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RESEARCH PAPER

Effect of mineral fertilizer applications in bread wheat varieties to yellow rust disease

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Abstract

This research was carried out to determine the effects of mineral fertilizer applications applied in different doses on disease severity according to phenological periods in some bread wheat varieties. In this study, bread wheat varieties (Bayraktar 2000, Demir 2000, Eser and Kenanbey) were used as plant materials. In the study, different doses of Fe (Fe_5, Fe_{10}, Fe_{20}) and Zn ($Zn_{7.5}$, Zn_{15}, Zn_{30}) and their combination Fe+Zn (Fe+Zn $_{(5+7.5)}$, Fe+Zn $_{(10+15)}$), in the period from tillering to stalking were investigated. When compared to the variety without fertilizer application in general, Eser, one of the bread varieties, caused a decrease in disease severity in all Fe dose applications, while Zn applications caused an increase in the early period and both an increase and a decrease in the late periods. Bayraktar variety caused an increase in disease severity in all Fe dose applications in all phenological periods and in all zinc applications except the $Zn_{7.5}$ dose. In the Kenanbey cultivar, Fe dose applications caused an increase in disease severity in all periods except the mid-late period, and zinc applications caused a decrease in disease in all periods except the early period. Variable increases and decreases were observed in all phenological periods in Demir 2000 variety. In the future, the effects of Fe and Zn, as well as other plant nutrients, will be studied. Disease development for local varieties can be revealed for different phenological periods and their accuracy can be increased.

Introduction

Rust diseases are the most common wheat diseases in the world, causing significant yield and quality losses in wheat-growing ecologies (Samborski, 1985; Roelfs, 1978; Ipek et al., 2023; Tekin et al., 2022) and they can spread over large areas with prevailing winds. Additionally, their capacity to form new strains (race/pathotypes) in the biological process of the disease poses a potential threat to wheat production at the global level (Saari and Prescott, 1985; Kolmer, 2005; Cat et al., 2017; Cat et al., 2021; Tekin et al., 2021).

In recent years, detecting and controlling diseases in the early period has become very important due to the excessive use of fungicides and their harmful effects on the environment and human health. Sustainable agriculture and food safety have become

