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Spatial Variability of Soil Macronutrients in Different Land Uses

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Research Article

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Abstract

In this study, the effects of different land use on certain soil properties were investigated. The study was carried out in forest, hazelnut, and tea cultivation areas in Giresun province. Soil samples were collected from these areas and the soil properties of the sites were investigated through chemical analysis. Distribution maps were generated from these data with the aid of GIS using the IDW method.

The pH, electrical conductivity (EC), total nitrogen (TN), and available phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) contents of the soils in the study area were determined. In the study, the soil pH was found to range between 4.56 and 7.26, generally indicating the slightly acidic class. Soil pH was found to be low in tea plantations, while higher values were determined in hazelnut orchards. There is no salinity problem in the study area. The maps generated as a result of the analyses indicated that the total N content was low in hazelnut orchards, while it was high in tea plantations. The amount of available P was generally found to be at insufficient levels in the study area. Available K was found to be low in hazelnut orchards and at adequate levels in tea plantations. Available Ca and Mg were found to be at adequate and high levels in hazelnut orchards, whereas in tea plantations, available Mg was determined to be at an adequate level and available Ca at an insufficient level.

The generated maps revealed that plant nutrient element levels varied depending on the land use type. This study has demonstrated that distribution maps prepared for areas with different land use types will facilitate site specific fertilization management.

Introduction

Soil is a natural resource containing various nutrient elements. Soil-forming factors lead to the formation of different soil types. The effects of climate, one of the active factors in soil formation, play a significant role in soils acquiring distinct characteristics. Under the same climatic conditions, variations in topography result in differences in soils. The differing properties of soils also cause nutrient elements to be present in varying amounts.

The elements required for plants to complete their development are termed plant nutrient elements. Plants require nutrients in varying quantities. Elements required by plants in large quantities are referred to as macro elements. These elements, taken up from the soil by plants, are nitrogen, phosphorus, potassium, calcium, and magnesium. (Campbell and Plank, 2000). For plants to achieve optimal growth, nutrient elements must be available for uptake from the soil. The uptake of nutrient elements from the soil by plants also varies depending on their availability in the soil. Plant species, growth stage, and soil properties are highly influential in the uptake of plant nutrient elements (Kacar and Katkat, 2018; Jones et al., 2011). Soil pH is one of the soil properties that most significantly affects the availability of nutrient elements in the soil.

Due to the dynamic nature of soil, soil properties undergo changes over very short distances. This situation may lead to nutrient elements being present in varying amounts in soils due to the influence of

spatial variability in the field. Even if the same fertilization practices are applied in agricultural areas, variations may occur in these areas due to soil properties. Therefore, the best way to determine these differences is to generate of spatial distribution maps.

GIS is utilized in the spatial determination of plant nutrient elements levels. It is possible to spatially determine the fertility status of soils using GIS. Utilizing distribution maps prepared with GIS for the site specific management of plant nutrient elements facilitates many applications, particularly fertilization practices. Many researchers have used GIS in the mapping of soil properties (Özyazıcı et al., 2017; Lahbib et al., 2023; Laribi et al., 2024).

In areas with uniform distribution and low soil variability, each of the geostatistical methods can provide appropriate results. However, in areas that do not exhibit a uniform distribution and where variability increases over short distances, the IDW method one of the geostatistical methods can yield better results. Therefore, the IDW method may be preferred for mapping the variable properties of soil and in studies conducted in areas where the variability of soil forming factors is high.

The IDW method is widely used in determining the spatial distribution of soil properties. Researchers (Pusch et. Al., 2022; Saraswat et al., 2023; Hashemi et al., 2025) used this method in their studies on soil properties.

The status of soil nutrient elements in different lands and their mapping are highly important for site-specific fertilization management aimed at increasing productivity for sustainable agriculture. Hazelnuts and tea are widely cultivated in the Black Sea region. Studies conducted on mapping the soil properties of hazelnut and tea cultivation areas in the region are limited in number. Therefore, this study was carried out to determine the status of soil macronutrient elements in hazelnut, tea, and forest lands according to different land use types and to generate distribution maps.

