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Research Article

Determination of Boron Contents of Arsuz Plain Soils and Mapping with Geographic Information Systems (GIS)

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Abstract
In this study, boron contents and the properties of soils in the Arsuz plain were determined, and distribution maps of these properties were made using Geostatistical methods. In the study, 46 soil samples were collected from 0-30 depth in Arsuz plain soils. In the samples that were taken from soils, pH, electrical conductivity (EC), organic matter (OM), lime, texture (sand, silt, and clay), and air-dried water content were analyzed using standard methods. In addition, the geographical coordinates of the sampling points were determined by GPS. Descriptive statistics (mean, median, minimum, maximum, etc.) were applied for all parameters. Correlation analyses were made to reveal the relationships between the boron content and the soil properties. Geostatistical methods were used to determine and map spatial variations of the soil properties in the Arsuz Plain. The mean B, pH, EC, lime, OM, sand, silt, clay, and MC values were found to be 0.23 mg kg^{-1}, 7.58, 672.4 µS cm^{-1}, 17.75 %, 2.01 %, 16.7 %, 37.3 %, 45.9 %, and 4.15 %, respectively. The most suitable semivariogram model was determined as Guassian and exponential in most of the soils. All soil samples showed strong and moderate spatial dependence. The maximum distances (A0) to which soil properties can be related varied between 200-2110 m.

Keywords: GIS (geographic information systems), arsuz plain, boron, soil properties

1. Introduction

Boron is one of the essential micronutrients required for plant growth. Boron deficiency is considered one of the most common microelement deficiencies after zinc. Adsorption and desorption reactions may be the main factors affecting boron concentration in solution and its availability by plants. In addition to the boron concentration in soil solution, the adsorption and desorption of boron by soils are also affected by soil properties. Four types of surfaces adsorb boron in soil. These are (i) clay minerals, (ii) oxides, (iii) calcium carbonate, and (iv) organic matter. Soil properties and other environmental factors can also affect boron adsorption. Boron adsorption reactions in soils are explained by various adsorption equations (Chaudhary et al., 2005).

The detrimental effects of both boron deficiency and toxicity on plant growth and development cannot be overstated. With the majority of boron (> 90 %) found in the cell wall of plants, its role in the formation of cell walls is crucial. The urgency of our research is underscored by the physiological and metabolic problems that arise in plants under deficiency and toxicity conditions (Bilir, 2022).

The soil texture affects the boron adsorption in the soil. A study by Singh (1964) determined that fine-texture soils adsorb boron more than coarse-texture soils. Another factor affecting boron adsorption in soils is pH. As the pH increases in soils up to a certain point, the B adsorption also increases. The lime content of soils also increases the B adsorption, increasing the pH. Another factor that affects the retention of boron in soils is organic matter content. Organic matter increases boron retention (Chaudhary et al., 2005).

Boron reduces yield and quality by causing physiological and metabolic problems in plants with deficiency and toxicity conditions. Boron deficiency is commonly observed in sandy soils where washing is excessive and organic matter is low. The pH and lime content in clay soils is high, and the adsorption capacity is high. In case of deficiency, the cell wall containing more than 90 % of boron is negatively affected, and therefore, healthy plant growth is prevented (Bilir, 2022).

The importance of the boron content and properties of soils in determining soil fertility cannot be overstated. Understanding their spatial distribution is crucial for effective agricultural production. Our research, which focuses on determining the spatial distribution of boron contents and properties of soils using geostatistical methods and geographical information systems, is therefore of great significance.

Geostatistics, a sub-branch of statistics, is a statistical method that estimates the properties studied in areas that could not be sampled in a few sampling studies and examines the spatial variation of these properties (Webster and Oliver, 2007).

Geostatistical studies are conducted in a two-stage process. The first stage involves the creation of semivariograms, which are crucial as they use the features of the sampled points. In the second stage, these semivariograms, along with an appropriate interpolation method, are used to estimate the characteristics of the points in the unsampled areas, leading to the creation of spatial distribution maps.