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increasingly important for both our country and the world in recent years. Although the physiological functions of plant nutrients are generally well understood, the dynamic interactions between plant nutrients and plant pathogen systems are poorly understood (Huber, 1996a). It has been reported, because of numerous studies, that fertilizer applications in the right amount and at the right time are important for higher unit area yield and for controlling some diseases (Marschner, 1995; Huber and Graham, 1999b; Graham and Webb, 1991). In recent years, nitrogen (N), phosphorus (P), potassium (K), manganese (Mn), zinc (Zn), boron (B), chlorine (Cl), and silicon (Si) have been used as plant nutrients in sustainable agriculture. These elements can be used to increase a plant's tolerance to disease or to reduce the severity of the disease. In general, plant nutrients can reduce plant diseases to an acceptable level (Dordas, 2008). While high N levels increase the severity of the disease in some cases where obligate pathogens are intense, it can be effective in reducing the severity of the disease in environments where facultative parasites are intense (Robert, et al., 2005). Potassium can reduce the development of host plants to their optimal growth level, while, unlike P and K, it can increase tolerance to diseases. Micronutrients play an important role in plant metabolism by affecting phenol, lignin content, and membrane stability (Graham and Webb, 1991). In addition, micronutrients have a variable effect on diseases, reducing the severity of the disease in some cases and increasing the severity of the disease in some cases (Huber and Graham, 1999b; Marschner, 1995; Römheld and Marschner, 1991). According to Graham and Webb (1991), the use of micro plant nutrients such as Mn and Zn instead of the recommended fungicide applications for the control and reduction of rust diseases during plant development can provide effective and lower-cost solutions as an alternative to fungicide applications without causing environmental pollution. The effects of micronutrients in reducing the severity of the disease seen in the plant are based on the healthy effect on the biochemistry and physiology of the plant. It has been reported that a significant portion of micronutrients has different and important responsibilities in the manifestation of resistant or tolerant reactions of plants against pathogens (Marschner, 1995). Micronutrients play a critical role in plant metabolism, influencing phenol and lignin content as well as membrane stability (Graham and Webb, 1991). Iron (Fe) is an important nutrient for human, animal, and plant health. However, research on the effect of Fe applications on strength to plant diseases is limited. Higher plants need higher amounts of Iron (Fe) for high productivity. Many foliar diseases, such as rust diseases in wheat and bananas, can be mitigated or controlled to varying degrees by iron (Graham and Webb, 1991). Iron applications increase tolerance to Sphaeropsis malorum in apples and pears and in pumpkins to Olpidium brassicae. In addition, additional fertilizer application in zucchini can prevent Fe deficiency in the host of the agent, but cannot prevent the spread of infection (Graham and Webb, 1991; Röhmeld and Marschner, 1991). Zinc can have a wide range of effects on plant disease susceptibility. In some cases, the severity and prevalence of the disease decrease, while in some cases it may not have any effect on the current situation (Graham and Webb, 1991; Grewal et al., 1996). Zn application can reduce disease severity in many cases due to its direct toxic effect on pathogens rather than plant metabolism (Graham and Webb, 1991). The role of Zn in the enrichment of growth parameters may be to increase resistance to rust diseases in wheat. This resistance is formed by the combination of three enzymes (carbonic anhydrase, alcohol dehydrogenase, and superoxide dismutase). Furthermore, zinc has a significant impact on the plant's "auxin" level (Ohki, 1978). Auxin stimulates meristematic activity in plants, resulting in increased cell division and expansion (Devlin and Witham, 1983). In addition to the protein content of the grain, the use of these elements can increase the concentrations of Fe, Mn, and Zn in the grain and flag leaf. According to Potarzycki and Grzebisz (2009), Zn has a significant impact on the plant's life cycle. It is known that protein synthesis and protein content decrease in plants with Zn deficiency. According to Morsy (2012), zinc, calcium, and manganese applications had a positive effect on faba bean growth (plant height) and yield (number of plants per plot and 100 seed weight). It has been reported in many cases that the effect of Zn application may not be on plant metabolism, but on disease severity reduction due to its direct toxic effect on pathogens (Graham and Webb, 1991). Increased disease severity was observed compared to the control group with zinc deficient Hevea brasiliensis, Oidium spp. (Bolle-Jones and Hilton, 1956).

The aims of this study are to have information about the severity of rust diseases (%DI) for different phenological periods in wheat, to reveal disease scores for disease symptoms occurring under mineral fertilizer applications, and to determine resistance classes according to infection coefficient values corresponding to disease severity according to different disease color changes. On the other hand, in this study; it is important to determine the Fe and Zn application doses that can be used in the fight against the disease in the early period, which will prevent the development of the disease in the early period for different development stages of wheat.

Material and Methods

Climatic and Soil Characteristics of the Experimental Area

The monthly average climate data (OMNI-Meteorology) of 2018-2019 for the location of Ankara Yenimahalle district, where the research was carried out is given below (Table 1). Considering the monthly total precipitation and temperature amounts for 2018-2019, it was determined that the monthly average precipitation was 33.2 mm, and the monthly average temperature was 12.08 °C. The texture of the soil was determined as clay loam.

Plant Materials

The Central Research Institute of Field Crops, Ankara, to investigate the seasonal effects of yellow rust (*Puccinia striiformis* f. sp. *tritici*) with hyperspectral data (multi-band) and to be tested under artificial epidemics, sensitive and resistant to yellow rust disease, registered the plants used in the experiment. Varieties with known resistant reactions and high reactions to fertilizer application were chosen as test materials (Table 2). In addition, "*Little Club*" was planted among the varieties as a sensitive control group genotype plant in the study. In this way, it was possible to simultaneously collect spectral data on susceptible and resistant varieties to yellow rust disease and compare each other. All planting was done by hand.