Material and Method

3.1. Study area

The study area is located in the Eynesil district of Giresun province in the Eastern Black Sea Region, between 510664–512209 m east longitudes and 4539249–4540853 m north latitudes (WGS-84, Universal Transverse Mercator Zone 37) (Fig. 1).

The forest, tea, and hazelnut lands are adjacent in the study area. The elevation of the study area varies between 300 m and 650 m. Hazelnut and tea are cultivated in the region.

The study area is located in the Eastern Black Sea region. It has a temperate Black Sea climate with generally abundant precipitation. According to meteorological data for the 1950–2018 period, the annual mean temperature in the study area is 14.6 ^{0}C, and the annual average total precipitation is 1275.9 mm.

Soil sampling and analysis

The total study area covers 233 hectares (66 hectares of forest, 65 hectares of tea, and 102 hectares of hazelnut). A total of 60 soil samples were collected in the study, with 20 samples each from forest, tea, and hazelnut lands. Soil samples were collected from a depth of 0–20 cm using the random sampling method. During soil sampling, the points were marked with a GPS device and coordinates were recorded. The soil samples were air dried, passed through a 2 mm sieve, and prepared for analysis.

Soil reaction (pH) was determined in a 1:2.5 (w/v) soil: water mixture using a glass-electrode pH meter, and electrical conductivity (EC) was determined in the same solution using an EC meter (Richard, 1954). Total soil nitrogen (N) was determined according to the Kjeldahl method (Bremner, 1965). Available soil phosphorus (P) was extracted according to the molybdophosphoric blue color method reported by Bray and Kurtz (1945) and determined spectrophotometrically (Kacar, 2009). Exchangeable calcium (Ca), magnesium (Mg), and potassium (K) were extracted with a 1N ammonium acetate solution and determined by AAS (Jackson, 1958).

Classification of soil samples

The classification values for the chemical properties of the soil samples are presented in Table 1. Maps of soil properties were prepared according to the threshold values provided in Table 1.

Table 1
Classification of soil parameters

Soil properties	Interpretation Class						Literature
	Very Low	Low	Optimum	High	Very High		
N %	< 0.045	0.045–0.090	0.090–0.170	0.170-0,320	> 0.320		Sillanpää, 1990
P, mg kg-¹	< 2.5	2.5-8.0	8.0–25	25–80	> 80		Sillanpää, 1990
K, mg kg-¹	< 50	50–110	110–290	290–1000	> 1000		Sillanpää, 1990
Ca, mg kg-¹	< 238	238–1150	1150–3500	3500–10000	> 10000		Sillanpää, 1990
Mg, mg kg-¹	< 50	50–160	160–480	480–1500	> 1500		Sillanpää, 1990
EC ds m-¹	Non saline	Slightly saline	Moderately saline	Strongly saline			Maas, 1986
	0–4	4–8	8–15	> 15			
pH	Strongly Acidic	Moderately Acidic	Slightly Acidic	Neutral	Slightly Alkaline	Strongly Alkaline	Richard 1954
	< 4.5	4.5–5.5	5.5–6.5	6.5–7.5	7.5–8.5	> 8.5	

Spatial distrubution of the macronutrient

Spatial distribution maps of soil nutrients were generated using ArcGIS 10.5 software in the study. The inverse distance weighting (IDW) interpolation method was applied in the preparation of these maps.

IDW is a method that calculates values for unknown points in inverse proportion to their distance from points with known locations and values. The closer a point is to the location being estimated, the greater its influence, and the farther it is the less its influence. There is an inverse relationship between distance and the calculated value. IDW calculates the points to be estimated by utilizing existing values. The accuracy of the estimated values is directly influenced by the number of samples and the distance between them. In this method, as the number of samples with known values increases and the distance between samples decreases, the estimated values approach the actual values.

IDW uses the weighted average of observed data at nearby sites to estimate values at unsampled points (Mihalikova et al., 2015).

