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Management systems impact on soil spatial variability under semi-arid climate conditions

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Abstract. Cropping systems are one of the most important living components affecting the surface soil spatial variability. Composite disturbed and undisturbed soils were collected (intersections of the grid system, 50 x 50 m) at 0-20 and 20-40 cm depths under maize (*Zea mays*), wheat (*Triticum aestivum*), and alfalfa (*Medicago sativa* L.) cropping systems from the farmer's field, in the Igdir Plain, eastern Turkey. Soil spatial variability was based on clay, silt, and sand, calcium carbonate ($CaCO_3$) and organic matter, the pH, electrical conductivity, bulk density, aggregate stability and penetration resistance of the soil were determined. The data was analysed using both statistical and geostatistical approaches and suggested that the spatial distribution model and spatial dependence level varied significantly within the farm soils. Exponential, Gaussian, and spherical semivariogram models were found to be the best models to explain the spatial structure of the soil properties. Clay and sand, electrical conductivity, soil organic matter, bulk density, aggregate stability, and penetration resistance were found to be significantly different between the soil depths. The soil property ranges of the variogram were between 58.5 and 305.9 m and showed a moderate to strong spatial dependence. The development of spatial distribution maps for the soil variables analysed provided for a comparison to be made between the various soil properties and raises the possibility of understanding heterogeneity within the farm in the form of a regional representation. It may be concluded that these maps will assist in determining site-specific soil use and identifying the impact of soil management.

Keywords: geostatistics, kriging, spatial variability, alfalfa, organic matter, aggregate stability

INTRODUCTION

Agricultural land use is one of the key management factors which affects soil quality. The degree of soil quality either in rejuvenation or degradation is influenced by land use and/or management in accordance with the capability classes of the soils. For example, in arid/semi-arid regions, soil organic matter (SOM) decreases in response to conventional agricultural practices and consequently, the soil degraded over time (Diacono and Montemurro, 2011). Due to the mutual effect between soil quality and its use, few areas are impacted due to conventional usage (Clair and Lynch, 2010). Therefore, soil management systems should be planned in order to protect soil quality in crop production. The choice of cropping system with or without cover crops is one of regulating factors that protects soil quality (Bronick and Lal, 2005). Several studies have demonstrated that cropping diversity influences soil properties due to the effects of management systems even if the soils are formed under similar pedological processes (Lupwayi *et al*., 2001). Therefore, the appropriate selection of crops is of great importance for sustainable soil management practices.

Soil is a dynamic, complex, and polydisperse system with a wide range of functional properties that change over time and, space and as a consequence of various management practices (Aksakal *et al*., 2019). Soil spatial variability

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*Corresponding authors e-mail: serdar.sari@igdir.edu.tr is influenced by intrinsic and/or extrinsic factors. Intrinsic factors are associated with soil forming factors such as; the parent material, topography, vegetation, climate and time. The main factors of intrinsic soil heterogeneity are geological, hydrological, and biological factors that are responsible for pedogenesis (Cambardella *et al*., 1994; Webster, 2000). By contrast, the extrinsic factors are greatly influenced by land use and/or management practices (tillage, field traffic operations, the crops planted and their rotation, fertilization, soil amendments, irrigation, drainage, *etc.*) and erosion (Mubarak *et al*., 2009). These factors may function on a wide variety of spatial and temporal scales, either alone or in conjunction with other factors. Changes in these variations influence soil fertility and crop productivity by changing soil properties such as the tillage draught energy, root penetration, ρb, PR, AS and the transport of air, water and solutes, *etc.* (Castrignanò and Stelluti, 1999).

While traditional statistical analyses suggest that the measured data are independent, other studies have indicated that soil properties are strongly and spatially dependent (Shi *et al*., 2007). Both the isotropic and anisotropic spatial dependency of soil properties may be defined and explained using geostatistics, which accounts for the structure of the natural variations (Some'e *et al*., 2011). Geostatistics is associated with identifying, measuring, and mapping the spatial dynamics of regional variables, with a focus on semivariogram modelling and analysis. Semivariogram models, which are an interpretative approach to investigating the structure of spatial soil heterogeneity, provide the requisite information for interpolating unsupervised results. Kriging estimates the optimal interpolation and its variance for a given coordinate (Fabijańczyk *et al*., 2016). Quantifying the spatial heterogeneity in soil properties and their relationships is critical for implementing long-term management approaches to improving soil quality for economic crop production and the conservation of natural resources. An awareness of the spatial variations in the core indicators of soil quality such as clay, silt, sand, calcium carbonate ($CaCO_3$), SOM, pH, electrical conductivity (ECe), bulk density (ρb), aggregate stability (AS), and penetration resistance (PR) within a site would provide useful information for improved management and increased performance.

Problems arising from the evaluation of large amounts of data in the field of soil science have led to the emergence of new equipment in this field. For this reason, various concepts such as digital soil mapping, pedometry, and geostatistics have been adopted for the mapping of soil properties (McBratney *et al*., 2003; Minasny and McBratney, 2016). With an increasing frequency, geostatistical methods have been used by many researchers to evaluate the spatial and temporal variability of many soil properties (Erşahin, 2003; Iqbal *et al*., 2005; Barik *et al*., 2014; Fabijańczyk *et al*., 2016).

This study was conducted at a micro scale (field scale) level to evaluate the spatial variations in selected soil properties (clay, silt, sand, $CaCO_3$, SOM, pH, ECe, ρb, AS and PR) under different cropping management systems.

MATERIALS AND METHODS

The study was conducted in Igdir Plain, which is located in eastern Turkey (Fig. 1). The area is located in a micro-climate region, which has an average annual relative humidity, precipitation, evaporation, and mean annual temperature of 56.9%, 257.2 mm, 1339.4 mm, and 12.2°C, respectively. The coldest month is January and the hottest months are July and August (Anonymous, 2018). Soils in the area are formed on alluvial parent materials and classified as a part of the Inceptisols order, Xerepts suborder and Haploxerepts great soil group (Soil Survey Staff, 2014).

Field samples were taken between the 2014 and 2020 from an area (4 ha) owned by a local farmer, the area was divided into 4 sections (1 ha each) and designated as A, B, C and D plots for ease of evaluation. The crop production systems area is given in Table 1. A composite of disturbed and undisturbed soils were collected from the 0-20 and 20-40 cm depth of the intersection points of the grid system (50 x 50 m). In order to minimize any errors in spatial variability, the soils were also sampled from the midpoints

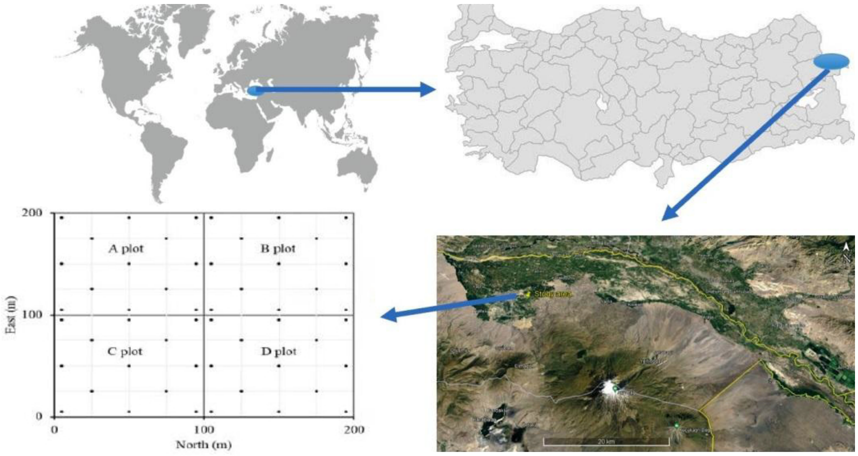


Fig. 1. Layout of soil sampling locations.