Geostatistical parameters are calculated for each variable as a result of semivariogram analyses. In order to determine the spatial dependence of each soil property, semivariograms are calculated from the equation given below (Isaaks and Srivastava,1989):

$$\gamma(h) = 1/2N(h)\ \Sigma[Z(xi) - Z(xi+h)]^2$$

Where γ(h) is the semivariance; N(h) is the number of experimental pairs separated by a distance h; Z(xi) is the measured sample value at point i, and Z(xi+h) is observed sample value at point i+h. Kriging is one of the most widely used interpolation methods in soil-related studies, which makes the most accurate and unbiased assessment.

Distribution maps of soil properties prepared with geostatistical methods and Geographic Information Systems provide important information about the soil properties studied in the area. In addition, these maps have important functions in adapting precision agricultural applications (Budak and Günal, 2015).

2.Materials and Methods

2.1. Material

2.1.1. Geographical location of the study area

The research area is located on the borders of the Arsuz district of Hatay province and between latitudes 4028732 – 4040284 N and longitudes 757949 – 767663 E (WGS-84, UTM, 36 Zone). There is the Mediterranean Sea in the west, the Amanos mountains in the east, the Iskenderun district in the north, and the Samandağ district in the south of the study area (Anonymous, 2016)

2.1.2. Climate of the study area

The study area is influenced by the Mediterranean climate, which has hot and dry summers and mild and rainy winters. The annual average precipitation is 1121.6 mm, and the annual average temperature is 18.3 °C. The highest average precipitation was recorded in January, and the lowest average precipitation was recorded in June (Anonymous, 2019).

2.1.3. Vegetation of the study area

Almost all of the Arsuz plain is under agricultural culture. The most cultivated plant in the area are parsley, wheat, olive, lemon and apricot, citrus, pomegranate, strawberry and peach (Anonymous, 2017).

2.1.4. Geology of study area

The study area is almost composed of quaternary-aged alluvions (Q-21-k). However, there are sedimentary rocks containing Pliocene sandstone, mudstone, and limestones (pl-20-s) in the western part of the area, sedimentary rocks consisting of limestone and shelf (mcmd-8-s) in the southern part, and sedimentary rocks containing sandstone, mudstone, and limestones (mcmd-20-s) in the eastern part (Figure 1) (Anonymous, 1982).

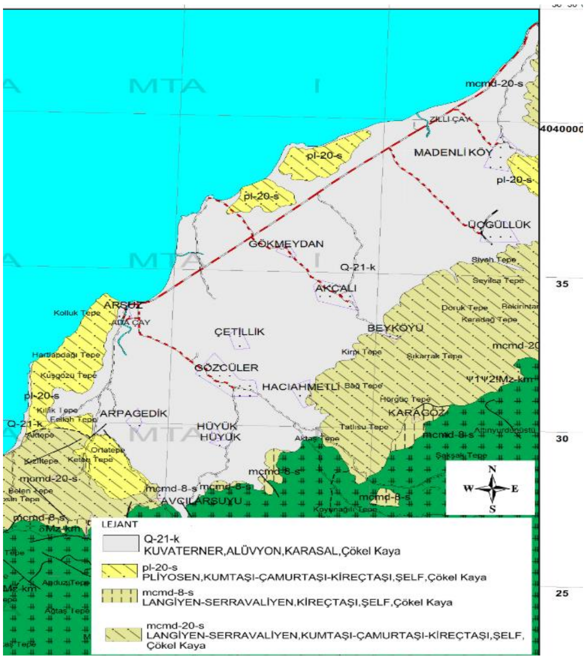

Figure 1. Geological map of study area

2.1.5. Taking soil samples

Forty-six soil samples were taken from the study area, from a depth of 0-30 cm, to represent the area and according to the random sampling method (Figure 2). The geographical coordinates of the points where all samples were taken were determined according to the UTM coordinate system with a GPS device (Magellan brand, eXplorist 710 model).

2.2. Methods

2.2.1. Soil analyses

Soil samples taken were dried in plastic pans in the shade, passed through a 2 mm sieve, and made ready for analysis. In soil samples, pH, electrical conductivity (EC), organic matter (OM), boron (B), lime, texture, and air-dried water content analyses were made. pH was measured in saturation mud with a pH meter, and EC in saturation extract was measured with an EC meter (Richards, 1954). Analyzes of organic matter by the Walkey-Black wet burning method (Allison, 1965), the available boron content was determined according to the Azomethin-H method (Bingham, 1982), the lime content was determined according to Allison and Moode (1964) and texture analyses by hydrometer method (Bouyoucos,1951). Air-dry moisture content was calculated as the percentage ratio of the difference between the weights of the soil samples taken from the field and the weights obtained from drying them in the oven at 105 °C for 24 hours (Richards, 1954).