IDW is based on that nearby points have a greater impact on a point's unknown value than do distant points. Equation can be used to calculate the weight: (1)

$$\hat{v} = \frac{\sum_{i=1}^{n} \frac{1}{d_i} v_i}{\sum_{i=1}^{n} \frac{1}{d_i}}$$

where d_i are the distances from each of the n sample locations to the point being estimated and V*i* are the sample values (Isaaks and Srivastava, 1989)

Results and Discussion

Descriptive statistics of soil fertility parameters

Descriptive statistics for the pH, EC, total N, and available P, K, Ca, and Mg values of the study area soils including the minimum, maximum, mean, standard deviation, coefficient of variation (CV), skewness, and kurtosis are presented in Table 2.

The study results showed that the soil pH in the study area ranged from 4.56 to 7.26, with a slightly acidic mean value of 5.85. The EC was found to range from 22.3 to 292.5 µS m^{-1}, with an average of 54.67 µS m^{-1}. In the study, the total N content ranged from 0.01% to 0.55% with a mean of 0.17%, and the available P content varied between 0.09 and 51.57 mg kg^{-1} with a mean of 3.45 mg kg^{-1}; the available K content ranged from 17.30 to 760.6 mg $kg^{-}1$ with a mean of 108.1 mg kg^{-1}, the available Ca content varied between 2.0 and 6258 mg $kg^{-1}$with a mean of 2915 mg kg^{-1}, and the available Mg ranged from 139.0 to 1772 mg kg^{-1} with a mean of 964.7 mg kg^{-1} was found.

When the coefficient of variation (CV) used to determine the variability of soil properties was examined, the highest CV in the study area was found for available P (203%), while the lowest CV was found for pH (12.4%). Researchers (Mulla and McBratney, 2002; Olorunfemi et al., 2018; Olubanjo and Ayoola, 2020) have stated that the coefficient of variation (CV) is an important indicator for expressing the variability of the physical and chemical properties of soils and that this parameter should be taken into consideration. CV value of less than 15% indicates low variability, between 15% and 35% indicates moderate variability, and greater than 35% indicates high variability (Wilding et al, 1994). In the study, low variability was detected only for pH, while high variability was detected for all other parameters.

Table 2
Descriptive statistics of soil fertility parameters

Variable	Mean	StDev	CV	Min	Max	Skewness	Kurtosis
pH	5.85	0.73	12.40	4.56	7.26	-0.24	-1.09
EC	54.67	39.39	72.05	22.3	292.5	4.30	23.39
N	0.17	0.12	73.87	0.01	0.55	1.06	1.02
P	3.45	7.01	203.58	0.09	51.57	5.78	38.69
K	108.1	128.2	118.7	17.30	760.6	3.02	11.29
Ca	2915	2070	71.01	2.00	6258	-0.03	-1.37
Mg	964.7	504.8	52.33	139.0	1772	-0.30	-1.33

StDev, standard deviation; CV, coefficient of variation; min, minimum; max, maximum

Pearson correlation relation

Pearson correlation coeffecient (r) relationships between soil samples are presented in Table 3. Significant positive correlations were determined between soil pH and Ca (r = 0.64) and Mg (r = 0.77), while significant negative correlation was identified with soil N in the study area. The significant positive correlation was determined between available Ca and Mg in the soils of the study area (r = 0.82).

Table 3
Pearson correlation relation

EC	pH	EC	N	P	K	Ca
	-0.21					
N	-0.75**	0.54**				
P	-0.12	0.32	0.25			
K	-0.32	0.11	0.32	0.19		
Ca	0.64**	-0.14	-0.63**	0.15	-0.29	
Mg	0.77**	-0.16	-0.71**	0.03	-0.31	0.82**
*, p < 0.05 ; ** p < 0.01						

Map of soil fertility parameter

In the study, the chemical properties of soil samples from forest, hazelnut, and tea areas were determined and distribution maps of the study area were generated. Distribution maps of pH, electrical

conductivity (EC), total nitrogen (TN), available phosphorus, available calcium, available potassium, and magnesium for the study area soils are presented in Figs. 2 and 3.