Table 1. Plant production patterns of the experimental area between the years 2014-2020

Plot	Plant production patterns
A	Alfalfa cultivation between the years 2014-2020. The alfalfa harvest was performed four times a year and no tillage operations have been completed since 2014. Diammonium phosphate and ammonium nitrate were applied at a rate of 150 kg ha^{-1} in 2014.
B	Alfalfa cultivation between the years 2014-2018, maize in 2019, and wheat in 2020. Tillage was performed in 2017 and 2018, using a plough. Diammonium phosphate and ammonium nitrate were applied at a rate of 150 kg ha^{-1} each year throughout the cultivation years.
C	Maize plantation between 2014-2016, and alfalfa cultivation in 2017-2019. The soil was tilled in 2014, 2015 and 2016 using a plough. No tillage operations have been performed since 2017. Diammonium phosphate and ammonium nitrate were applied at a rate of 150 kg ha^{-1} in 2014 and 2017.
D	Maize cultivation between the years 2014-2020. Tillage was performed every year using a plough. Diammonium phosphate and ammonium nitrate were applied at a rate of 150 kg ha^{-1} each year throughout the cultivation years. In 2018, 40 t ha^{-1} of animal manure was also applied.

of the grids (Fig. 1). For each depth, 26 soil samples (13 disturbed and 13 undisturbed) were randomly collected from each plot in 2018. 208 soil samples were taken in total (4 plot x 2 depth x 26 soil samples). Grid sampling is widely used in model-based sampling designs that are easy to execute and result in an equitable distribution of sampling regions and in kriging mapping, as it is an excellent method for reducing the mean interpolation error (Burgess and Webster, 1984).

Field-moist disturbed soil samples were air-dried (~25°C), and sieved (2 mm). PR was measured in-situ within each sampling site at a 0 to 40 cm depth using the Eijkelkamp penetrologger (Lowery and Morrison, 2002). Antecedent soil moisture during PR measurements were between 26.2 and 28.1% for A (0-20 and 20-40 cm), 22.8 and 24.5% for B (0-20 and 20-40 cm), 28.1 and 31.9% for C (0-20 and 20-40 cm), and 18.9 and 21.9% for D (0-20 and 20-40 cm), respectively. As PR varies with soil moisture content, the measurements were standardized for moisture changes using the following relationship developed by Aksakal *et al*. (2011).

The Bouyoucos hydrometer method was used for soil particle-size analysis (Gee and Or, 2002), while, the Scheibler calcimeter was used for the determination of $CaCO_3$ (Loeppert and Suarez, 1996), and the Smith-Weldon method was followed for SOM contents (Nelson and Sommers, 1996). Soil pH and ECe were determined in saturated extracts (Thomas, 1996 and Rhoades, 1996). The standard wet sieving method was used for determining AS (Nimmo and Perkins, 2002) while ρb was determined at 0-20 and 20-40 cm depths using a field penetrometer (Grossman and Reinsch, 2002).

Analysis of variance (ANOVA) was performed on all data collected using the SPSS Statistical Package v.20.0, and significant means were compared using Tukey's multiple reference test (IBM, 2011) at a significance level of $p<0.05$. The Pearson correlation was used to examine the relationship between land management, clay, silt, sand, pH, ECe, $CaCO_3$, SOM, ρb, AS and PR values.

Using GS+ Version 10.0 geostatistics, geostatistical analyses such as semivariogram and ordinary Kriging analyses were performed to determine the land management impact distribution of spatial variability in clay, silt, sand, pH, ECe, $CaCO_3$, SOM, bulk density (ρb), AS and PR (Gamma Design Software, 2015). The following equation, given by Isaaks and Srivastava (1989), was used to produce experimental semivariograms:

$$\gamma(h)=\frac{1}{2N(h)}\sum_{i=1}^{N(h)}\left[Z\left(x_i\right)-Z\left(x_i+h\right)\right]^2 , \qquad (1)$$

where: $\gamma(h)$ is the semivariance for the inner distance class h, h is the lag interval, $N(h)$ is the total number of sample pairs for the lag interval h, $Z(x_i)$ is the measured sample value at point i, $Z(x_i+h)$ is the measured sample value at point $i+h$.

If the variogram increases and remains stable at some value, it has reached a sill (C) (*e.g.*, theoretical sample variance). The distance that the variogram to sill reaches is called range (a), and the values beyond this distance are independent, while failure to reach it may suggest that it has an infinite dispersion capacity. There may be discontinuities at the variogram origin; such as an unstructured component of variation at h=0 which is known as the nugget effect (C_0), and it may be caused by sampling errors and short-scale variability. The calculation of the variogram is called isotropic if the spatial variability is the same in all directions, otherwise it is anisotropic.

In order to assess directional variability in the experimental plots, experimental semivariograms for the measured soil parameters were developed at 0, 45, 90, and 135°, respectively. Since there is no meaningful difference in the structures of the directional semivariogram models, the semivariogram is only determined by the distance (h) between the samples. As a result, isotropy was assumed, and omni-directional (isotropic) semivariograms were fitted in order to characterize the spatial variability.

The best-fit models were chosen based on the lowest residual sum of squares (RSS) and highest R^2. The best-fitting models for explaining spatial variability were the exponential (2), Gaussian (3), and spherical semivariogram (4) models:

$$\gamma(h) = C_0 + C\left[1 - exp\left(-\frac{h}{A_0}\right)\right] , \tag{2}$$

$$\gamma(h) = C_0 + C\left[1 - exp\left(-\frac{h^2}{A_0^2}\right)\right] , \tag{3}$$

$$\gamma(h) = C_0 + C\left[1.5\frac{h}{A_0} - 0.5\left(\frac{h}{A_0}\right)^3\right] \text{ if } h \le A_0 , \tag{4}$$

$$\gamma(h) = C_0 + C \text{ if } h > A_0 , \tag{5}$$

where: $\gamma(h)$ is the semivariance for the internal distance class h, h is the lag interval, C_0 is the nugget variance, C is the structural variance, and A_0 is the range of influence.