Table 1. Average monthly climate data of Yenimahalle district for the year 2018-2019

Climate data	Month (2018 Year)				Month (2019 Year)							Mean
	Aug.	Sep.	Oct.	Nov.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	
Mean Temperature (°C)	20.0	14.94	9.0	3.3	2.0	4.8	7.2	10.8	18.2	22.4	23.1	12.08
Highest temperature , °C	33.2	21.65	23.5	12.6	10.8	15.8	20.4	25.5	34.2	33.4	34.9	24.43
Lowest temperature , °C	8.1	9.43	-2.3	-10.2	-10.4	-2.4	-3.3	-0.9	6.1	11.7	10.7	0.71
Mean precipitation ş, mm	7.4	1.57	24.9	60.4	40.6	33.2	38.0	28.9	30.8	37.4	30.4	33.2
Relative humidity , %	46	69.83	65	81	79	70.2	55.4	42.5	47.2	52.1	42.0	58.04
Wind speed , m/s (2 m)	2.1	2.2	1.6	1.5	1.7	2.0	2.1	1.3	1.3	1.6	1.8	1.7

Table 2. Some characteristics of bread wheat varieties used in the study

Bread Group		
Variety	Registration year	Disease reactions
Bayraktar 2000	28.04.2000	Moderately Sensitive
Demir 2000	28.04.2000	Sensitive
Eser	02.05.2003	Resistant
Kenanbey	06.04.2009	Sensitive

- Little Club (sensitive) precision control genotype plant was planted between varieties.

Trial Design and Fertilizer Application Times

For the fertilizer-applied disease garden, four rows were planted from each variety. The test material was sown by hand on 14 November 2018 in 4 rows (20 kg/da seed) with 2.5-3 g seeds per row. With the planting, diammonium phosphate (DAP) 6.3 g/0.45 m²) fertilizer was applied with an account of 14 kg/da. In the calculation of the application dose to be given to the parcel for iron (Fe) and zinc (Zn) and iron+zinc (Fe+Zn) fertilizer applications, the parcel width is 0.60 m and the parcel length is 10 m was calculated. Fe, Zn, and Fe+Zn doses were applied in different phenological periods, starting from the tillering period, in a total of 6 applications. Dosage for Fe fertilization applications; It is prepared to be given to 1 decare by dissolving 75-100 g Fe-6 Forte (GÜBRETAŞ) in 100 liters of water. Accordingly, for three different fertilizer application doses for Fe; in the first application, 5g/5L/6m^2 Fe, II. In application 10g/5L/6m^2 Fe, III. In the application, 20 g/5L/6m^2 Fe was calculated and fertilizer application was made. Dose for Zn fertilization applications; Starting from the tillering period, it was applied 6 times in the form of Powder-Forte with the calculation of 150 g/100L water/1 da (0.60 m*10 m = 6 m2). In the first application, 7.5g / 5L/6m^2 Zn, II. 15g/5L/6m^2 Zn in practice, III. In the application, 30 g / 5lt / 6m^2 Zn was applied. Dose for Fe+Zn fertilization applications; was made by starting from the tillering period and dividing it into 6 application periods. In the first application, Fe 5g/5L+Zn7.5g/5L II. in practice, Fe 10g/5L+Zn15g/5L and III. in the application, Fe 20g/5L+Zn30g/5L fertilizer doses were applied (Table 3).

Disease Inoculation

Disease inoculation was done following the "National Plant Protection Standards" for field stage studies (Li et al., 1989). On May 6, 2019, the first inoculation was made (Feekes 6), which can be considered as the plant's stemming period. The second inoculation of rust was done on May 13, 2019 (pre-flowering period, Feekes 10), seven days after the first application. Freshly produced rust spores were used for disease inoculation and it was aimed to obtain the highest viable spore in this way. Disease inoculation was made especially in windless weather, and plastic barriers (shields) were used between the blocks to prevent the application dose from passing to the other

Table 3. Mineral fertilizer application doses and dates for bread wheat varieties

Application Dates	Fertilizer Applications								
	I. Application*			II. Application*			III. Application*		
	Fe	Zn	Fe+Zn	Fe	Zn	Fe+Zn	Fe	Zn	Fe+Zn
21.03.2019	5 g/5L	7.5g/5L	12.5g/5L	10g/5L	15g/5L	25g/5L	20g/5L	30g/5L	50 g/5L
02.04.2019	5g/5L	7.5g/5L	12.5g/5L	10g/5L	15g/5L	25g/5L	20g/5L	30g/5L	50 g/5L
16.04.2019	5g/5L	7.5g/5	12.5g/5L	10g/5L	15g/5L	25g/5L	20g/5L	30g/5L	50 g/5L
29.04.2019	5g/5L	7.5g/5L	12.5g/5L	10g/5L	15g/5L	25g/5L	20gr5L	30g/5L	50 g/5L
06.05.2019	5g/5L	7.5g/5L	12.5g/5L	10g/5L	15g/5L	25g/5L	20g/5L	30g/5L	50 g/5L
13.05.2019	5g/5L	7.5g/5L	12.5g/5L	10g/5L	15g/5L	25g/5L	20g/5L	30g/5L	50 g/5L