The soil pH in the study area ranged from 4.56 to 7.26, varying from moderately acidic to neutral (Table 1). The pH map of the study area shows that the lowest pH value of 4.56 was found in tea soil, while the highest value of 7.26 was found in hazelnut soil. The pH of the tea growing areas was found to be moderately acidic (Fig. 2).

Kacar (2010) reported that the tea plant generally exhibits optimum growth between pH 4.5 and 6.0 and that tea plant development is adversely affected if the soil pH is outside this range. In this study, pH values in tea soils ranged from 5.56 to 5.80, with an average of 5.04. The pH values of the tea soils in the study are within the limits specified by the researcher. Previous studies have indicated that soil pH decreases in areas where long term tea cultivation is practiced (Chen et al., 2025). The soil pH in tea growing areas was found to be at a suitable level for tea cultivation. Soil pH is one of the most important soil properties for tea, and pH value of 4.0 constitutes a critical threshold; values below pH 4.0 lead to yield losses (Kacar et al., 2004). This study reveals that there is no pH related issues in the tea growing areas.

Furthermore, on the map, the soil pH in hazelnut growing areas was found to be at a neutral level and within the suitable pH range for hazelnut cultivation. Studies have reported that the hazelnut plant can grow across a wide pH range (4.5–7.5) and exhibits optimum growth between pH 6.0 and 7.0 (Tercan et al., 2022; Şenol et al., 2026). Furthermore, in this study, the soil pH in hazelnut areas was found to be in the range of 5.75 to 7.26, with an average of 6.57. The pH values of the hazelnut areas in the study fall within the range reported by researchers.

When the pH distribution map of the study area was examined, the highest pH levels were found in the hazelnut areas in the west. However, the areas with lower pH on the map are the tea areas in the eastern part (Fig. 2). The long term practice of tea cultivation and the fertilizers applied in the study area have caused a decrease in soil pH. In studies related to tea, researchers have also reported that this situation causes a decrease in soil pH. (Roy et al., 2024)

The average EC value of the soils in the study area was found to be 53.68 $\mu S\ m^{-1}$. When the soil distribution maps were examined, the lowest EC value was determined to be 22.30 $\mu S\ m^{-1}$ in hazelnut lands, while the highest EC value was 292.50 $\mu S\ m^{-1}$ in tea land (Fig. 2). The results indicated that the study area is the non saline class (Table 2). Researchers conducting studies in the Eastern Black Sea region have reported that the region soils do not exhibit salinity issues (Özyazıcı et. al. 2010; Özyazıcı et. al. 2013). The findings of this study were consistent with the results of previous researchers.

Soil macronutrient map

When the total N distribution map of the study area was examined, the N content of the soils varied from very low to very high. In the study, the minimum total N content was determined to be 0.01% in hazelnut areas, while the maximum N content was 0.55% in areas under tea cultivation.

The total nitrogen content was determined to be low in 43.3% of the study area, while it was sufficient or high in the remaining parts. The nitrogen content of the areas where hazelnut cultivation is practiced was found to be low (Fig. 3). Previous studies have also noted that the nitrogen content of areas where hazelnut cultivation is practiced is generally low (Horuz 1996; Özyazıcı et al. 2014).

The nitrogen content of the areas under tea cultivation was found to be high (Fig. 3). The presence of high nitrogen content in these areas is due to the excessive use of nitrogenous fertilizers. Previous studies have also reported that nitrogen content in tea growing areas is generally high, attributing this to the excessive use of nitrogenous fertilizers. (Kacar, 2010). In studies related to tea, it has been stated that traditional nitrogen fertilizer applications decrease soil pH and that there is a negative correlation between pH and nitrogen fertilizer applications (Jahan et al., 2022). Consistent with the findings of previous researchers, a negative correlation between total N and pH was determined in this study.