Figure 2. The geographical location of the study area and the places where soil samples were taken

2.2.2. Statistical and geostatistical analyses

In the study, descriptive statistical analyses (mean, lowest and highest values, standard deviation, coefficient of variation, skewness, etc.) of all soil parameters were calculated. Then, Kolmogrov-Sminrov analysis was performed to determine whether the parameters of the soil samples showed a normal distribution (Table 1) (Liu et al., 2006). The Windows-compatible SPPS 23 statistical package program was used for all statistical analyses.

3. Results and Discussion

3.1. Boron contents and physical and chemical properties of the soils

Descriptive statistical analysis results of the basic characteristics of the soils in the research area are presented in Table 2. The available B content of the soils varied between 0.00-1.32 mg kg^{-1}, and the average B content was determined as 0.23 mg kg^{-1}. According to the criteria determined as mg kg-1 by Wolf (1971), B contents are meager in 89.1 % of soils, low in 8.7 %, and moderate in 2.2 %. A study by Niaz et al. (2007) in the Institute of Soil and

Environmental Sciences of Faisalabad Agricultural University (ICES) found similar results on the level of boron in soils. However, in a study conducted by Budak and Günal (2015) in the Kizilca Koyun village in the Bor district of Niğde province, they found the B concentrations of the soils to be relatively high (between 1.41-97.84 mg kg^{-1}). According to researchers, boron is so high because of the formation of the soils on the main materials, such as marine sediments and volcanic sediments, with a high salt and boron content. According to researchers, another reason for the high boron is that precipitation is too low, evaporation is high, and surface drainage is insufficient. Again, in a study conducted by Kalkanci et al. (2023), it was determined that the B content was very insufficient in 10 % of the Edirne lands, insufficient in 40 %, moderate in 37 %, high and very high in 13 %. The study conducted by Cüre (2023) found that the boron content of Mustafakemalpaşa Plain is high in about 55 % of the surface soils, moderate in about 40 %, and very high in 1.5 %. Şimşek et al. (2023) determined that the boron content of the soils in the olive Decking areas in Kilis ranged between 0.262-1.894 mg kg^{-1}, and the B content was low in 34.7 % of the soils and sufficient in 65.3 %.

Table 1. Normality test results

Parameter	Kolmogorov-Smirnov	
	Statistic	P
B	0.181	0.001
pH	0.102	**0.200***
EC	0.202	0.000
Lime	0.150	0.011
Organic matter	0.122	0.083
Moisture content	0.209	0.000
Sand	0.099	**0.200***
Silt	0.136	0.033
Clay	0.111	**0.198***

*P> 0.05 data showing normal distribution, p <0.05 data not showing normal distribution

In a study conducted by Ağca and Karanlık (2011) in the Amik plain, the B contents in the soils varied between 0.13 and 5.29 mg kg^{-1}. In addition, with the exception of one sample, the B concentration of all other samples was below 5 mg kg^{-1}, which is the critical limit.

The pH values of the soil samples, meticulously ranged between 6.94 and 8.00, with the average pH value determined as 7.58. This comprehensive analysis, when compared with Ülgen and Yurtsever (1995) criteria, revealed that 34.8 % of the samples are neutral and 65.2 % are basic, providing a detailed understanding of the soil's acidity.

It was determined that the soils' electrical conductivity (EC) values were between 139 and 2510 μScm^{-1}, and the mean EC value was 672.4 µS cm^{-1}. According to Richards's salinity criteria (1954), all soils are salt-free. In the study conducted by Peker et al. (2024), the EC values of the soils ranged between 240 and 6250 µS cm^{-1}, and almost all of the soil samples belonged to the salt-free class except for two.

The lime content of the soils varied between 0.57-31.18 %, and 2.2 % of them were slightly calcareous (<1), 10.9 % were medium calcareous, 10.9 % were calcareous, 67.4 % were too calcareous, and 8.6 % were too calcareous (Ülgen and Yurtsever, 1995). According to a study by Peker et al. (2024), the lime content of the soils varied between 0.11-13.79 %, and the soils were generally moderately calcareous. Karadeniz and Özkutlu (2023) determined that 40 soil samples taken from the Sandy region of Ordu had low lime content, 7 had medium lime content, 14 had lime content, 2 had too much lime content, and 8 had too much lime content.