Due to its sensitivity to short range variation, the ordinary kriging procedure was applied for estimating the clay, silt, sand, pH, EC, $CaCO_3$, OM, ρb, AS and PR values at unsampled points with intervals of 1 m, using 6 to 16 measured values for clay, silt, sand, pH, EC, $CaCO_3$, OM, ρb, AS and PR using the following equation. The kriged values were mapped to produce distribution patterns of the measured variables:

$$Z^*\left(x_0\right) = \sum_{i=1}^{N} \lambda_i Z\left(x_i\right) , \tag{6}$$

where: $Z^*(x_0)$ is the clay, silt, sand contents, and pH, EC, $CaCO_3$, OM, ρb, AS and PR values at an unknown location X_0, $Z(x_i)$ is the measured values from N-sampled locations while x_i and λ_i are the weights.

RESULTS AND DISCUSSION

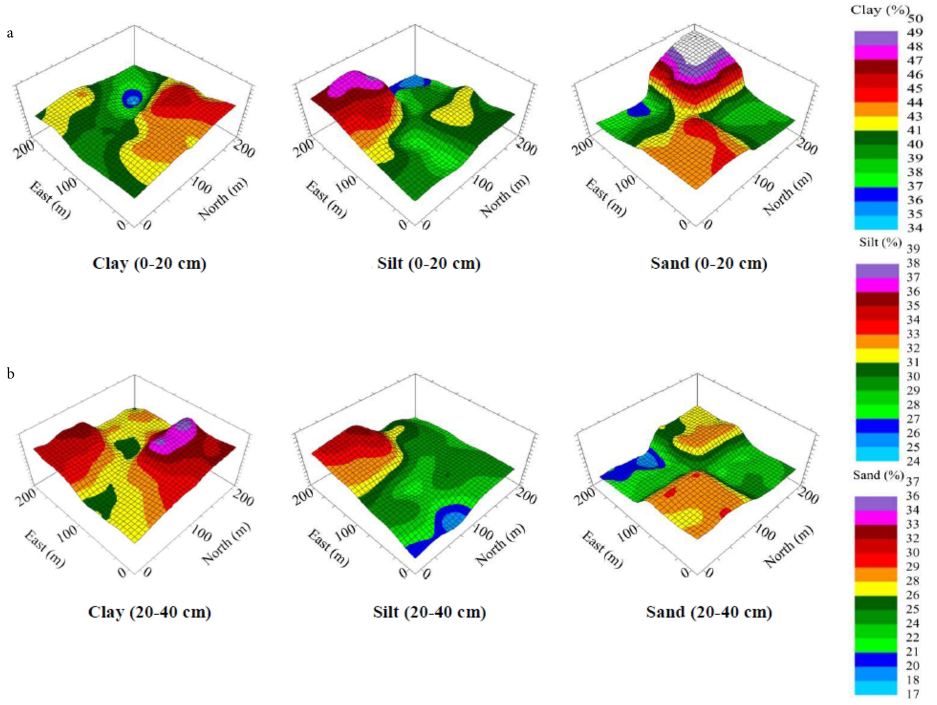
Spatial variations in clay, silt, and sand content, and also in pH, ECe, $CaCO_3$, SOM, ρb, AS, and PR values in the field were studied and with their geostatistics parameters they were presented in Table 2.

The clay, silt and sand contents of the study area in 0-20 cm soil depth ranged between 34.4-44.9, 24.7-37.3, and 19.9-36.9%, respectively. These values were 39.7-49.7, 25.1-35.2, and 17.8-29.9% for the 20-40 cm soil

Table 2. Descriptive statistics, semivariogram model and model parameters for soil clay content, silt content, sand content, pH, electrical conductivity (ECe), lime content ($CaCO_3$), soil organic matter content (SOM), bulk density (ρb), aggregate stability (AS), penetration resistance (PR) in the field studied

Properties	Depth (cm)	Min.	Max.	Mean	Std.	CV (%)	Spatial dependence and model*	Nugget (C_0)	Sill (C_0+C)	Nugget/Sill (%)*	Range of influence (A_0) (m)	R^2
Clay (%)	0-20	34.40	44.90	41.33b	2.00	4.84	S. Sph.	0.010	4.43	2.26	100.20	0.991
	20-40	39.70	49.70	43.77a	2.38	5.44	M. Gau.	1.82	7.09	25.67	107.91	0.990
Silt (%)	0-20	24.70	37.30	30.58ns	3.02	9.88	S. Gau.	1.75	10.82	16.17	131.98	0.989
	20-40	25.10	35.20	29.86ns	2.31	7.74	S. Gau.	0.87	6.75	12.89	168.01	0.997
Sand (%)	0-20	19.90	36.90	27.68a	4.59	16.58	S. Sph.	0.84	29.03	2.89	172.40	0.971
	20-40	17.80	29.90	25.01b	3.29	13.15	M. Gau.	3.40	13.10	25.95	113.45	0.940
pH	0-20	8.01	8.67	8.20ns	0.14	1.71	M. Sph.	0.012	0.024	48.73	114.50	0.980
	20-40	8.06	8.43	8.20ns	0.08	0.98	S. Sph.	0.076	0.674	11.28	58.50	0.790
ECe	0-20	480	739	609.58b	74.81	12.27	S. Sph.	1110	6368	17.43	96.60	0.826
	20-40	464	762	643.88a	65.85	10.23	M. Gau.	1763	4228	41.70	106.35	0.999
$CaCO_3$ (%)	0-20	9.20	13.50	11.15ns	1.14	10.22	S. Exp.	0.326	1.628	20.02	206.70	0.990
	20-40	9.40	12.70	10.89ns	0.84	7.71	S. Sph.	0.013	0.701	1.85	73.20	0.975
SOM (%)	0-20	1.68	4.82	3.27a	0.94	29.05	M. Gau.	0.498	1.115	44.66	122.63	0.991
	20-40	1.32	3.92	2.33b	0.67	28.76	S. Sph.	0.067	0.406	16.50	75.20	0.767
ρb (g cm^{-3})	0-20	1.15	1.55	1.28b	0.09	7.03	S. Sph.	0.075	0.717	10.46	90.30	0.945
	20-40	1.23	1.54	1.38a	0.08	5.80	S. Sph.	0.054	0.541	9.98	80.00	0.953
AS (%)	0-20	45.63	74.70	61.91a	7.79	12.58	S. Gau.	15.40	76.00	20.26	162.81	0.987
	20-40	40.85	70.15	54.57b	7.82	14.33	M. Gau.	22.90	80.86	28.32	170.26	0.995
PR (MPa)	0-20	0.64	3.92	1.69b	0.81	47.93	S. Gau.	0.064	1.075	5.95	221.70	0.997
	20-40	1.12	4.92	2.36a	0.95	40.25	S. Gau.	0.116	2.342	4.95	305.88	0.996

* – % nugget = (nugget semivariance/total semivariance) ×100, S. – strong spatial dependence (% nugget<25), M. – moderate spatial dependence (% nugget between 25 and 75), Sph. – spherical, Gau. – gaussian, Exp. – exponential. Small letters show differences between soil depths, ns: no significant.