One of the reasons for the high nitrogen content in forest areas is the abundance of plant residues. In this study, the nitrogen content of the soils varied according to the type of land use.

When the available P content of the study soils was examined, the lowest P content was found in hazelnut areas at 0.09 mg kg^{-1}, while the highest P content was detected in forest lands at 51.57 mg kg^{-1} (Table 2) In the distribution map generated as a result of the study, the P content of the soils was found to be insufficient across the majority of the study area (Fig. 3). In the hazelnut fields located in the western part of the study area, the P content of the soils was found to be very low, whereas in the forest and tea fields located in the east it was at insufficient levels. P was found in higher amounts in the tea fields than in the hazelnut fields. Similar to the findings of the study, Kacar (2010) reported that the phosphorus status of the tea soils in the region was generally at insufficient levels.

The long term exclusive use of nitrogenous fertilizers in tea cultivation can lower soil pH, thereby causing nutrient elements such as available phosphorus and calcium to remain at insufficient levels. In the studies conducted, researchers have also found similar results regarding this (Jahan et al., 2022; Roy et al., 2024).

When the available K content of the study soils was examined, the lowest K content was determined as 17.26 mg kg^{-1} in the hazelnut field, while the highest K content was determined as 760.62 mg kg^{-1} in the tea field (Table 2). When the available K distribution maps were examined, very low amounts of K were found in the hazelnut fields located in the western part of the study area, while low levels were detected in the forest areas and sufficient levels of K were determined in the tea fields (Fig. 3). Özer (2007),, found that K was sufficient and high in 81.4% of the soils in tea field. Taşkın et al. (2015), determined that plant available potassium was very low and low in 37.40% of the study soils and

sufficient and high in 62.60% of the study soils in tea fields. This study, with other studies conducted in tea fields, generally indicates that K is sufficient.

When the available Ca content was examined, the lowest available Ca content was determined as 0.09 mg kg^{-1} in the tea fields and the highest as 6258 mg kg^{-1} in the forest area (Table 2) When the Ca distribution maps of the soils were examined, the Ca contents of the study area were found to be low and very low in the tea fields, while they were determined to be at optimum and high levels in the hazelnut and forest areas (Fig. 3). The distribution map indicates that there is generally a deficiency problem related to Ca in the areas where tea cultivation is practiced in the study area. Özyazıcı et al. (2013) stated that the macronutrient elements were at insufficient levels in the soils of the region. In study conducted on tea soils, plant available calcium was determined to be in the very low and low classes in 70.11% of the soils (Taşkın et al., 2015). The studies indicate that there is Ca deficiency in tea soils.

When the available Mg content of the study soils was examined, the lowest amount was determined as 139 mg kg^{-1} in the tea fields, the highest amount as 1772 mg kg^{-1} in the forest areas, and the Mg contents of the study area were generally determined to be at high levels. When the distribution maps of the soils were examined, the available Mg content was found to be at sufficient levels in the tea fields, while it was determined to be at high levels in the forest and hazelnut areas. The distribution map indicates that there is no nutritional problem related to Mg in the study area (Fig. 3). In the study conducted by Taşkın et al. (2015), plant available magnesium was determined to be sufficient and high in 41.77% of the soils taken from Giresun province.

Conclusions

In this study, soil chemical properties such as pH, TN, available P, K, Ca, and Mg were investigated in different land uses (forest, hazelnut, and tea). According to the data obtained from the soils, distribution maps of these different land use areas were generated using the IDW method with the GIS.

In this study, the distribution maps of the soils have revealed that the levels of plant nutrient elements differ according to the land use type. In this study, the nutrient potentials of the soils for tea and hazelnut plants have been evaluated. In the tea fields, soil pH was moderately acidic, available Ca was insufficient, while potassium and magnesium were found in sufficient amounts. In these fields, due to the continuous use of nitrogenous fertilizers, the nitrogen contents of the soils were found to be high. In the map, calcium fertilizer should be taken into consideration in the fertilization programs for the tea fields. In the hazelnut fields, soil pH was slightly acidic to neutral, N, P, and K were found in insufficient amounts, while available Ca was high and Mg was found in sufficient amounts. In the map, N, P, and K fertilizer should be taken into consideration in the fertilization programs for the hazelnut fields. In the forest areas, pH was found to be slightly acidic, while the nutrient element contents of the soils were generally at sufficient and high levels.