I*. Application: Fe 833.33 g/da, Zn 1.250 kg/da, II*. Application: Fe 1.667 kg/da, Zn 2.500 g/da, III*. Application: Fe 3.333 kg/da Zn 5.000 kg/da
Mineral fertilizer applications were calculated as g/6 m^2 for each parcel (0.60 m*1.0 m=6 m^2).

parcel. Yellow rust inoculation was made to determine the reactions of different doses of fertilizer applications (Fe_5, Fe_{10}, Fe_{20}, $Zn_{7.5}$, Zn_{15}, Zn_{30}, $Fe+Zn_{(5+7.5)}$, $Fe+Zn_{(10+15)}$, $Fe+Zn_{(20+30)}$) to yellow rust disease. Yellow rust disease spores were applied as 2.0 g/200 ml for three replications in all fertilizer applications and the disease was inoculated twice with the ULV+ device, 172 and 179 days after sowing (06 May 2019 and 13 May 2019). Disease inoculation was carried out, especially in windless weather.

Field Observations, Leaf Sampling and Evaluation of Disease Reactions

Field observations were taken at different phenological development stages (Feekes) of all test material cultivated in the application areas (Large, 1954). Observations were made in 4 periods, from 25 May to 23 June 2019, in which disease reactions were evaluated (first part). These periods are; at the beginning of flowering (Feekes 10.5.1), during the grain filling period (Feekes 10.5.3), during the milking period (Feekes 10.5.4) and the Yellowing period (Feekes 11.1) (Fowler, 2018) (Table 4).

Table 4. Date and phenological periods of leaf samples taken

Sampling Dates	Different development stages	Feekes	Zadoks scale
25 May 2019	Flowering Beginning (Early Period)	10.5.1	60
06 June 2019	Grain Binding (Early-Middle Period)	10.5.3	69
15 June 2019	Milk Settlement Period (Middle-Late Period)	10.5.4	71
23 June 2019	Ripening Period (Late Period)	11.1	75

Leaf samples were collected from the inoculated and non-inoculated plots once every 7 days (25 May 2019, 06 June 2019, 15 June 2019) 19 days after the yellow rust disease inoculation (06 May 2019). (Table 4). A total of 60 leaves were collected from three replications, with 20 leaves from each replication (4 types *5 leaf sample"s). To make the same application in the collection of leaf samples, the third leaf of the plant was taken from the top, but in cases where sampling was not possible in this way, the second leaf from the top was taken as a sample. In each sampling period (4 terms) 240 plant leaf samples were collected from 4 blocks (20 sample-no fertizer+60 samples*3 blocks). In addition to this study, a total of 40 leaves (8 plots*5 leaves) were collected from 6 plots of the precision control Little Club variety, and the number of leaf samples reached 240 (200+40). The samples for counting were placed in paper envelopes and kept in the refrigerator until the study was completed. To determine the degree of mean severity of the disease, one means disease score was calculated for 5 leaves collected for each variety from each replication. In this way, one means disease severity was calculated for each variety. A disease score was determined for each variety by subjecting the images of the leaf sample taken with a digital and thermal camera to a controlled classification (Supervised Classification) in the "Image Classification" image classification module in ArcGIS 10.5.1 Program. Disease severity (%DI) was obtained by dividing the diseased area covered by yellow rust disease on the leaf by the total leaf area and multiplying by the activity coefficient. In the disease evaluations, the plants were divided into 9 classes according to the disease severity of the diseased area (0%, 1%, 10%, 20%, 30%, 45%, 60%, 80%, and 100%). A value of 0% indicates that no disease was detected, and

100% indicates the class of the most severe disease (the leaf is completely covered with disease). The disease indice (Di%) was calculated with the following formula (Huang et al., 2007) (1). Disease Severity (DS) is calculated by multiplying the disease indice (Di%) with the infection coefficient (IC) into which the reaction type is included (Table 5) (2).

