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Research Article

Mapping the Local Distribution of Some Physico-chemical Properties of the Soils of the Meriç Delta Using Geographic Information Systems (GIS)

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Abstract: The aim of this study is to analyse the some physical and chemical properties of the soils of the Meriç Delta, which is located in northwestern Türkiye and has a high agricultural potential, and to investigate the relationship between these properties and plant nutrients. Due to its alluvial soil, the Meriç Delta is a fertile agricultural area and the soil properties of the region directly affect agricultural productivity. In the study, pH, organic matter, lime and essential nutrients were analysed in 89 soil samples taken from 30 different sites at a depth of 0-90 cm. Soil texture, organic matter content, electrical conductivity and nutrient spatial distribution were mapped using Geographic Information Systems and correlation tests were carried out. The data obtained show that there is a strong positive relationship between the percentage of clay and organic matter, and that the percentage of silt is positively correlated with electrical conductivity (EC). A significant relationship was found between soil pH and organic matter, with higher pH values increasing the amount of organic matter. The results showed that nutrients such as nitrogen, phosphorus and iron are better retained in areas with high organic matter. In addition, high levels of electrical conductivity were found to reduce the bioavailability of zinc. A negative relationship was found between potassium and sand percentage and it was observed that the potassium ratio decreased as the amount of sand increased. The results of the study provide important data for improving the soils of the Meriç Delta for sustainable agricultural practices. Increasing soil organic matter content, optimising pH levels and maintaining nutrient balance are recommended to sustainably increase agricultural productivity. This study provides a valuable resource for improving the agricultural potential of the region and developing appropriate soil management strategies for sustainable agricultural practices.

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1. Introduction

The Meriç Delta is located in northwestern Türkiye and has a great potential for agricultural production. This delta offers a favorable environment for agricultural activities thanks to its soil structure enriched by the alluvium of the Evros River. The soils of the Meriç Delta show a remarkable diversity in terms of both physical and chemical properties. This is a factor that directly affects agricultural productivity in the region (Koca et al., 2019; Altunbaş et al., 2020).

The Evros Delta, located in the Thrace region of Türkiye, is an ecologically important area characterized by diverse soil properties and agricultural potential. Understanding the spatial distribution of soil properties is crucial for effective land management and agricultural practices. Geographic Information Systems (GIS) have emerged as powerful tools for mapping and analyzing soil properties, allowing researchers to visualize spatial variability and make informed decisions regarding soil management and crop production (Bağdatlı, 2023; Namozov et al., 2023).

Soil properties such as pH, electrical conductivity, organic carbon content and nutrient availability exhibit significant spatial variability, influenced by numerous factors such as topography, land use and climatic conditions (Behera and Shukla, 2015; Tripathi et al., 2015). For example, studies have shown that soil acidity and nutrient levels can vary significantly even over small geographical areas, requiring precise mapping techniques to optimize agricultural practices and increase crop yields (Hufford et al., 2014; Behera and Shukla, 2015). Furthermore, the integration of GIS with geostatistical methods such as soil sampling and kriging allows for more accurate estimation of soil properties over larger areas, facilitating better resource management (Quan and Shen, 2012; Shit et al., 2016).

The application of GIS in soil mapping not only helps to identify areas of soil degradation, but also improves understanding of the interactions between soil properties and vegetation, which can inform restoration and conservation efforts (Hufford et al., 2014; Nkwunonwo et al., 2019). Furthermore, the use of remote sensing technologies in combination with GIS has proven to be effective in assessing soil health and monitoring changes over time, thus contributing to sustainable land use practices (Bağdatlı and Can, 2021; Bağdatlı, 2023). GIS and geostatistical applications have been shown to be highly effective in identifying spatial patterns of soil texture, organic matter and salinity, all of which strongly influence crop suitability and agricultural productivity (Şenyer et al., 2022; Dengiz et al., 2022). Studies conducted under varying land-use conditions also demonstrate that key physical and chemical soil properties, such as infiltration rate, organic matter and particle-size distribution, differ substantially across landscapes and directly shape nutrient behavior (Karahan and Yalım, 2022). In addition, multi-criteria evaluation approaches indicate that soil pH, texture and nutrient availability are among the most decisive parameters in determining land-use suitability and guiding sustainable management strategies (Şatır and Berberoğlu, 2021). Findings from different agro-ecological contexts thus highlight the importance of detailed spatial analysis when evaluating the complex soil environments of regions such as the Meriç Delta.

