	-0.495**
Sand	-0.212*	0.262*	-0.136	0.767**
Silt	0.060	-0.034	0.682**	-0.110
Clay	0.223*	-0.309**	-0.379**	-0.893**
BD	-0.469**	0.569**	0.201	0.852**
SOC_{stock}	-	-0.951**	-0.300**	-0.465**
Compaction		-	0.324**	0.455**
CF			-	0.369**
Ero.-K				-

BD: Bulk Density, OM, Organic matter, SOC: Soil organic carbon, EC: Electrical conductivity, Ero.-K: Erodobility K factor, CF: Crust formation, **. Correlation is significant at the 0.01 level, *. Correlation is significant at the 0.05 level.

Conclusion

The most vulnerable farmlands for soil compaction, erodibility and crust formation are the centre part of the study area where were the lowest amount of organic carbon and clay, highest bulk density, silt and sand concentration.

Soil compaction and susceptibility to erodibility (K) and crusting are the soil quality parameters that, on the whole, show minor changings, both in layers. Comparing the farmland use maps for 2020-2021 with the soil properties maps, we can see that for the most vulnerable location for soil erodibility-K, crust formation and compaction the prevention agriculture techniques such as land cover by grass are already used. The land cover should be continued use in the risky territory for preventing erosion. The correlation analysis showed that soil compaction, crust formation, erodibility K is highly significantly (P<0.001) related to organic carbon, organic carbon stock, organic matter and between each other. Here was a not identified significant difference between the soil properties in top and bottom layers. The study showed importance of the soil quality assessment for tracking the soil degradation and making policies for improving soil quality.

Finally, the soil sensitivity indicators based on chemical and biological characteristics and attributes may be a topic for future investigation. Also, similar methods considered cropping systems on certain types of soil could be used to explore variations in critical soil managements and soil fertility factors such as manure application, nutrient availability, soil reaction and so on.

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