Table 5. Types of plant reactions against yellow rust disease in wheat (Roelfs et al., 1992)

Reaction Types	Infection Coefficients	Description
0	0	No visible infection.
R (Resistant)	0,2	There are necrotic (dead tissue) spots. These do not have rust pustules or are very small.
MR (Moderately) Resistant)	0,4	Small pustules surrounded by necrotic areas are seen.
MS (Moderately Sensitive)	0,8	Small to medium sized pustules are seen. There are no necrotic spots, there are obvious chlorotic spots.
S (Sensitive)	1	There are large pustules, no necrotic or chlorotic areas.

$$Di\,(\%) = \frac{\sum xf}{n \sum f} x100 \qquad \textbf{(1)}$$

Di (%)= Disease indice

n= Highest disease severity value

f= Number of leaves per disease severity grade

$$DI\,(\%) = Di\,(\%) \times IC \qquad \textbf{(2)}$$

DS (%) = Disease Severity

IC = Infection Coefficient

Yellow rust's severity and the reaction types (Roelfs et al., 1992) of plants against yellow rust disease were also recorded using the Modified Cobb scale (Peterson et al., 1948) on the collected leaf samples (Table 5). It has been classified into 5 groups according to the infection coefficients (IC) reactions (Disease Severity %DS) (Immune: 0 EK, Resistant: 0.1-5.0, Moderately resistant: 5.0-20.0, Moderately susceptible: 20.1-40.0, Sensitive: 41.0-100.0) (Akan, 2019).

To calculate the change in disease severity of different mineral fertilizer applications (Fe_5, Fe_{10}, Fe_{20}) applied according to phenological periods, the difference between the disease severity value obtained as a result of the applied fertilizer dose application, based on the 0% dose without mineral fertilizer applied (control), is multiplied by 100, and the % increase rate is calculated by dividing the disease severity value (%DI) of the application without fertilizer.

Results and Discussion

Investigation of Disease Severity Change under Mineral Fertilizer Applications (Fe, Zn, Fe+Zn) in Bread Varieties

The use of plant nutrients, especially against plant pathogens, has gained importance in terms of increasing tolerance or resistance to diseases (Graham and Webb, 1991). All plant nutrients affect disease severity to varying degrees (Huber and Graham, 1999b). However, while not a general rule, any specific nutrient can reduce or increase the severity of any plant disease depending on the severity of other diseases in the environment and environmental conditions. (Huber, 1980a; Marschner, 1995; Graham and Webb, 1991). Despite the recognition of the importance of plant nutrients in the control of many important plant diseases, proper fertilizer management strategies in sustainable agriculture have always received less attention. Iron applications increase the tolerance against Sphaeropsis malorum in apples and pears and pumpkin against Olpidium brassicas. Furthermore, additional fertilizer application in zucchini can prevent Fe deficiency in the agent's host but cannot prevent infection spread (Graham and Webb, 1991; Römheld and Marschner, 1991). Zinc (Zn) applications have very different interactions in the reactions of plants against diseases. It has been reported that in some cases it reduces the effect of the disease on the plant, and in some cases, it increases the effect of the disease on the plant or has no effect (Graham and Webb, 1991; Grewal et al., 1996). In many cases, It has been reported that Zn application may have an effect on disease severity rather than plant metabolism due to its direct toxic effect on pathogens (Graham and Webb, 1991).

When all phenological periods are evaluated together; in Eser variety a decrease in the disease reaction was determined (Tukey B*HSD Test). Among all Fe dose applications, Fe_{10} and Fe_{20} doses caused the greatest reduction in disease severity (-28.57% and -22.23% respectively) in the early period. Similarly, in the mid-late period, it was determined that the dose of Fe_{20} fertilizer caused a decrease in disease severity (-22.23%) (Tables 6 and 8). It was determined that in early, early-middle, and mid-late periods, applications of $Zn_{7.5}$ and Zn_{15} fertilizer doses had a significant effect on disease severity with $p \leq 0.05$. It was determined that the application of $Zn_{7.5}$ and Zn_{15} fertilizer doses in the early period had an increasing (+28.58% and +14.29%) effect on disease severity. It was determined that the application of Zn_{15} fertilizer dose in the early-middle and mid-late period increased the severity of the disease (+16.67%), while the application of Zn_{20} and $Zn_{7.5}$ fertilizer doses decreased the disease severity (-22.23%) (Tables 7 and 8). Basic statistical analysis of variation (ANOVA) for all phenological periods was