Clay (0-20 cm) Silt (0-20 cm) Sand (0-20 cm)

Clay (20-40 cm) Silt (20-40 cm) Sand (20-40 cm)

Fig. 2. Spatial variability in clay, silt and sand content at different depths: a – 0-20 cm, b – 20-40 cm of the field studied.

depth, respectively (Table 2). In general, the clay, silt and sand contents in the field for the 0-20 and 20-40 cm soil depths were 41.3-43.8, 30.6-29.9, and 27.7-25%, respectively. While the clay content of the 20-40 cm soil depth was significantly higher than that of the 0-20 cm depth, the sand content was lower. There was a lack of any statistical differences between the silt content of the depths (Table 2).

The spatial variability in the clay, silt, and sand content of the plots for 0-20 and 20-40 cm are presented in Fig. 2. When the plots were investigated, it was clearly observed that the clay content of the A, B, and D plots were higher in the 20-40 cm depth. However, there were no clear statistical differences in the clay content of the C plot. While the highest clay content was determined in the D plot with

Table 3. The effects of different soil management techniques at different depths and soil characteristics ($p<0.05$)

Plots	Depth	Clay	Silt	Sand	pH	ECe	$CaCO_3$	SOM	ρb	AS	PR
Plot A	0-20	40.88±1.13b	34.72±1.93ns	23.62±2.20ns	8.08±0.03b	610±52ns	12.45±0.61a	4.21±0.27a	1.31±0.12ns	70.12±5.15a	2.68±0.80b
	20-40	44.51±1.93a	33.04±1.59	21.07±1.77	8.18±0.08a	582±76	10.73±0.63b	3.11±0.44b	1.31±0.06	61.23±5.42b	3.78±0.64a
	Mean	42.70±2.41B	33.88±1.93A	22.34±2.35D	8.13±0.08C	596±66B	11.59±1.07A	3.66±0.67A	1.31±0.09	65.67±6.88A	3.23±0.91A
Depth p		<0.05	ns(0.093)	ns(0.206)	<0.05	ns(0.289)	<0.05	<0.05	ns(0.983)	<0.05	<0.05
Plot B	0-20	39.51±2.06b	27.63±1.64b	34.28±1.99a	8.23±0.06ns	556±32b	10.58±0.69b	3.22±0.47a	1.26±0.05b	61.75±6.31a	1.83±0.36b
	20-40	41.85±1.26a	29.45±1.07a	27.38±1.21b	8.18±0.07	631±50a	11.35±0.81a	2.51±0.44b	1.39±0.06a	54.20±5.98b	2.15±0.33a
	Mean	40.70±2.05C	28.54±1.64C	30.83±3.87A	8.21±0.07B	594±56B	10.97±0.83B	2.86±0.59B	1.33±0.09	57.98±7.15B	1.99±0.38B
Depth p		<0.05	<0.05	<0.05	ns(0.080)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Plot C	0-20	41.50±1.30ns	29.33±1.44ns	28.59±1.17ns	8.37±0.14ns	562±56b	11.13±1.26ns	1.95±0.16ns	1.32±0.06b	54.27±5.56a	1.37±0.19b
	20-40	42.32±1.31	28.01±1.67	28.41±1.05	8.25±0.09	679±47a	11.08±1.02	1.76±0.41	1.38±0.06a	46.44±3.69b	2.08±0.20a
	Mean	41.91±1.34B	28.67±1.67C	28.50±1.10B	8.31±0.13A	621±78B	11.10±1.12B	1.86±0.32C	1.35±0.07	50.36±6.11C	1.72±0.41B
Depth p		ns(0.120)	ns(0.140)	ns(0.676)	ns(0.220)	<0.05	ns(0.906)	ns(0.146)	<0.05	<0.05	<0.05
Plot D	0-20	43.41±1.12b	30.65±0.74a	24.23±0.70ns	8.12±0.02ns	710±19a	10.42±0.55ns	3.69±0.65a	1.21±0.04b	61.48±4.94ns	0.88±0.28b
	20-40	46.42±1.63a	28.95±0.71b	23.17±1.08	8.18±0.02	684±22b	10.38±0.59	1.93±0.32b	1.42±0.08a	56.41±7.58	1.45±0.21a
	Mean	44.92±2.06A	29.80±1.12B	23.70±1.05C	8.15±0.04C	697±24.A	10.40±0.56C	2.81±1.03B	1.31±0.12	58.95±6.78B	1.16±0.38C
Depth p		<0.05	<0.05	ns(0.107)	ns(0.216)	<0.05	ns(0.865)	<0.05	<0.05	ns(0.054)	<0.05

Capital letters show differences between plot means. Other explanations as in Table 2.

Table 4. The effects of different soil management techniques at different depths and soil characteristics ($p<0.05$)

Depth	Plots	Clay	Silt	Sand	pH	ECe	$CaCO_3$	SOM	ρb	AS	PR
0-20 cm	A plot	40.88±1.13b	34.72±1.93a	23.62±2.20c	8.08±0.03c	610±52b	12.45±0.61a	4.21±0.27a	1.31±0.12a	70.12±5.15a	2.68±0.80a
	B plot	39.51±2.06c	27.63±1.64c	34.28±1.99a	8.23±0.06b	556±32c	10.58±0.69c	3.22±0.47b	1.26±0.05ab	61.75±6.31b	1.83±0.36b
	C plot	41.50±1.30b	29.33±1.44b	28.59±1.17b	8.37±0.14a	562±56c	11.13±1.26b	1.95±0.16c	1.30±0.06a	54.27±5.56c	1.37±0.19c
	D plot	43.41±1.12a	30.65±0.74b	24.23±0.70c	8.12±0.02c	710±19a	10.42±0.55c	3.69±0.65b	1.21±0.04b	61.48±4.94b	0.88±0.28d
Mean		41.33±2.00B	30.58±3.02ns	27.68±4.59A	8.20±0.14ns	610±75B	11.15±1.13ns	3.27±0.94A	1.28±0.09B	61.91±7.79A	1.69±0.81B
p		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
20-40 cm	A plot	44.51±1.93b	33.04±1.59a	21.07±1.77c	8.18±0.08b	582±76c	10.73±0.63ab	3.11±0.44a	1.31±0.06b	61.23±5.42a	3.78±0.64a
	B plot	41.85±1.26c	29.45±1.07b	27.38±1.21a	8.18±0.07b	631±50b	11.35±0.81a	2.51±0.44b	1.39±0.06a	54.20±5.98b	2.15±0.33b
	C plot	42.32±1.31c	28.01±1.67c	28.41±1.05a	8.25±0.09a	679±47a	11.08±1.02a	1.76±0.41c	1.38±0.06a	46.44±3.69c	2.08±0.20b
	D plot	46.42±1.63a	28.95±0.71c	23.17±1.08b	8.18±0.02b	684±22a	10.38±0.59b	1.93±0.32c	1.42±0.08a	56.41±7.58b	1.45±0.21c
Mean		43.77±2.38A	29.86±2.31ns	25.01±3.29B	8.20±0.08ns	644±66A	10.89±0.84ns	2.33±0.67B	1.38±0.07A	54.57±7.82B	2.36±0.95A
p		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Capital letters show differences between plot means. Other explanations as in Table 2.