In the context of the Meriç Delta, the integration of GIS-based approaches for mapping soil properties is particularly important. The hydrological and geological characteristics of the delta, combined with anthropogenic influences, create a complex landscape where soil properties can vary greatly. Using GIS methodologies, researchers can develop detailed soil maps that reflect these variations and ultimately support agricultural productivity and environmental sustainability in the region (Namozov et al., 2023). Soils are one of the most critical natural resources that directly influence food security, ecosystem stability, and sustainable land management. In regions like the Meriç Delta, where agriculture forms the backbone of the local economy, understanding the spatial variability of soil properties is essential not only for enhancing productivity but also for ensuring long-term ecological balance. Previous studies have highlighted the role of soil characteristics in determining crop yield and land-use suitability; however, there is still a lack of detailed spatial assessments specifically focused on the Meriç Delta, which is a unique ecosystem shaped by both natural and anthropogenic factors. This study addresses this gap by hypothesizing that the integration of GIS techniques with soil analyses can provide a more accurate representation of the physico-chemical properties of soils in the Meriç Delta. Such an approach is expected to contribute to the development of sustainable agricultural practices while supporting conservation strategies in this ecologically sensitive region

In conclusion, the mapping of some physico-chemical soil properties in the Meriç Delta using GIS represents a critical step towards understanding and managing the agricultural potential of the region. The information obtained from such studies not only increases our knowledge of soil dynamics, but also provides a basis for the implementation of effective land management strategies in line with ecological sustainability goals.

2. Materials and Methods

The Meriç Delta is located in İpsala and Enez districts of Edirne province in the Marmara Region of northwestern Türkiye and is one of the most important wetland systems in Türkiye (Köse, 2015). The delta covers a total area of 111 937 km² and is of great geographical importance with its transboundary water resources and rich biodiversity (Eken et al., 2005). The delta is located at coordinates 40°47'20 "N 26°4'45 "E and is shown in Figure 1. Although it has a simple form in appearance, it exhibits a complex structure due to its morphological diversity and the ecosystems within it (Göçmen, 1976). The Evros River forms the Türkiye-Greece border according to the 1923 Treaty of Lausanne; the border line was determined by the middle line of the river and the immutability of this line was guaranteed by the 1926 protocol (Sağlam and Köşker, 2015). Most of the delta is within the borders of Greece. This delta was shaped by the combination of fresh water and alluvium brought by the Evros River with sea currents. The Evros River, which originates from the Rila Mountains, merges with the Tunca, Ergene and Arda rivers and forms a large flood plain north of Ipsala (Zal et al., 2006). This flood plain continues to expand with alluvium from the Meriç and its tributaries. The upper basin of the river is topographically high and the lower basin has a lower slope (Göçmen, 1976). With its hard-to-reach areas, mild climate and location on bird migration routes, the delta offers favorable conditions for a rich variety of plants and animals. The region provides an important feeding and breeding ground for many bird species such as flamingos, herons, dwarf swans, birds of prey and cormorants. Despite bans, poaching continues in the region (Kaya and Kurtonur, 2003). In the Meriç Delta, which is one of the most important areas of Thrace in terms of wetlands, Sığırcı and Gala Lakes constitute the main water resources (Tokatli, 2018). The Delta is classified as "A" among the wetlands of international importance (Tokatli and Islam, 2022). While there is an increase in water resources in the winter months, these resources decrease significantly in the summer months and some river tributaries dry up completely, reducing the water potential. Dams and ponds have been built to ensure this balance. The land use of the region has undergone major changes over time. While there were 24,000 hectares of wetlands south of Ipsala in the early 1900s, this area decreased to 9,500 hectares in the 1970s. Approximately 85% of the wetlands in the region have been destroyed due to paddy cultivation (Özhatay et al., 2005).

Soil samples taken at 0-30, 30-60 and 60-90 cm depths from the points determined in the research area were dried in the laboratory, pounded with a wooden mallet, sieved through a 2 mm sieve and prepared for analysis. Grain size distribution (texture) was determined by Bouyoucos (1951) method using hydrometer. Texture triangle was used for naming texture classes (Soil Survey Division Staff, 1993). Soil pH was measured in the prepared saturation sludge using a pH meter (Richards, 1954). Salt content was measured in the saturation sludge with Wheatstone Bridge condensivity device and calculated (Tüzüner, 1990). Lime content (%) was determined by volumetric calcimeter and organic matter content was analyzed by Modified Walkley-Black wet combustion method (Walkley, 1934). Nitrogen content in the soil was determined by calculating according to FAO (1990) method. Phosphorus

(P) content (ppm) was measured using the Olsen method and a spectrophotometer (Olsen, 1954; FAO 1990). Potassium, calcium, magnesium and sodium (ppm) contents were extracted with ammonium acetate and analyzed by ICP (FAO, 1990). Iron, copper, manganese and zinc contents (ppm) were analyzed by ICP on the solution obtained by DTPA extraction (Follet, 1969; Lindsay and Norvell, 1969; FAO, 1990). The classification of nitrogen, phosphorus, potassium, calcium, magnesium and sodium values was done according to FAO (1990) standards. Iron and copper contents in soils were classified according to Lindsay and Norvell (1969) criteria; zinc and manganese values were evaluated according to FAO (1990) classifications. Correlation analyses of the results of soil properties analysis were performed with IBM SPSS Statistics 27 software. In this study, the basic geographical information of the region and the data obtained from the analysis results were evaluated by creating a database in ArcGIS software and maps were prepared. The analysis values of the soil samples taken from the field according to a certain coordinate system were analyzed using the "Inverse Distance Weighting (IDW)" interpolation method, which is a deterministic approach, with a spatial resolution of 30 meters, and maps were created by interpolation methods using ArcGIS Pro and statistics were calculated with SPSS 27. The map of the study area and sample points are given in Figure 1.