In addition to the statistical evaluation of the analysis results of the study, it has also demonstrated the importance of performing spatial distributions. The determination of the status of nutrient elements in the field and the presentation through maps both spatially and locationally is of great importance in terms of site specific management. The maps will enable the facilitation of site specific fertilizer management. The region has different land use therefore; the site specific management is of great importance.

Declarations

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Ethics declarations

Conflict of interest

The authors declare no competing interests.

Ethical approval

The authors have read, understood, and complied as applicable with the statement on “Ethical Responsibilities of Authors” in the Instructions for Authors.

Consent to participate

Not applicable.

Consent to publication

The authors confirm that this paper has not been published before and is not under consideration for publication elsewhere.

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Author Contribution

MD conducted the fieldwork and laboratory analyses. FT planned the study, prepared the maps, and wrote the article. All authors read and approved the final manuscript.

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Figures

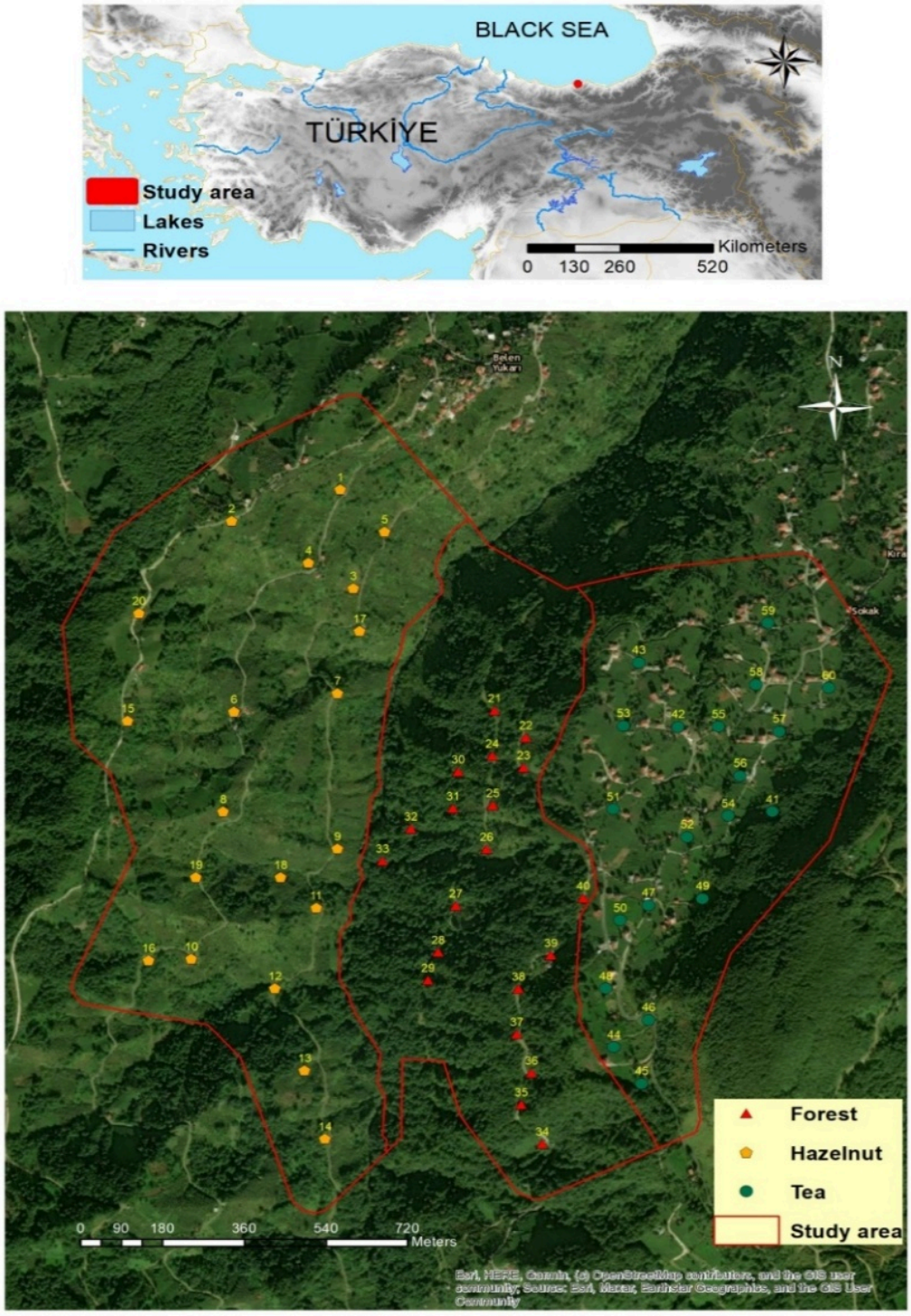


Figure 1

Map of the study area and soil sample points for each land use types.