a value of 44.9%, the lowest level was determined in the B plot as 40.7% (Table 3). The silt content showed a lack of significant difference between the two depths of the A and C plots. However, the silt content in the 20-40 cm depth of plot B and in the 0-20 cm depth of plot D was found higher. While the highest silt content was determined in the A plot (33.9%), the lowest was determined in the B plot (28.5%) (Table 3). In general, there were a lack of significant differences between the soil depths and the silt contents of the 0-20 cm and 20-40 cm depths, they were determined to be 30.6 and 29.9%, respectively (Table 4). Similar differences were observed in the sand contents of the soil depths. While the average sand content at the 0-20 cm depth was found to be 27.7%, it was found to be 25.0% for the 20-40 cm depth (Table 4). Wilding (1985) classified the variability in soil properties into 3 categories according to the coefficient of variance (CV). According to this classification a CV of <15% shows low, 15-35% moderate and >35% high variation. When this classification is taken into account, it may be clearly observed that the CV of the clay and silt contents at the 0-20 cm and 20-40 cm depths were calculated as 4.8-5.4, and 9.9-7.7%, respectively. The CV of the sand content at the 20-40 cm soil depth was calculated at 13.9%. These results have shown that the effect of soil depth on textural fractions shows a low degree of variation. However, the CV of the sand content at a depth of 0-20 cm was found to be 16.6% (moderate variation), which is close to a CV of <15%. Cambardella *et al*. (1994) have used the nugget-to-sill ratio to determine spatial dependence.

This variable was considered to be highly dependent if the ratio was found to be less than 25%, moderately dependent if the ratio was between 25 and 75%, and weakly dependent if the ratio was greater than 75%. As may be observed from Table 2, a close spatial dependence exists between the clay content at the 0-20 cm depth (2.3%), the silt content at the 0-20 cm (16.2%) and 20-40 cm (12.9%) depths, and the sand content at the 0-20 cm (2.9%) depths. These results are in agreement with those gained from the calculation of CV. The results obtained have shown that changes in the textural fractions are not caused by soil management/land use. The variation in textural fractions within the different soil depths and plots is thought to be controlled by intrinsic variations. The key causes of intrinsic soil heterogeneity are geological, hydrological and biological factors that cause pedogenesis (Webster, 2000).

The average pH of the soils studied was determined to be 8.20. There were no statistical differences between the depths studied. While the pH of the surface soil (0-20 cm) ranged between 8.01-8.67, it ranged from 8.06-8.43 at the 20-40 cm soil depth. The CV values at 0-20 cm, and 20-40 cm were calculated as 1.71 and 0.98%, respectively. The nuggets to sill ratios were calculated to be 48.7 and 11.3% for these depths, respectively. While the pH values for the 0-20 cm and 20-40 cm depths showed a low degree of variation according to Wilding (1985), they showed a moderate spatial dependence at a depth of 0-20 cm and a close spatial dependence at a depth of 20-40 cm according to Cambardella *et al*. (1994) (Table 2, Fig. 3). When the plots were investigated, it may be observed that the pH of the A and D plots were lower in the upper depth. However, the pH at the 0-20 cm depth was determined to be 8.08 and 8.12 for the A and D plots, and this value was determined to be 8.18 for the 20-40 cm depth, respectively.

There were no statistical differences between the soil depths of the B, C, and D plots. However, the pH value at the 20-40 cm depth (8.18) was found significantly higher than at the 0-20 cm depth (8.08) in plot A, in which alfalfa cultivation is performed. The average pH values of the A, B, C, and D plots were 8.13, 8.21, 8.31, and 8.15, respectively (Table 3). Significant variations were determined between

Table 5. Pearson correlation coefficients between parameters

	Clay	Silt	Sand	pH	ECe	$CaCO_3$	SOM	ρb	AS	PR
Clay	–									
Silt	0.10	–								
Sand	–0.67**	–0.67**	–							
pH	–0.08	–0.37**	0.41**	–						
EC	0.35**	–0.014	–0.33**	–0.42**	–					
$CaCO_3$	–0.30**	0.40**	–0.040	0.12	–0.17	–				
SOM	–0.20*	0.53**	–0.19	–0.56**	–0.015	0.20*	–			
ρb	0.21*	–0.05	–0.11	0.23*	0.09	0.24*	–0.53**	–		
AS	–0.01	0.54**	–0.27**	–0.37**	–0.12	0.33**	0.69**	–0.20*	–	
PR	0.10	0.56**	–.40**	–0.16	–0.23*	0.28**	0.18	0.21*	0.28**	–

Correlation is significant at the: *0.05, and **0.01 levels.

the plots. The lowest pH value was determined in plot A in which the highest SOM was determined (Tables 3, 4). When all of the plots and soil depths were investigated, a significant negative correlation (–0.56**) was determined between pH and SOM (Table 5). According to Thomas *et al.* (2007), pH and organic C concentration have a negative relationship. A change in pH may be explained in part by the organic anion concentration of the plant material (Wang *et al*., 2013).

The ECe values in the field studied are given in Tables 2-4, while the ECe of the surface soil (0-20 cm) ranged between 480-739 µS cm^{-1}, it ranged from 464-762 µS cm^{-1} in the 20-40 cm soil depth. The average ECe of the 0-20 and 20-40 cm soil depths were determined to be 610 and 644 µS cm^{-1}, respectively. The ECe at a depth of 20-40 cm was statistically significantly higher than that of the 0-20 cm depth. The CV values at 0-20 and 20-40 cm were calculated to be 12.3, and 10.2%, respectively. The nugget-to-sill ratios were calculated as 17.4 and 41.7% for these depths, respectively. The ECe values for the 0-20 and 20-40 cm depths showed a low degree of variation according to Wilding (1985), they showed a high degree of spatial dependence at 0-20 cm and a moderate degree of spatial dependence at 20-40 cm according to Cambardella *et al.* (1994) (Table 2, Fig. 4).

There were no statistical differences between the ECe values of the soil depths in plot A, in which alfalfa was cultivated. The average ECe values at the 0-20 and 20-40 cm depths in plot A were determined to be 610 and 582 µS cm^{-1},

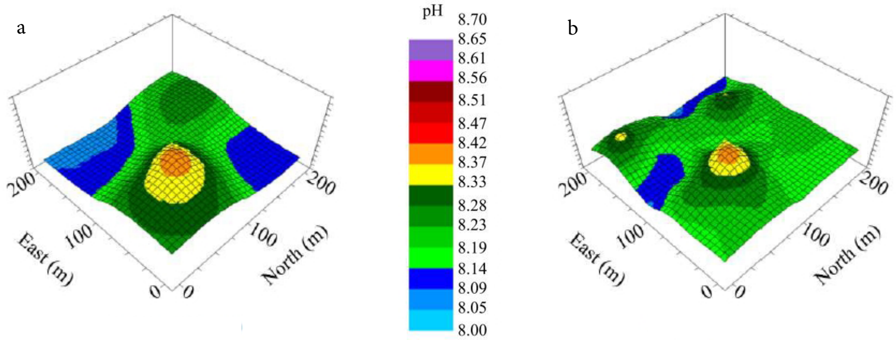


Fig. 3. Spatial variability in pH at different depths: a – 0-20 cm and b – 20-40 cm of the field studied.