Figure 1. Map of the study area and sample points.

3. Results

It was determined that 49 of the 89 samples taken from 30 points in the Meriç Delta belonged to clay soil, 10 to clay loam, 7 to sandy clay, 7 to sandy clay, 7 to sandy clay clay loam, 4 to silty clay, 4 to silty clay loam, 3 to sand, 3 to sandy loam, 2 to loamy soil texture classes.

The average clay content of the Meriç Delta soils at 0-30 cm depth is 44.07%, the lowest value is 1 and the highest value is 70. Silt content varied between 21.77% and 48%, while sand content varied between 6% and 95%. The pH values in this layer varied between 5.26 and 8.70, while the organic matter content ranged between 0.43% and 5.73%, reaching quite high levels especially at some points. Electrical conductivity (EC) values vary between 0.14 and 17.30 dS/m, while lime content varies between 0.04% and 13.31%. In terms of nutrients, nitrogen content varied between 0.02% and 0.29%, while phosphorus (P) was measured between 1-73 mg kg^{-1}, potassium (K) 45.79- 1793.13 mg kg^{-1}, calcium (Ca) 74.21-11616.14 mg kg^{-1}, magnesium (Mg) 53.89-1774.42 mg kg^{-1}and sodium (Na) 22.67-8923.55 mg kg^{-1}. In terms of microelements, iron (Fe) content ranged between 17.67-220.62 mg kg^{-1}, copper (Cu) 0.29-20.80 mg kg^{-1}, manganese (Mn) 5.36-218.39 mg kg^{-1} and zinc (Zn) 0.22-13.05 mg kg^{-1}.

When the soil properties at 30-60 cm depth were analyzed, the clay content varied between 2% and 80% and the average was calculated as 44.03%. Silt content ranged between 22.57% and sand content between 6% and 93%. pH values ranged between 5.96% and 8.71% and organic matter content between 0.33% and 4.17%. Electrical conductivity values varied between 0.11 and 24.10 dS m^{-1}, while lime content was between 0.04% and 13.04%. Nitrogen (N) content varied between 0.02% and 0.21%, while phosphorus (P) ranged between 1-65 mg kg^{-1}, potassium (K) 39.13-1892.97 mg kg^{-1}, calcium (Ca) 57.44-10638 mg kg^{-1}, magnesium (Mg) 29.63-1683.57 mg kg^{-1}and sodium (Na) 50.09-10881.32 mg kg^{-1}. Among the micro elements, iron (Fe) was measured between 9.84-230.33 mg kg^{-1}, copper (Cu) 0.16-11.89 mg kg^{-1}, manganese (Mn) 4.50-161.05 mg kg^{-1} and zinc (Zn) 0.14-6.97 mg kg^{-1}.

At a depth of 60-90 cm, the clay content was 45.69%, with a minimum value of 1 and a maximum value of 73. Silt content is 22.62% and sand content varies between 5% and 99%. pH values vary between 6.19 and 8.66 and organic matter content is at lower levels between 0.15% and 3.08%. Electrical conductivity varied between 0.16 and 26.90 dS m^{-1}, while lime content was determined between 0.04% and 14.03%. Nitrogen (N) content varied between 0.01% and 0.15%, while phosphorus (P) content was 1-41 mg kg^{-1}, potassium (K) 30.11-1416.99 mg kg^{-1}, calcium (Ca) 49.41- 8859.09 mg kg^{-1}, magnesium (Mg) 28.89-1727.64 mg $kg^{-1}$and sodium (Na) 74.79-10394.89 mg kg^{-1}. Among the micro elements, iron (Fe) ranged between 4.94-169.62 mg kg^{-1}, copper (Cu) 0.15-9.45 mg kg^{-1}, manganese (Mn) 2.98-183.32 mg kg^{-1} and zinc (Zn) 0.19-4.15 mg kg^{-1}.

According to these data, while the amount of organic matter decreased from the surface to the bottom, a slight increase in pH values was observed. In addition, it was determined that nutrients such as nitrogen and phosphorus were more abundant in the upper layers, whereas sodium and lime ratios reached higher values in the lower layers. Statistical data of the study are given in Table 1.