Table 6. According to different phenological periods for mineral fertilizer applications (Fe, Zn, Fe+Zn) disease change rates (%) (Eser 2019)

	Phenological Periods									
Eser Variety	25 May 2019 (10.5.1)		06 June 2019 (10.5.3)		15 June 2019 (10.5.4)		23 June 2019 (11.1.1)		Mean	
Application	% DS	% Change	% DS	% Change	% DS	% Change	% DS	% Change	% DS	% Change
No Fertilizer (Control)	9.333	-	12.00	-	12.00	-	0.00	-	8.33	-
Fe 5g/5 L	8.000	-14.26	9.333	-22.23	12.00	0.00	0.00	0.00	7.33	-18.24
Fe 10 g/5 L	6.667	-28.57	12.00	0.00	12.00	0.00	0.00	0.00	7.67	-7.14
Fe 20 g/5 L	6.667	-28.57	9.333	-22.23	9.333	-22.23	0.00	0.00	6.33	-3.97
Zn 7.5 g/5 L	12.000	+28.58	9.333	-22.23	9.333	-22.23	0.00	0.00	7.67	-3.97
Zn 15 g /5 L	10.667	+14.29	14.00	+16.67	14.00	+16.67	0.00	0.00	9.67	+11.91
Zn 30 g/5 L	9.333	0.00	12.00	0.00	12.00	0.00	0.00	0.00	8.33	0.00
Fe+Zn 5+7.5 g/5 L	8.000	-14.28	12.00	0.00	12.00	0.00	0.00	0.00	8.00	-3.57
Fe+Zn 10+15g/5 L	9.333	0.00	12.00	0.00	12.00	0.00	0.00	0.00	8.33	0.00
Fe+Zn 20+30g/5 L	9.333	0.00	12.00	0.00	12.00	0.00	0.00	0.00	8.33	0.00

Table 7. Multiple comparison (ANOVA) variance analysis results of the effects of different mineral fertilizer applications (Fe, Zn, Fe+Zn) on disease reaction in Eser variety

Perods (Feekes)		10.5.1	10.5.3	10.5.4	11.1.1
Eser		25 May 2019	06 June 2019	15 June 2019	23 June 2019
		Disease Severity, % DI (Average ± SD)			
Doses	Rec.	(DAS-185)	(DAS-197)	(DAS-206)	(DAS-214)
0	12	9.33±0.57 a	12.00±0.00 a	12.00±0.00 a	0.00±0.00 a
Fe5	12	8.00±0.00 a	9.33±0.57 b	12.00±0.00 a	0.00±0.08 a
Fe10	12	6.67±1.14 a	12.00±0.00 a	12.00±0.00 a	0.00±0.00 a
Fe20	12	6.67±1.14 a	9.33±0.57 b	9.33±0.57 b	0.00±0.00 a
Sig.	48	0.136	1.000	1.000	0.497
0	12	9.33±0.57 b	12.00±0.00 b	12.00±0.00 b	0.08±0.00 a
Zn7.5	12	12.00±0.00 a	9.33±0.57 c	9.33±0.57 c	0.00±0.00 a
Zn15	12	10.67±1.97 ab	14.00±0.85 a	14.00±0.85 a	0.00±0.00 a
Zn30	12	9.33±1.97 b	12.00±0.00 b	12.00±0.00 b	0.00±0.00 a
Sig.	48	0.237	0.237	1.000	0.497
	12	9.33±0.57 a	12.01±0.01 a	12.01±0.01 a	0.08±0.00 a
Fe+Zn(5+7.5)	12	8.00±0.00 a	12.00±0.00 a	12.00±0.00 a	0.00±0.00 a
Fe+Zn(10+15)	12	9.33±0.80 a	12.00±0.00 a	12.00±0.00 a	0.00±0.00 a
Fe+Zn(20+30)	12	9.33±0.80 a	12.00±0.00 a	12.00±0.00 a	0.00±0.00 a
Sig.	48	0.497	0.497	0.497	0.497

Mean.: Mean Disease Intensity (%DI), SD: Average Standart Deviation DAS: Day After Sowing
Successive lowercase letters in the same column indicate differences between doses within the same phenological period. Consecutivelowercase letters are not statistically significant (Tukey Post hoc test)
* The difference in the mean is significant at the $p \leq 0.05$ level (Tukey's HSD test ($p < 0.05$).