The organic matter contents of the soils changed between 0.89–5.64 %, and the average organic matter content was determined as 2.01 %. According to Ülgen and Yurtsever (1995) criteria, organic matter content in soils of the research area is very low (<1) in 4.3 % of soils, low (1-2 %) in 54.3 %, medium (2-3 %) in 32.6 %, and good (3-4 %) in 8.9 %. According to the study conducted by Peker et al. (2024), the OM contents of soils were found to be between 1.42- 15.12 %.

Table 2. Descriptive statistical analysis results of the basic characteristics of the soils

Parameters	Unit	Min	Max	Mean	SD	CV	Skewness	Kurtosis
B	mg kg^{-1}	0.00	1.32	0.23	0.22	95.65	2.95	12.91
pH	----	6.94	8.00	7.58	0.25	3.30	-0.70	0.13
EC	µS cm^{-1}	139.0	2510.0	672.4	501.0	74.51	1.81	3.93
Lime	%	0.57	31.18	17.75	7.50	42.25	-0.99	0.29
OM	%	0.89	5.64	2.01	0.93	46.27	1.62	4.14
Sand	%	0.6	61.1	16.7	14.4	86.23	0.98	0.58
Silt	%	20.5	55.4	37.3	9.2	24.67	-0.07	-0.81
Clay	%	18.3	69.0	45.9	12.1	26.36	-0.11	-0.46
MC	%	1.52	9.10	4.15	1.43	34.46	1.47	2.93

Min: Minimum, Max; Maximum, SD: Standard deviation, CV: Coefficient of variation (%), OM: Organic matter, MC: Moisture content

The average clay, sand, and silt contents of the soils in the study area were determined as 45.9 %, 16.7 %, and 37.3 %, respectively. When the average values are taken into consideration, it is seen that the sand content of the study area soils is low, whereas the clay and silt contents are high. This situation is also seen as evident in the texture class. 65 % of the soils are fine-texture (silty clay and clay), and 35 % are medium-texture (clay loam, silty clay loam, sandy clay loam, loam, and sandy loam). It has been found that almost all of the soils are clay and loam textured (Table 3). In the study conducted by Peker et al. (2024), the sand content of the study area soils varies between 4.07 % and 51.05 %; silt content varies between 7.53 % and 43.65 %; clay content varies between 8.78 % and 70.32 %. The texture class of soils is generally clay. In the study conducted by Şimşek et al. (2023), It was determined that 47.9 % of the soils in the olive grove areas in Kilis have a loam texture, and 52.1 % have a clay loam texture. According to the study by Sökmen et al. (2024) in the Demirci and Selendi districts of Manisa, it was determined that 26.51 % of the soils were sandy loam and 24.10 % were clay loam.

Among the main properties of soils, the coefficient of variation (VK) is the lowest (3.3 %) in pH and the highest (95.65 %) in B content. In the study conducted by Cüre (2023), the VK value of the B content was also calculated as relatively high (74.25). As in this study, in the studies conducted by many researchers also, it has been determined that the pH values of soils have the lowest coefficient of variation (Sağlam and Dengiz, 2013; Budak and Günal, 2015; Günal et al., 2020; Courage, 2023; Peker et al., 2024). This situation shows that the spatial variability of pH values in the research area is too small, and the B content is too high. The skewness values also confirmed this situation. The smaller the skewness values, the more homogeneous the distribution of this feature in the research area.

3.2. Modeling of the spatial distribution of boron content and properties of soils

Due to the low skewness values of the soils' pH, sand, and clay contents, no transformation was applied to these data sets before geostatistical modeling. On the other hand, due to the high skewness values, geostatistical evaluations were made after applying logarithmic transformation to EC, lime, OM, silt, and MC values and square root transformation to B contents.

To determine the best-fitting semivariogram model for all soil properties, the active separation distance was taken as 6715 m. Again, to create the best-fitting semivariogram model, separation distances were taken between 444 m (for silt content) and 463 m (for sand content), which would give the highest r^2 values.