Table 1. 0-30 cm statistical results of the analyses of the research area

	%Clay	%Silt	%Sand	EC	pH	%Lime	%Org. Mat.
Average	44.07	21.77	34.10	2.4093	7.6293	2.4010	2.3633
Mean standard error	2.927	1.815	3.700	.54902	.13889	.60394	.26145
Standard deviation	16.032	9.940	20.266	3.00712	.76074	3.30792	1.43204
Variance	257.030	98.806	410.714	9.043	.579	10.942	2.051
Distance	69	44	89	17.16	3.44	13.27	5.30
Minimum	1	4	6	.14	5.26	.04	.43
Maximum	70	48	95	17.30	8.70	13.31	5.73

	N - mg kg^{-1}	P - mg kg^{-1}	K - mg kg^{-1}	Ca - mg kg^{-1}	Mg - mg kg^{-1}	Na - mg kg^{-1}
Average	.1183	27.03	435.9807	5671.8327	722.6500	934.6973
Mean standard error	.01312	3.310	55.03235	445.94791	72.31635	287.19598
Standard deviation	.07188	18.129	301.42461	2442.55729	396.09297	1573.03715
Variance	.005	328.654	90856.795	5966086.098	156889.641	2474445.888
Distance	.27	72	1747.34	11541.93	1720.53	8900.88
Minimum	02	1	45.79	74.21	53.89	22.67
Maximum	.29	73	1793.13	11616.14	1774.42	8923.55

	Fe - mg kg^{-1}	Cu - mg kg^{-1}	Mn - mg kg^{-1}	Zn - mg kg^{-1}
Average	76.3480	4.8713	90.5110	2.7923
Mean standard error	9.95174	.77936	10.17456	.49760
Standard deviation	54.50791	4.26874	55.72834	2.72546
Variance	2971.112	18.222	3105.648	7.428
Distance	202.95	20.51	213.03	12.83
Minimum	17.67	.29	5.36	.22
Maximum	220.62	20.80	218.39	13.05

Table 2. 30-60 cm statistical results of the analyses of the research area

	%Clay	%Silt	%Sand	EC	pH	%Lime	%Org. Mat.
Average	44.03	22.57	33.33	2.8443	7.6543	2.0790	1.7833
Mean standard error	3.107	2.142	3.717	.76502	.11623	.55018	.20652
Standard deviation	17.016	11.732	20.361	4.19019	.63662	3.01344	1.13118
Variance	289.551	137.633	414.575	17.558	.405	9.081	1.280
Distance	75	48	87	23.99	2.75	13.00	3.84
Minimum	5	2	6	.11	5.96	.04	.33
Maximum	80	50	93	24.10	8.71	13.04	4.17

	N - mg kg^{-1}	P - mg kg^{-1}	K - mg kg^{-1}	Ca - mg kg^{-1}	Mg - mg kg^{-1}	Na - mg kg^{-1}
Average	.0900	21.17	449.6640	5186.0257	794.5127	1124.6377
Mean standard error	.01029	2.747	59.77563	395.74878	79.39410	348.36516
Standard deviation	.05639	15.045	327.40460	2167.60532	434.85938	1908.07459
Variance	.003	226.351	107193.770	4698512.805	189102.684	3640748.625
Distance	.19	64	1853.84	10580.56	1653.94	10831.23
Minimum	.02	1	39.13	57.44	29.63	50.09
Maximum	.21	65	1892.97	10638.00	1683.57	10881.32

	Fe - mg kg^{-1}	Cu - mg kg^{-1}	Mn - mg kg^{-1}	Zn - mg kg^{-1}
Average	88.3920	4.3413	81.0413	2.2877
Mean standard error	10.96331	.55671	8.63038	.27490
Standard deviation	60.04853	3.04920	47.27054	1.50571
Variance	3605.826	9.298	2234.504	2.267
Distance	220.49	11.73	156.55	6.83
Minimum	9.84	.16	4.50	.14
Maximum	230.33	11.89	161.05	6.97

Table 3. 60-90 cm statistical results of the analyses of the research area

	%Clay	%Silt	%Sand	EC	pH	%Lime	%Org. Mat.
Average	45.69	22.62	31.79	3.0255	7.9590	2.3979	1.2221
Mean standard error	3.248	2.355	3.952	.88509	.10091	.54296	.15103
Standard deviation	17.491	12.681	21.284	4.76635	.54343	2.92395	.81334
Variance	305.936	160.815	453.027	22.718	.295	8.549	.662
Distance	72	50	94	26.74	2.47	13.99	2.93
Minimum	1	0	5	.16	6.19	.04	.15
Maximum	73	50	99	26.90	8.66	14.03	3.08

	N - mg kg^{-1}	P - mg kg^{-1}	K - mg kg^{-1}	Ca - mg kg^{-1}	Mg - mg kg^{-1}	Na - mg kg^{-1}
Average	.0614	17.90	449.8472	5243.4141	795.5938	1271.8314
Mean standard error	.00742	2.458	59.32014	388.31736	71.29568	341.52339
Standard deviation	.03998	13.238	319.44873	2091.15296	383.93901	1839.15974
Variance	.002	175.239	102047.490	4372920.689	147409.163	3382508.558
Distance	.14	40	1386.88	8809.68	1698.75	10320.10
Minimum	.01	1	30.11	49.41	28.89	74.79
Maximum	.15	41	1416.99	8859.09	1727.64	10394.89