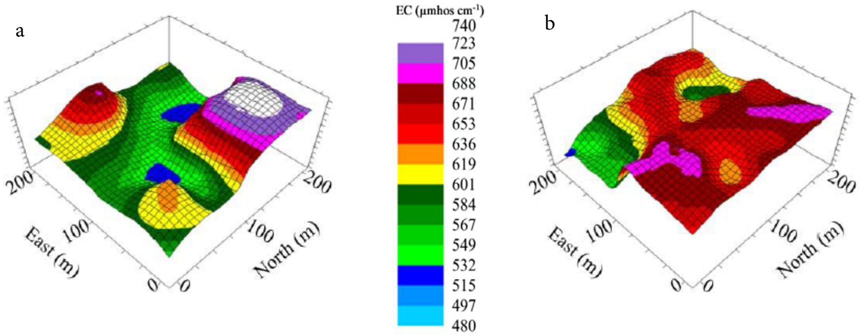


Fig. 4. Spatial variability in electrical conductivity at different depths: a – 0-20 cm and b – 20-40 cm of the field studied.

respectively. However, significant changes in ECe values of these soil depths were observed in the B, C, and D plots. While the ECe of the lower depth was higher in the B and C plots, while that of the upper depth was higher for the D plot. The average ECe values of the A, B, C, and D plots were determined to be 596, 594, 621 and 697 µS cm^{-1}, respectively (Table 3). The higher ECe value in the D plot may be explained by the cultivation of maize in this plot. The application of chemical fertilizers (diammonium phosphate and ammonium nitrate) may be responsible for this increase. It is possible for fertilizers to increase the EC of the soil due to the salts they contain (Sankar *et al*., 2007).

While the $CaCO_3$ content of the surface soil (0-20 cm) ranged between 9.20 and 13.50%, it ranged from 9.40 to 12.70% at the 20-40 cm soil depth. The average $CaCO_3$ content at the 0-20 cm depth was determined to be 11.15%, it was determined to be 10.89% at a 20-40 cm depth. The high $CaCO_3$ content in this area is due to the parent material in this region. There were no statistical differences between the soil depths studied (Table 2). The average $CaCO_3$ content of plots A, B, C, and D were determined to be 11.59, 10.97, 11.10, and 10.40%, respectively. The highest $CaCO_3$ content was determined in plot A, in which alfalfa was cultivated (Table 3).

According to the classification made by Wilding (1985) and Camberdella *et al*. (1994), the $CaCO_3$ content showed a low degree of variation and strong spatial dependence, respectively (Tables 2-4, Fig. 5).

Variations in SOM in the field studied are given in Tables 2, 3, and 4. Spatial variations in SOM are shown in Fig. 6a and 6b. The SOM content of the field studied ranged between 1.32 and 4.82% while the SOM of the surface soil (0-20 cm) ranged between 1.68 and 4.82%, it ranged from 1.32 to 3.92% at the 20-40 cm soil depth. The average SOM of the 0-20 cm and the 20-40 cm soil depths were determined to be 3.27 and 2.33%, respectively. The SOM at 0-20 cm was statistically significantly higher than that at the 20-40 cm depth. The CV values at 0-20 cm, and 20-40 cm were calculated to be 29.05, and 28.76%, respectively. The nugget-to-sill ratios were calculated to be 44.66 and 16.50% for these depths, respectively. While the SOM values for the 0-20 and 20-40 cm depths showed a moderate variation according to Wilding (1985), they showed a moderate spatial dependence for the 0-20 cm depth and strong spatial dependence for the 20-40 cm according to Cambardella *et al.* (1994) (Table 2, Fig. 6). The SOM content of the surface soil (0-20 cm) was determined to be 4.21, 3.22, 1.95, and 3.69%, for plots A, B, C, and D, respectively. These values were determined to be 3.11, 2.51, 1.76, and 1.93%, for the 20-40 cm depth, respectively. The SOM content of the surface soil was found to be significantly higher than that of the 20-40 cm depth in plots A, B, and D. However, there were no statistical differences between the depths of plot C. The average SOM contents of plot A, B, C, and D were determined to be 3.66, 2.86, 1.86, and 2.81%, respectively (Tables 3, 4). The highest SOM content was found in plot A, in which alfalfa was cultivated.

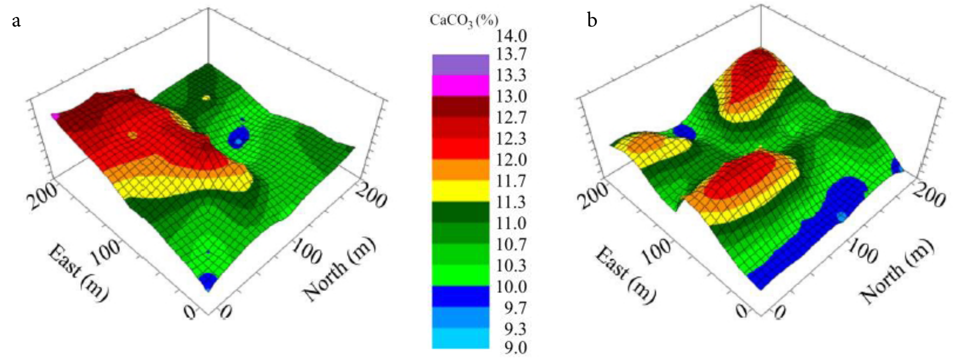


Fig. 5. Spatial variability in lime content at different depths: a – 0-20 cm and b – 20-40 cm of the field studied.

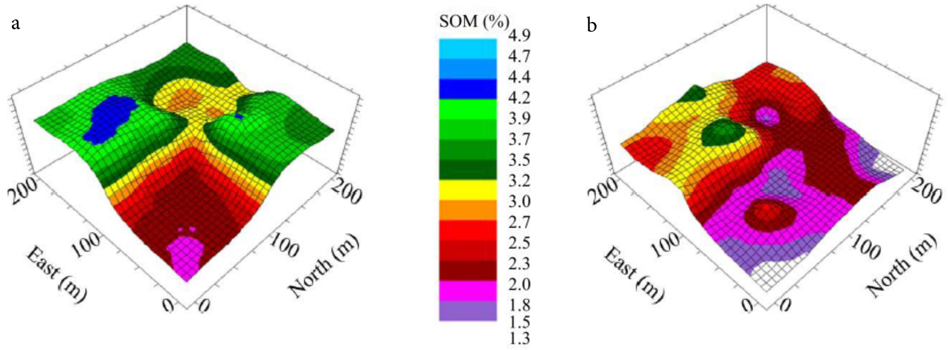


Fig. 6. Spatial variability in organic matter content at different depths: a – 0-20 cm and b – 20-40 cm of the field studied.