Table 8. According to phenological periods disease severity (%DS) evaluations at repetitive fertilizer application (Fe, Zn, Fe+Zn) doses Anova Results in Eser variety

Eser Variety	Phenological Periods (Feekes)	RMSE	df	MSE	F	Sig. (P)
Fe	10.5.1	58.667	3	19.556	2.241	0.097
	10.5.3	85.833	3	28.444	14.667	0.000
	10.5.4	64.000	3	21.333	22.000	0.000
	11.1	0.01	3	0.000	1.000	0.402
Zn	10.5.1	58.667	3	19.556	6.722	0.001
	10.5.3	132.000	3	44.000	13.962	0.000
	10.5.4	132.000	3	44.000	13.962	0.000
	11.1	0.01	3	0.000	1.000	0.402
Fe+Zn	10.5.1	16.000	3	5.333	0.917	0.441
	10.5.3	0.001	3	0.000	1.000	0.402
	10.5.4	0.001	3	0.000	1.000	0.402
	11.1	0.001	3	0.000	1.000	0.402

RMSE: Error Sum of Squares F: Comparison Table Value of Sample Means df: Degrees of Freedom
MSE: Error Mean Squares Sig.(p): Significance Level in Comparison

Table 9. According to different phenological periods for mineral fertilizer applications (Fe, Zn, Fe+Zn) disease change rates (%) in Kenanbey variety

Kenanbey Variety	25 May 2019 (10.5.1)		06 June 2019 (10.5.3)		15 June 2019 (10.5.4)		23 June 2019 (11.1.1)		Mean	
Application	% DS	% Change	% DS	% Change	% DS	% Change	% DS	% Change	% DS	% Change
No Fertilizer (0)	18.67	-	48.00	-	69.00	-	87.00	-	55.67	-
Fe 5g/5 L	32.00	+71.40	51.00	+6.25	69.00	0.00	90.00	+3.45	60.50	+8.68
Fe 10g/5 L	16.00	-14.30	51.00	+6.25	60.00	-13.04	81.00	-6.90	52.00	-6.59
Fe 20g/5 L	24.00	+28.55	45.00	-6.25	69.00	0.00	84.00	-3.45	55.50	-0.31
Zn 7.5g/5 L	32.00	+71.40	45.00	-6.25	54.00	-21.74	81.00	-6.90	53.00	-4.80
Zn 15g/5 L	25.33	+35.67	51.00	+6.25	66.00	-4.35	84.00	-3.45	56.58	+1.63
Zn 30g/5 L	20.00	+7.12	45.00	-6.25	57.00	-17.39	72.00	-17.24	48.50	+12.88
Fe+Zn 5+7.5g/5 L	22.67	+21.42	51.00	+6.25	75.00	+8.70	84.00	-3.45	58.17	+4.49
Fe+Zn 10+15g/5 L	22.00	+17.84	39.00	-18.75	60.00	-13.04	72.00	-17.24	48.25	-13.33
Fe+Zn 20+30g/5 L	26.67	+42.85	45.00	-6.25	69.00	0.00	84.00	-3.45	56.17	+0.90

performed using SPSS-22® version statistical package program (IBM SPSS Statistics, 2014).

A limited decrease in disease severity (-14.28%) was observed in Fe+Zn $_{(5+7.5)}$ fertilizer application in the early period, while no significant change was detected in all other phenological periods (Table 8).