	Fe - mg kg^{-1}	Cu - mg kg^{-1}	Mn - mg kg^{-1}	Zn - mg kg^{-1}
Average	63.1007	3.5779	67.4314	1.4583
Mean standard error	7.69233	.45303	8.89504	.19122
Standard deviation	41.42446	2.43964	47.90127	1.02976
Variance	1715.986	5.952	2294.532	1.060
Distance	164.68	9.30	180.34	3.96
Minimum	4.94	.15	2.98	.19
Maximum	169.62	9.45	183.32	4.15

Table 4. 0-30 cm correlation results

	EC	pH	% Lime	% Org. Mat.	N mg kg^{-1}	P mg kg^{-1}	K mg kg^{-1}	Ca mg kg^{-1}	Mg mg kg^{-1}	Na mg kg^{-1}	Fe mg kg^{-1}	Cu mg kg^{-1}	Mn mg kg^{-1}	Zn mg kg^{-1}	% Clay	% Silt	% Sand
EC	1	0.233	.447*	.504**	.501**	.603**	.912**	0.24	.459*	.982**	0.046	.428*	.404*	0.326	0.288	.386*	-.426*
pH	0.233	1	.404*	-0.175	-0.18	0.199	0.29	.623**	0.213	0.199	-0.018	0.331	0.013	0.128	.441*	0.216	-.464**
% Lime	.447*	.404*	1	0.175	0.185	0.218	0.288	.516**	0.187	.388*	-0.117	0.059	0.225	0.03	0.261	0.193	-0.305
% Org. Mat.	.504**	-0.175	0.175	1	.999**	.460*	.508**	0.094	0.307	.463*	.376*	.511**	.751**	.582**	0.222	0.282	-0.314
N	.501**	-0.18	0.185	.999**	1	.454*	.500**	0.091	0.295	.460*	.372*	.505**	.751**	.575**	0.217	0.286	-0.311
P	.603**	0.199	0.218	.460*	.454*	1	.596**	0.147	0.333	.554**	.381*	.657**	.586**	.564**	0.261	.509**	-.465**
K	.912**	0.29	0.288	.508**	.500**	.596**	1	0.274	.594**	.905**	0.188	.520**	.432*	0.34	.414*	0.359	-.514**
Ca	0.24	.623**	.516**	0.094	0.091	0.147	0.274	1	.426*	0.146	-0.005	0.262	0.181	0.093	.754**	0.211	-.707**
Mg	.459*	0.213	0.187	0.307	0.295	0.333	.594**	.426*	1	.417*	0.125	0.322	0.242	0.043	.726**	0.243	-.705**

The physical properties of the digital maps of the soil samples made according to the IDV method are given in Figure 2 and macro elements are given in Figure 3.