The best-fitting semivariogram model was found to be Gaussian for pH, lime, and B; Exponential for sand, silt, and clay content; and Spherical for EC and OM. However, structural variance could not be identified among the MC contents of the soils in the study area, leading to the determination that the measurement values of the samples were independent of the distance between them and the variance produced random values (Pure nugget). The r2 values of the semivariogram models ranged from 0.270 (for silt content) to 0.884 (for Na content) (Table 3).

Budak and Günal (2015) determined the most suitable semivariogram model for the lime, sand, and clay contents as Gaussian, exponentially for B, pH, EC, OM, and lime. A_0 values ranged from 104 m to 6993 m, and values of r^2 ranged from 0.706 to 0.976. According to Günal et al. (2020), the most suitable semivariogram model in the soils of the Central Black Sea region was determined globally for clay, pH, and EC and exponentially for sand and lime. The range values ranged from 384 m (for EC) to 17220 m for these parameters.

Table 3. Semivariogram parameters of soil properties and B contents

Parameters	Model	A_0 (m)	Nugget (C_0)	Sill (C_0+C)	Nugget/Sill *100	r^2
B	Guassian	3250	0.018	0.069	26.00	0.788
pH	Guassian	3900	0.027	0.112	24.10	0.815
EC	Spherical	6640	0.251	0.538	46.66	0.756
Lime	Guassian	490	0.100	40.620	0.25	0.621
OM	Spherical	770	0.001	0.374	0.27	0.484
Sand	Exponential	21080	2.060	7.129	28.89	0.467
Silt	Exponential	200	7.300	80.350	9.08	0.270
Clay	Exponential	270	6.400	118.400	5.40	0.380
TC	Exponential	340	0.042	0.360	11.67	0.472
MC	Pure nugget					

OM: Organic matter, TC: Texture classes, MC: Air dried moisture content

3.3. Spatial distribution maps of boron contents and properties of soils

A comprehensive understanding of the research area was achieved through the creation of a change pattern map using the (2x2) block kriging interpolation technique to B contents and all properties of the soils (Figure 3).

Boron is insufficient in the central and southern parts, moderate in the north-western parts, and very insufficient in other parts. The most common B contents ranged between 0.22-0.31mg kg^{-1} (insufficient) (Figure 3a). A small area south of the study area and its central parts are neutral, while other parts are basic reactions. The most common pH values are 7.5-8.5 (Figure 3b). According to the EC values, which indicate soil salinity, all the soils in the area are in the unsalted class. The EC values of the soils are the smallest in the extreme sections in the southern section and the highest in the central sections. The most common EC values in the field are 300-600 µS cm-1 (Figure 3c).