The reason for this result may be related to the dense vegetative parts of alfalfa and soil tillage, which encouraged the accumulation of SOM (Sáez *et al*., 2012).

Alfalfa has the capacity to produce high amounts of phytomass. Its finer rooting structure exhibits a high degree of decomposability (Roumet *et al*., 2016). No tillage operations were performed in this plot since 2014. If high-input cropping systems are used concurrently, then no-till may potentially succeed as a soil conservation practice to increase SOM and organic carbon contents. Legume species with high phytomass production are good candidates for meeting this goal, particularly when combined with grasses that use biologically fixed nitrogen (Bayer *et al*., 2009). Tillage reduces SOM content because of the aeration of the soil, which facilitates the rapid mineralization of SOM (Thomas *et al*., 2007).

The ρb values of the soils studied occurred in the range between 1.15-1.55 g cm^{-3}. While the ρb of the surface soil (0-20 cm) was ranged between 1.15-1.55 g cm^{-3}, it ranged from 1.23-1.54 g cm^{-3} at the 20-40 cm soil depth. The average ρb at the 0-20 and 20-40 cm depths were found to be 1.28 and 1.38 g cm^{-3}, respectively. Significant statistical differences were determined between the soil depths studied. The CV values at the 0-20 and 20-40 cm depths were calculated to be 7.03, and 5.80%, respectively. The nugget-to-sill ratios were calculated to be 10.46 and 9.98% for these depths, respectively. While the ρb values for the 0-20 and 20-40 cm depths showed a low degree of variability according to Wilding (1985), they showed strong spatial dependence for both depths according to Cambardella *et al.* (1994) (Table 2, Fig. 7).

When the plots were investigated, it may be clearly observed that the ρb of the B, C, and D plots were significantly higher at the lower depth (20-40 cm). While the ρb value at the 0-20 cm depth was determined to be 1.26, 1.32, and 1.21 g cm^{-3} for plots B, C, and D, it was determined to be 1.39, 1.38, and 1.42 for the 20-40 cm depth, respectively. However, no statistical difference was obtained between the depths at plot A. The average ρb values of the A, B, C, and D plots were determined to be 1.31, 1.33, 1.35, and 1.31 g cm^{-3}, respectively. There were no statistical differences between the plots studied (Tables 3, 4). A statistically significant negative correlation (–0.534**) was determined between ρb and SOM. The high SOM content of the soil reduces ρb (Stavi *et al*., 2008). The ρb values were lower in plot A, in which alfalfa was cultivated and also, the soil was found to have a high SOM content, and plot D, to which organic matter was added. Higher amounts of SOM may result in lower ρb values because SOM has a lower particle density than mineral particles. This soil behaviour has been attributed to the dilution effect (Logsdon and Karlen, 2004). Also, SOM in soils increased the intra-aggregate porosity and decreased the ρb of the structural aggregates (Mbagwu, 1990). Furthermore, the variations in ρb may be related to plant roots and their effects. The plant root system is the most important biotic factor affecting the macro-micro pore formation process, pore distribution, and their size in the soil. Therefore, root composition in the soil increases the degree of porosity and causes the bulk density to decrease (Qadir *et al*., 2007; Gould *et al*., 2016; Huang *et al*., 2019; Hu *et al*., 2019).

AS changes in relation to soil management are presented in Tables 2, 3, and 4. While the AS of the surface soil (0-20 cm) ranged from 45.63 to 74.70%, it ranged from 40.85 to 70.15% in the 20-40 cm soil depth. The average AS of the 0-20 and 20-40 cm soil depths were determined to be 61.91 and 54.57%, respectively. The ECe value of 0.20 cm was higher to a statistically significant extent than that of the 20-40 cm depth. The CV values of the 0-20 and 20-40 cm depths were calculated to be 12.58 and 14.33%, respectively. The nugget-to-sill ratios were calculated to be 20.26 and 28.32% for these depths, respectively. While the AS values for the 0-20 and 20-40 cm depths showed a low degree of variation according to Wilding (1985), they indicated strong spatial dependence for the 0-20 cm layer and a moderate spatial dependence for the 20-40 cm layer according to Cambardella *et al*. (1994) (Table 2, Fig. 8).

The AS values of the surface soil (0-20 cm) were determined to be 70.12, 61.75, 54.27, and 61.48%, for plots A, B, C, and D, respectively. These values were determined to be 61.23, 54.20, 46.44, and 56.41% for the 20-40 cm depth, respectively (Table 3). Statistically significant changes were determined between the soil depths investigated. While

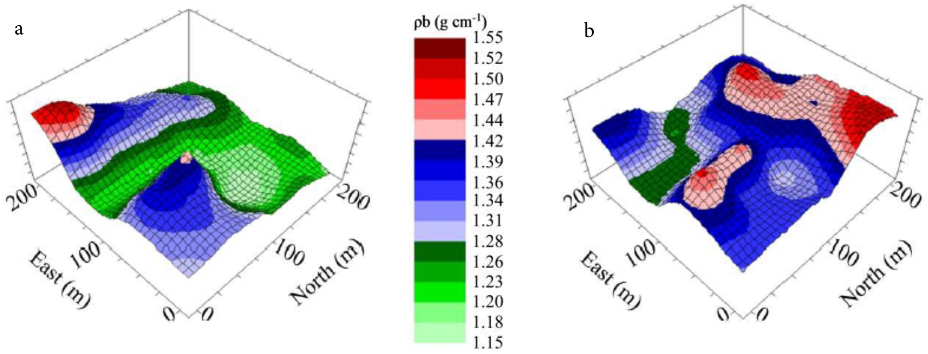


Fig. 7. Spatial variability in bulk density at different depths: a – 0-20 cm and b – 20-40 cm of the field studied.

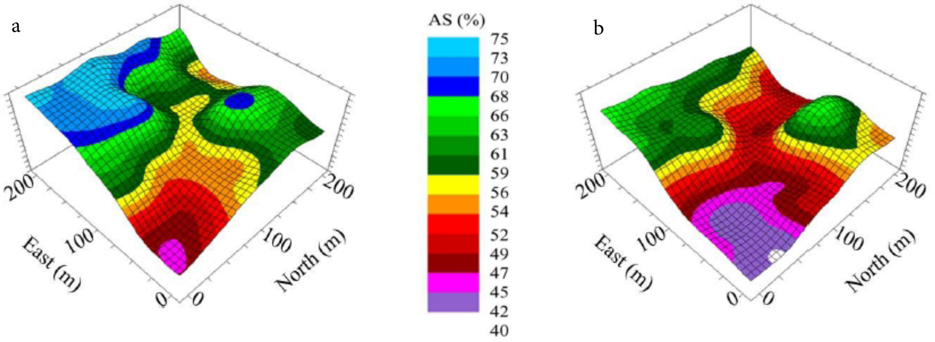


Fig. 8. Spatial variability in aggregate stability at different depths: a – 0-20 cm and b – 20-40 cm of the field studied.