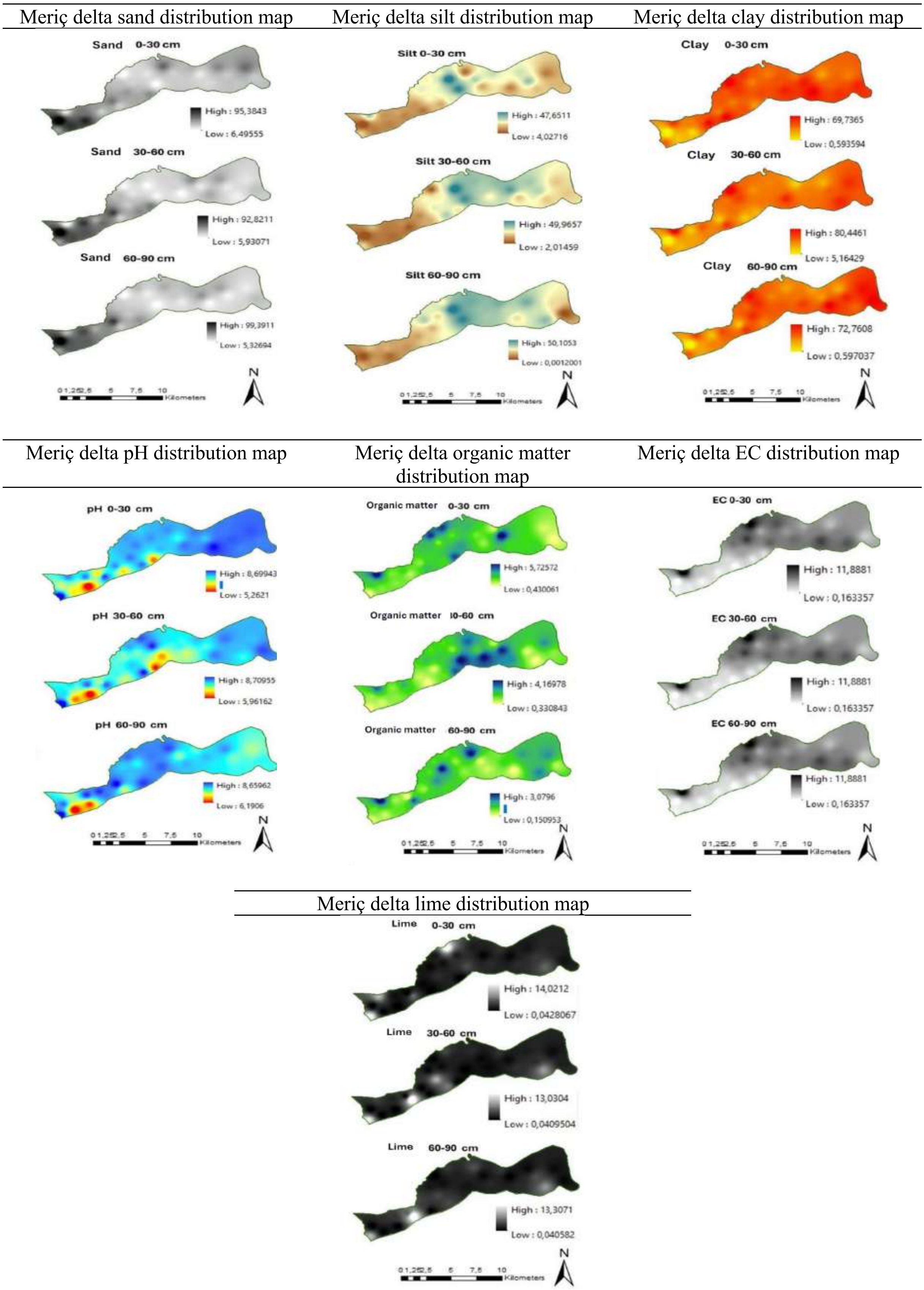

Figure 2. Soil physical properties maps.