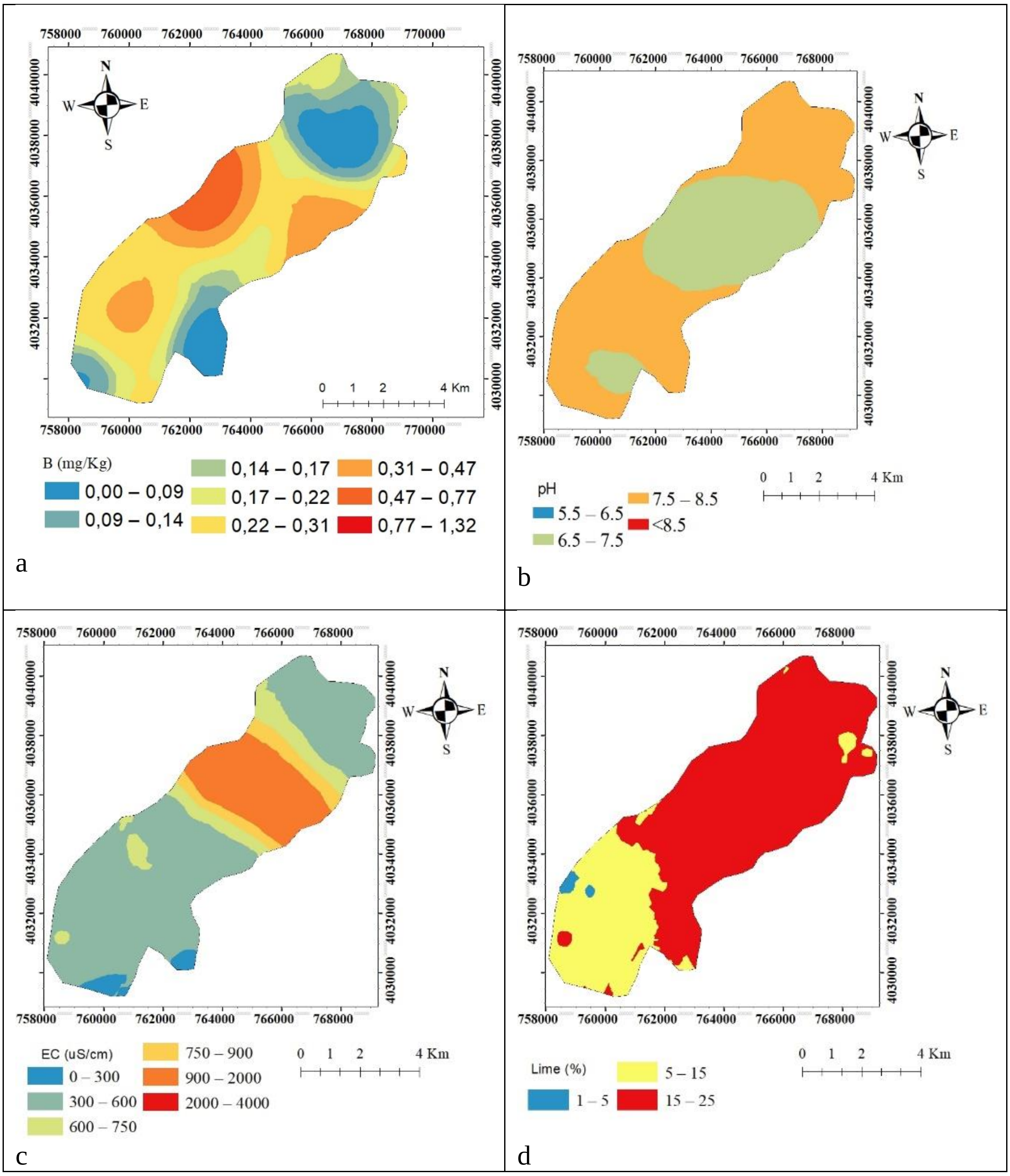

Figure 3. Distribution maps of soil properties in the study area

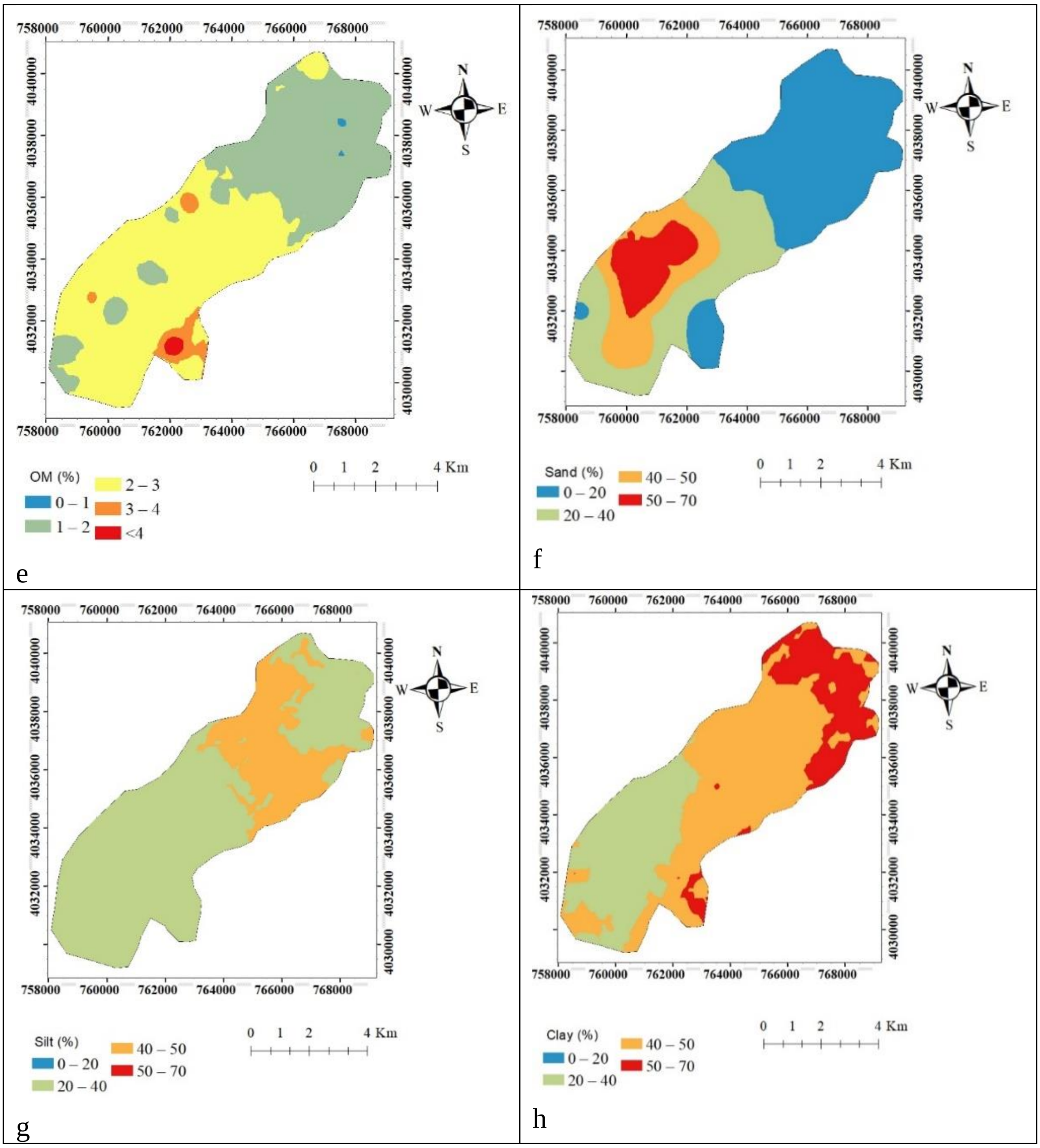

Figure 3. (Continued) Distribution maps of soil properties in the study area

The lime values are moderate in the southwestern part of the study area and high in other parts. The lime content of the soils increases from the southwest to the northeast of the area. The most common lime contents are 15-25 % (Figure 3d). The organic matter content is low in the northeastern part, moderate in the central, southern, and southwestern parts, and sufficient and high in a small area in the southern part. The most common organic matter contents vary between 2-3 % (Figure 3e).