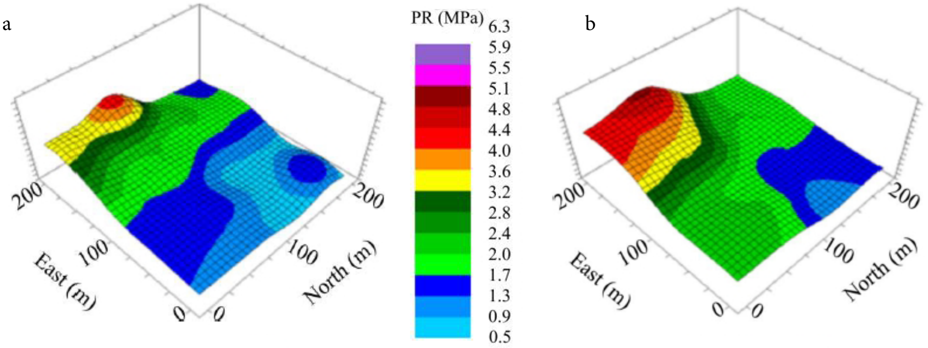


Fig. 9. Spatial variability in penetration resistance at different depths: a – 0-20 cm and b – 20-40 cm of the field studied.

the AS value of the 0-20 cm layer was found to be significantly higher than that of the 20-40 cm depth in the A, B, and C plots, there were no significant changes between the depths for plot D. The average AS value of the surface soil (0-20 cm) was determined to be 61.91%, and a value of 54.57% was determined for the 20-40 cm depth (Table 4). AS values of plot A, B, C, and D were determined to be 65.67, 57.98, 50.36, and 58.95%, respectively, which indicates statistically significant variations between the plots (Table 3). The AS values were the highest in plot A, in which alfalfa was cultivated (alfalfa has a dense root system) and which was found to have a high SOM content, and a high $CaCO_3$ content. Statistically significant positive correlations were determined between AS-SOM (0.693**), and AS-$CaCO_3$ (0.33**). SOM plays an important role in stabilizing soil aggregates (Aksakal *et al*., 2016). Another important factor affecting soil aggregation and AS is the belowground behaviour of plants (Gould *et al*., 2016). Root functional properties (root length, density, and compaction effect, *etc.*), root secretions and flocculating substances formed as a result of microbial activity are highly effective in aggregate formation and stabilization in terms of soil AS (Gyssels *et al*., 2005; Rillig *et al*., 2015). In addition, $CaCO_3$ has a well-known beneficial effect on soil structure and provides favourable conditions for soil organic carbon stabilization. The beneficial effects of $CaCO_3$ for soil structure have been reported in various studies, aggregation is promoted due to the cementing effect of $CaCO_3$ in the soil (Virto *et al*., 2013; Inagaki *et al*., 2017; Rowley *et al*., 2018).

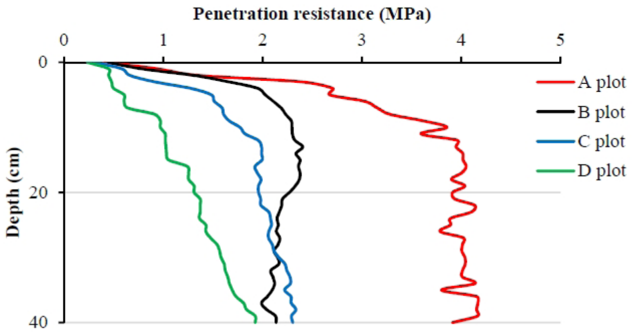


Fig. 10. Penetration resistance curves of the field studied.

Changes in PR are presented in Tables 2, 3, and 4. Spatial variations in PR and its variation with depth are presented in Figs 9 and 10. While the PR of the surface soil (0-20 cm) ranged between 0.64 and 3.92 MPa, it ranged from 1.12 to 4.92 MPa in the 20-40 cm soil depth. The average PR of the 0-20 and 20-40 cm soil depths were determined to be 1.69 and 2.36 MPa, respectively.

The PR of the 20-40 cm layer was higher to a statistically significant extent than that of 0-20 cm depth. The CV values of the 0-20 and 20-40 cm soil layers were calculated to be 47.93, and 40.25%, respectively. The PR values for both depths showed a degree of high variation according to Wilding (1985) (Table 2). When the plots were investigated, it may be clearly observed that the PR of all of the plots were significantly higher in the lower depth (20-40 cm) (Table 3). While the PR of the 0-20 cm depth was determined to be 2.68, 1.83, 1.37, and 0.88 MPa for the A, B, C, and D plots, it was determined to be 3.78, 2.15, 2.08, and 1.45 MPa for the 20-40 cm depth, respectively. The average PR of the 0-20 and 20-40 cm depths were found to be 1.69 and 2.36 MPa, respectively (Table 4). Significant variations with regard to PR were obtained among the plots. The PR values were found to be the highest in plot A, in which alfalfa was cultivated. Alfalfa has a dense root system, and these roots enhance soil cohesion (Gould *et al.*, 2016). A dense root system and a high level of cohesion may have led to high PR measurements. Also, the reason for the high PR values may be due to heavy field traffic. Wheel traffic is a necessary consequence of alfalfa cultivation (to cut, rake, bale and remove alfalfa from the field). Studies have demonstrated that as much as 70% of the field area could be driven upon for each cutting/harvest performed. Both deep soil compaction and surface soil compaction due to the multiple trips taken are important factors (Undersander, 2010; Sadeghi *et al.*, 2021).

CONCLUSIONS

1. The topsoil properties had higher coefficients of variation than the subsoil.

2. Penetration resistance was found to be the most variable soil property in the region, while pH was the least variable.

3. Because of the influence of geology and the differences in land use and land management measures, the coefficients of variation of soil properties are high, thereby indicating that soil properties are not homogeneous with regard to spatial distribution.

4. All of the soil properties determined had variogram ranges between 305.9 and 58.5 m. Moreover, the soil properties have a spatial structure which is critical for depicting the impact of management activities on soil quality parameters.

5. The development of spatial distribution maps for the soil variables analysed provided a comparison of soil properties and the possibility of understanding heterogeneity within the study region. As a result, these maps have the potential to help farmers with site-specific soil usage and to identify adversely affected areas in the region.

6. Kriging is the most common estimate approach since it is a set of generalized linear regression techniques for reducing and estimating the variance specified by a previous model for a covariance. Kriging is used to develop probabilistic models of uncertainty about the unknown, but estimated expected values, in addition to estimating the characteristics of the unsampled areas. This technique has been successfully applied in this study.

Conflict of interest: The authors declare no conflict of interest

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