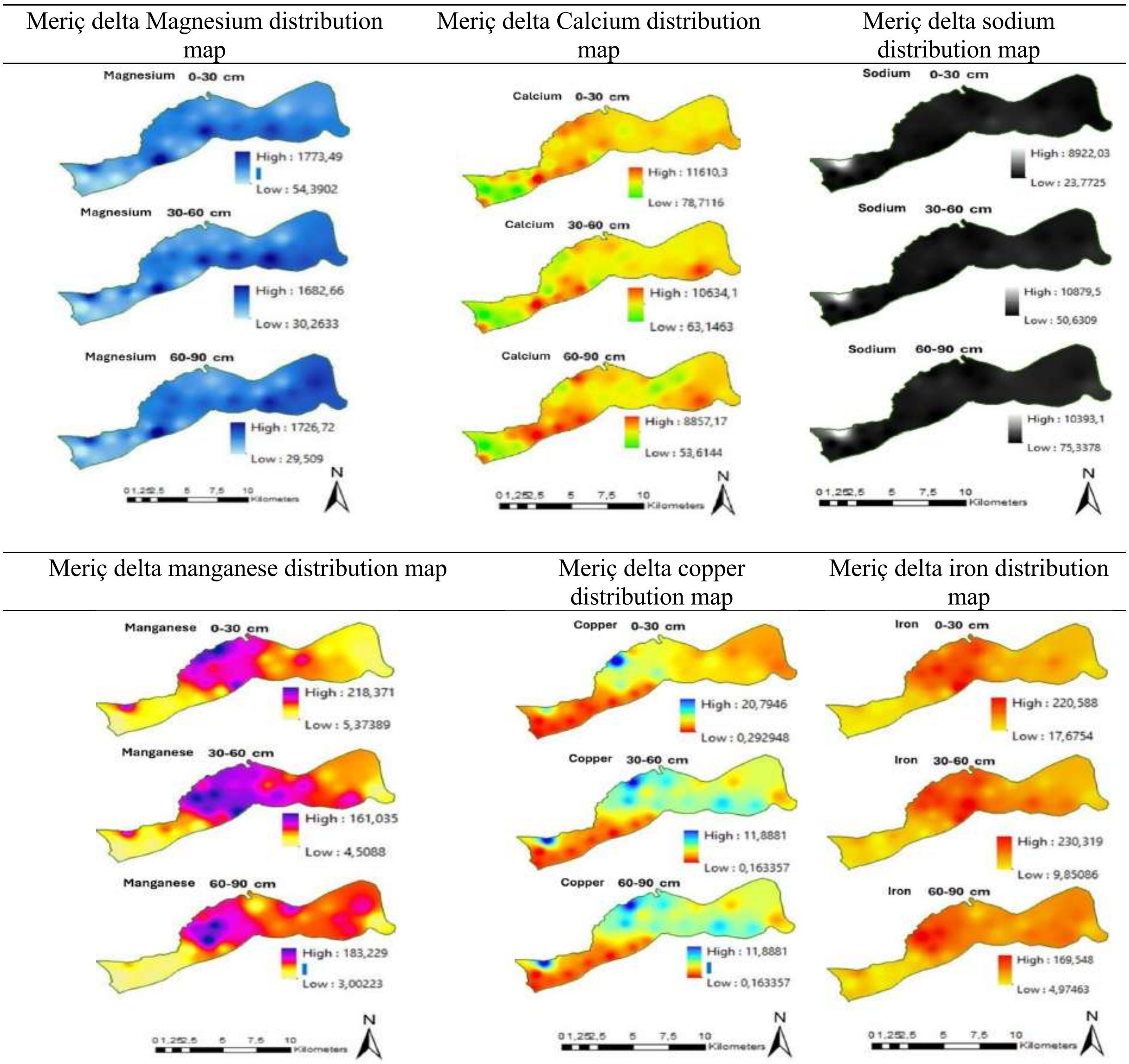

Figure 3. Micro and microelements.

4. Discussion

The relationships between soil components and nutrients are critical factors affecting soil chemical structure and agricultural productivity. The findings of this study show that there is a strong positive correlation (0.982**) between electrical conductivity (EC) and sodium (Na). This result is in agreement with previous studies that increased salinity is closely related to sodium accumulation (Richards, 1954; Rengasamy, 2010). High sodium content can adversely affect water holding capacity and plant root growth by causing decomposition of clay minerals and disruption of soil structure (Qadir and Schubert, 2002).

Furthermore, the relationships between EC and potassium (0.912**) and phosphorus (0.603**) indicate that high concentrations of these nutrients contribute to soil salinity. It has also been reported in the literature that soils with high potassium and phosphorus content are generally over-fertilized, which increases the risk of salinity (Cheng et al., 2014).

The positive correlation between pH and lime content (0.404*) supports that lime lowers soil acidity and raises the pH level. Lime applications are widely used to neutralize acidic soils and improve plant access to nutrients, as reported in previous studies (Fageria and Baligar, 2008). However, the negative relationship between pH increase and organic matter (-0.175) suggests that some organic compounds decompose under high pH conditions. This suggests that loss of organic matter may negatively affect soil fertility in the long term (Sollins et al., 1996).

The high correlation between nitrogen (N) and potassium (K) (0.500**) and the positive correlation between nitrogen and iron (Fe) (0.376*) suggest that nitrogen fertilization also contributes to the mineralization and plant uptake of other nutrients. Similar results have been reported in previous studies that nitrogen fertilization contributes to making elements such as potassium and iron more available to plants (Mengel and Kirkby, 2012).

The high correlations between clay content and lime (0.441*) with calcium (Ca), magnesium (Mg), iron (Fe) and zinc (Zn) (0.754**, 0.726**, 0.514**, 0.412*, respectively) indicate that clay has a high capacity to retain nutrients in soil. High clay content alters the availability of these elements to plants by increasing the cation exchange capacity (CEC) (Brady et al., 2008).

The positive correlations (0.458* and 0.499**) between silt content and copper (Cu) and zinc (Zn) indicate that the higher the silt content, the more microelements are concentrated in the soil. It is known that the nutrient retention capacity of the silt fraction is higher than that of the sand fraction (Sparrow et al., 2006; Cheng et al., 2016). However, the negative correlations between sand content and many nutrients (-0.342, -0.514**, -0.265) support the low nutrient retention capacity of sand and the higher risk of nutrients being washed away (White, 2006).

These findings suggest that interactions between soil components and nutrients play a critical role in agricultural productivity and need to be carefully managed through fertilization strategies. Further research could contribute to the development of more sustainable soil management strategies by revealing how these relationships vary across different soil types and climatic conditions.

Soil fertility and its impact on sustainable agriculture: This study shows that correlations between soil properties and nutrients provide important guidance for soil fertility and sustainable agriculture. Strong relationships between electrical conductivity (EC) and nutrients such as sodium (Na), potassium (K) and phosphorus (P) reveal that EC increases with increasing nutrients in the soil. This is considered as a limiting factor for plant growth, especially in agricultural areas with increased salinity levels (Rengasamy, 2010). High EC values can increase osmotic pressure, making it difficult for plants to take up water, and create an ion imbalance, negatively affecting nutrient uptake (Munns and Tester, 2008). Therefore, excessive accumulation of ions such as sodium is a serious risk factor for sustainable agriculture and should be controlled, especially through appropriate irrigation methods (Qadir et al., 2004).

Furthermore, high positive correlations between organic matter content and nutrients such as calcium (Ca), potassium (K) and zinc (Zn) indicate the direct effect of organic matter on soil fertility. Organic matter improves soil structure, increases water holding capacity and promotes microbial activity (Lal, 2004). For example, a study by Lal (2006) showed that organic fertilizers improve soil nutrient content and increase yields in sustainable agricultural practices. However, it was stated that if the amount of organic matter is high, nitrogen levels may decrease and nitrogen losses may increase, especially with low pH levels (Brady et al., 2008). Therefore, it is important to apply a balanced nitrogen fertilization strategy when managing organic matter.