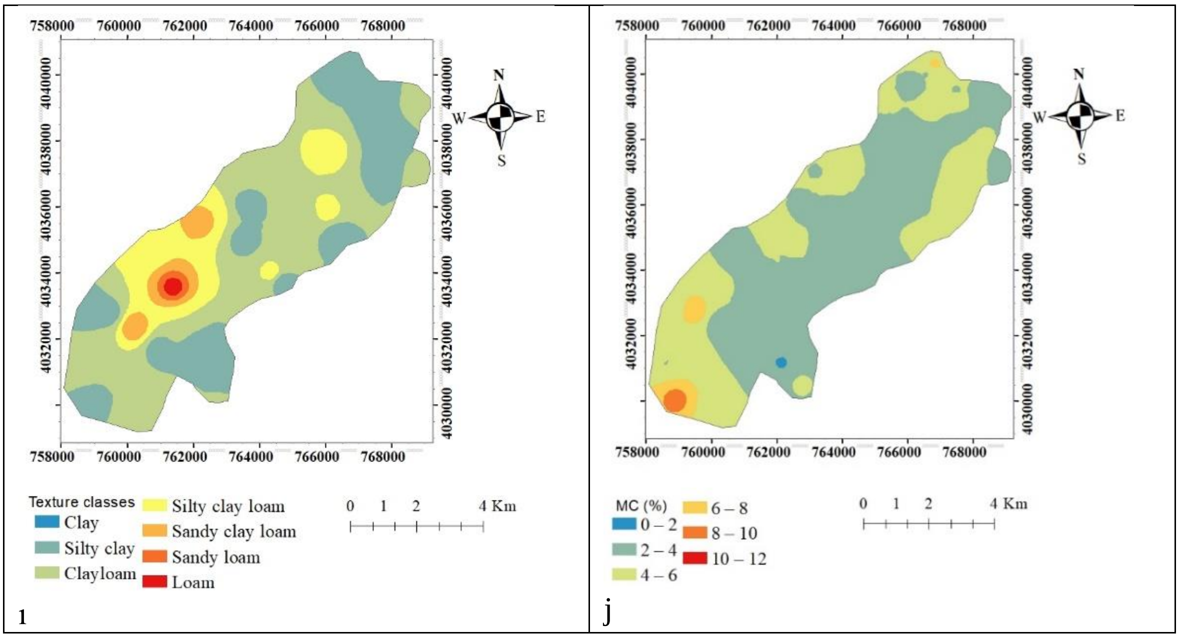

Figure 3. (Continued) Distribution maps of soil properties in the study area

Sand content in the study area is low in the northeastern parts and increases towards the south and southwest. The most encountered sand contents range between 0-20 % (Figure 3f). Silt contents are low in the central, southwestern, and northeastern parts and higher in a small area in the central part. The silt contents, seen as the most widespread, vary between 20-40 % (Figure 3g). The clay content of the soils is low in the southwestern part of the area and increases towards the northwestern direction. The texture of the soils has shown a very different distribution in the study area. The texture distribution does not have a regular change depending on the directions. However, generally, the sections in the northeast, middle, and southwest of the area are clay-textured. On the other hand, the soils with loam texture are more located in the middle parts of the area. The moisture content of the soils is higher in the middle sections than in the other sections (Figure 3j).

3.4. The relationship between boron content and soil properties

In order to determine the relationships between boron concentration and soil properties, a correlation analysis was performed between the parameters. The correlation analysis results determined negative relations between boron content and pH and a positive relation between EC (Table 4). However, these relationships were not found to be statistically significant. This is most likely because the boron contents of the soils were very low. Budak and Günal (2015) found statistically significant relationships between boron and lime, organic matter, pH, sand, and clay content in areas with high boron content. Again, Niaz et al. (2007) determined significant statistical relationships between B content and pH, organic matter, and lime.

Significant negative relations between EC and pH at the 0.01 level, negative relations between sand and lime at the 0.05 level; positive relations between silt and lime at the 0.01level, positive relations between sand at the 0.01 level; significant negative relations between moisture content and lime at the 0.05 level and silt at the 0.01 level were determined in soils. A positive relation between moisture content and clay content at the level of 5 % has been determined. This shows that as the clay content increases in soils, the moisture content also increases in air-dry conditions. Again, statistically significant negative relationships between clay and silt content and sand content at the level of 1 % have been determined.

Table 4. Correlation analysis results

	B	pH	EC	Lime	OM	Sand	Silt	Clay
pH	-0.236							
EC	0.273	**-0.569****						
Lime	0.004	-0.076	0.252					
OM	0.210	-0.173	-0.087	-0.174				
Sand	0.094	-0.153	-0.023	**-0.349***	-0.065			
Silt	0.071	0.263	0.095	**0.383****	0.001	**-0.550****		
Clay	-0.167	-0.022	-0.041	0.127	0.079	**-0.773****	-0.104	
MC	-0.050	0.045	-0.069	**-0.339***	-0.027	-0.045	**-0.379****	**0.343***

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

4. Conclusions

This study is of significant importance as it determines the B content and productivity-related characteristics of the Arsuz plain soils. Furthermore, distribution maps of these characteristics in the study area were meticulously created, providing a comprehensive understanding of the soil's properties.

It is crucial to note that the B content of the soils in the Arsuz plain is at a very low level, primarily due to the main material. As a result, the application of boron fertilizer is not just necessary, but a recommended practice to significantly enhance the yield and quality of the product in the work area.

The reaction of soils varies from slightly acidic to medium alkaline levels. The organic matter content is generally low, with no salinity problems. The lime content of the soils varied within wide limits. The soils are thin and medium-sized. There is no rough soil structure. Therefore, the nutrient and water retention capacities of these soils are suitable. However, air and water permeability problems may be encountered in clay-content soils. For this reason, organic fertilizer application should be made to increase the organic matter content of the soils and improve the air and water permeability in clay-content soils. In addition, since the lime content of the soils is high, acid-containing fertilizers such as urea and ammonium sulfate should be preferred when applying chemical fertilizers.

The maximum distances (A0) at which any soil properties can be related to each other have ranged from 200 m (in silt content) to 21080 m (sand). This shows that sampling intervals vary within vast limits according to soil properties.

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