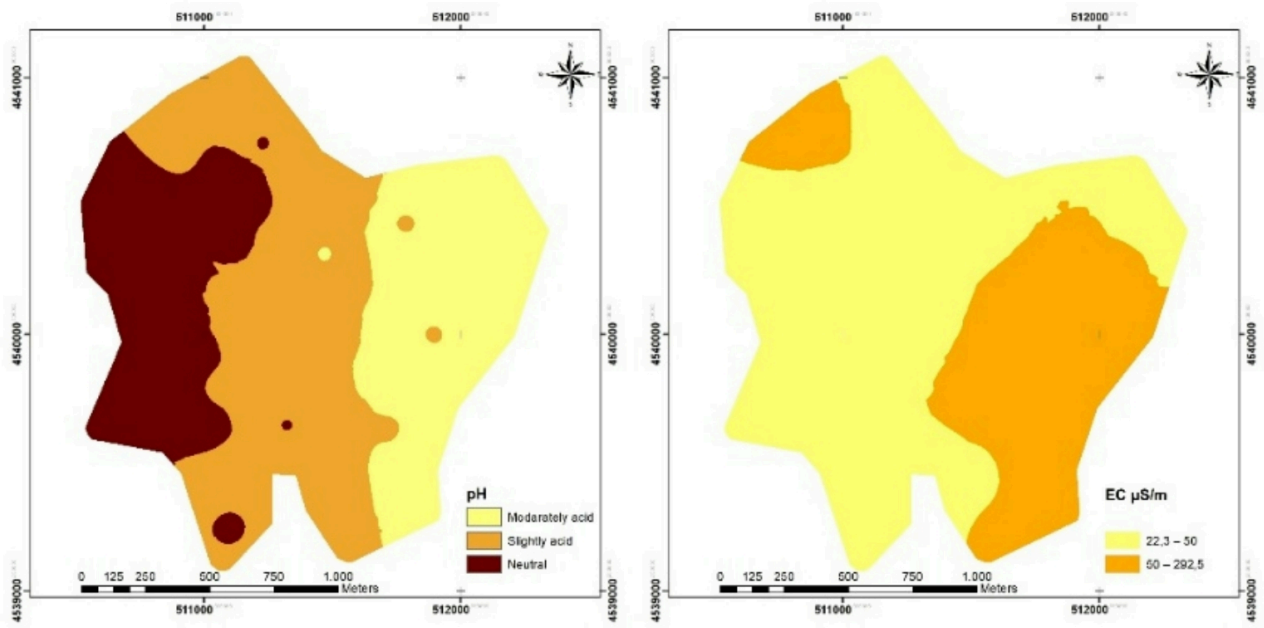


Figure 2

Maps of soil pH and EC