The relationship between clay and silt content and nutrients also plays a critical role in soil fertility. Clay adsorbs nutrients, increasing their retention capacity in the soil and allowing them to be utilized by plants for longer periods of time, especially elements such as zinc (Zn) and calcium (Ca) (Sparks, 2003). Similarly, silty soils have been reported to increase water holding capacity and allow nutrients to be utilized more efficiently by plants (Rawls et al., 2003). Therefore, balanced clay and silt ratios are of great importance in maintaining soil fertility in sustainable agricultural practices.

On the other hand, soils with high sand content are known to have low nutrient retention capacity, which can negatively affect agricultural productivity (Brady et al., 2008). Especially in sandy soils, the rapid washing away of nutrients by rainfall or irrigation can reduce soil fertility (Lehmann and Kleber, 2015). Therefore, increasing the amount of organic matter and regular fertilization in the management of sandy soils is recommended as an approach that supports soil health and sustainable agriculture. The percentage of silt is positively correlated with electrical conductivity (EC). This observed increase in electrical conductivity (EC) with a higher silt fraction can be attributed to the physical properties of silt particles. Unlike clay particles, silt particles are larger and have a lower specific surface area, resulting in a relatively low cation exchange capacity (CEC). However, the primary contribution of silt is its role in regulating soil porosity and water retention. Silty soils form finer pores than sandy soils, though not as fine as clayey soils. These finer pores create continuous networks where capillarity is effective. This structure facilitates the transport and accumulation of salts (via capillary rise) near the surface, leading to increased EC values. Consequently, in soils with high silt content, leaching of salts is more difficult, which can result in surface salt accumulation and, ultimately, higher EC readings (Hillel, 2004).

These correlations provide important information for the development of soil management and sustainable agriculture strategies. Proper management of soils, especially considering factors such as organic matter content, pH, EC and sand content, is critical to ensure sustainability of productivity. Studies in the literature reveal that soil physicochemical properties should be carefully analyzed and productivity can be increased by developing appropriate agricultural practices (Marschner, 2012).

Conclusion

In order to make the soils of the Meriç Delta suitable for sustainable agricultural practices, there is a need for improvement works such as increasing organic matter levels, maintaining the balance of nutrients and bringing the soil pH to the optimum range. Increasing the organic matter content, especially in areas with high clay content, will strengthen the soil structure and support plant nutrient uptake. Also, since bioavailability of micronutrients such as zinc may decrease in areas with high soil electrical conductivity (EC), stabilization is recommended in these areas. With appropriate fertilization and pH regulation strategies, a soil structure that supports plant root growth, increases water holding capacity and provides a suitable environment for microorganisms should be targeted. Correlations obtained from soil analyses indicate high productivity potential in the Meriç Delta. Maintaining the balance of essential elements such as calcium, magnesium, nitrogen and phosphorus will directly increase soil fertility. By balancing clay, silt and sand ratios, a soil structure with high water retention capacity and low nutrient loss can be achieved. Adjusting soil pH and keeping electrical conductivity values under control will provide ideal conditions for agricultural productivity and plant health. In line with these analyses, soil management strategies can be planned specifically for the region to ensure sustainable productivity. Some significant challenges were encountered during this study. During the field work, the homogeneous collection of soil samples from specified depths was difficult due to some logistical obstacles. In addition, the wide geographical spread of the study area created some limitations in terms of time and cost. More detailed analyses were needed to increase the sensitivity of the determination of some nutrients during laboratory analyses. In spatial analysis using GIS, interpolation methods are based on modeling the data within certain assumptions. Therefore, in some areas, estimates may differ from the actual values. This study also has some limitations. For example, increasing the number of sampling points and examining seasonal changes would be useful to understand how soil properties change over time. In addition, a detailed examination of the relationship between plant productivity and soil nutrient content would increase the applicability of the study. In order to conduct similar studies on a wider scale, it is recommended to implement long-term monitoring programs covering multiple soil parameters. In addition, examining soil nutrient dynamics with different crops may contribute to agricultural planning. In order to increase the sensitivity of GIS-based analyses, the use of new generation remote sensing techniques, especially supported by spectral analysis, will enable more detailed determination of soil properties. In conclusion, this study has been an important step in understanding the characteristics of the soils of the Meriç Delta and improving agricultural processes. However, long-term studies with a wider scope, including seasonal variability, will make a greater contribution to the development of soil management strategies.

Ethical Statement

This study did not involve any human participants or animals. Therefore, ethical approval was not required. All data were collected and analyzed in accordance with academic and research ethics principles.

Conflict of Interest

The author declares that there is no conflict of interest regarding the publication of this paper.

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Author Contributions

The authors jointly designed the study, collected and analyzed the data, interpreted the results, and wrote the manuscript. All authors read and approved the final version of the paper.

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