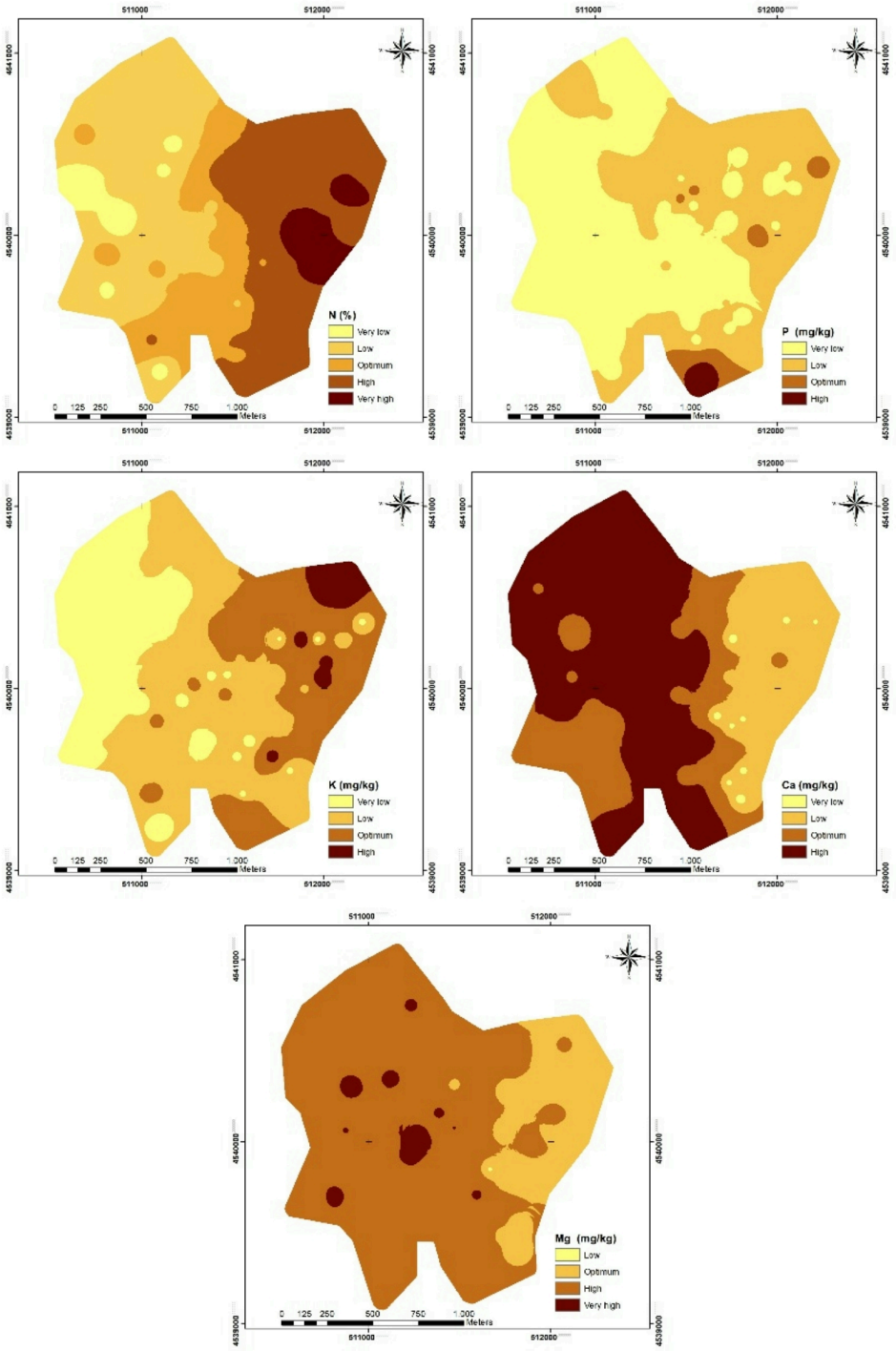


Figure 3

Maps of soil macronutrients