In the bread Ekmeklik Kenanbey variety; The differences between the disease reactions in Fe fertilizer dose applications, the early and early-mid periods, in particular, were found to be statistically significant ($p<0.05$) and an increase in the severity of the disease was determined with the advancing biological process (Table 10). It was determined that Fe_5 and Fe_{20} doses of Fe fertilizer dose applications caused the highest increase (+71.40%, +28.55%) in the disease reaction severity in the early period. In the early-middle period (06 June 2019), an increase in the disease severity was observed at the Fe_5 and Fe_{10} fertilizer application doses (+6.25%), and a decrease in the disease severity was observed at the Fe_{10} fertilizer application dose in the mid-late period (-13.04%) (Table 9). Among the Zn applications, the differences between the disease reactions at the fertilizer application doses of $Zn_{7.5}$, Zn_{15}, and Zn_{30} in the early period were found to be statistically significant. It was determined that $Zn_{7.5}$, Zn_{15}, and Zn_{30} fertilizer application doses were effective in increasing the disease reaction severity (+71.40%, +35.67%, +7.12%) in the early period. In the early-middle period, an increase in disease severity was observed at the Zn_{15} fertilizer application dose (+6.25%), and a decrease in the disease severity at $Zn_{7.5}$ and Zn_{30} fertilizer application doses (-6.25%) (Table 9). In the mid-late period, a decrease in disease severity was determined at all Zn fertilizer application doses ($Zn_{7.5}$, Zn_{15}, Zn_{30}) (-54%, -66%, -57%). It was determined that different Fe+Zn fertilizer application doses caused

Table 10. Multiple comparison (ANOVA) variance analysis results of the effects of different mineral fertilizer applications (Fe, Zn, Fe+Zn) on disease reaction in Kenanbey variety

Periods (Feekes) Kenanbey Variety		10.5.1 25 May 2019	10.5.3 06 June 2019	10.5.4 15 June 2019	11.1.1 23 June 2019
		Disease Severity, % DS (Average ± SD)			
Doses	Rec.	(DAS-185)	(DAS-197)	(DAS-206)	(DAS-214)
0	12	18.67±2.84 ab	48.00±1.28 ab	69.00±1.28 a	87.00±1.28 ab
Fe5	12	32.00±0.00 a	51.00±1.28 a	69.00±1.28 a	90.00±0.00 a
Fe10	12	16.00±1.71 c	51.00±1.28 a	60.00±1.28 a	81.00±0.00 c
Fe20	12	24.00±0.00 b	45.00±0.00 b	69.00±2.56 b	84.00±1.28 bc
Sig.	48	0.261 / 1.000	0.237	1.000	0.103
0	12	18.67±2.84 b	48.00±1.28 ab	69.00±1.279 a	87.00±1.28 a
Zn7.5	12	32.00±0.00 a	45.00±0.00 b	54.00±0.000 b	81.00±0.00 b
Zn15	12	25.33±2.84 ab	51.00±1.28 a	66.00±1.279 a	84.00±1.28 ab
Zn30	12	20.00±0.85 b	45.00±0.00 b	57.00±1.279 b	72.00±0.00 c
Sig.	48	0.115	1.000	0.237	1.000
0	12	18.67±2.84 b	48.00±1.28 ab	69.00±1.28 a	87.00±1.28 a
Fe+Zn5+7.5	12	22.67±1.99 ab	51.00±1.28 a	75.00±1.28 a	84.00±1.28 a
Fe+Zn10+15	12	22.00±0.85 ab	39.00±1.28 c	60.00±1.28 b	72.00±0.00 b
Fe+Zn20+30	12	26.67±1.14 a	45.00±0.00 b	69.00±2.56 a	84.00±0.00 a
Sig.	48	0.441 / 0.306	1.000 / 0.237	1.000 / 0.073	1.000 / 0.237

Table 11. According to phenological periods disease severity (%DI) evaluations at repetitive fertilizer application (Fe, Zn, Fe+Zn) doses Anova results in Kenanbey variety

Kenanbey Variety	Phenological Periods (Feekes)	RMSE	df	MSE	F	Sig. (P)
Fe	10.5.1	1792	3	597.333	18.118	0.000
	10.5.3	297.000	3	99.000	6.722	0.001
	10.5.4	729.000	3	243.000	7.071	0.001
	11.1	540.000	3	180.000	18.333	0.000
Zn	10.5.1	1322.667	3	440.889	8.702	0.000
	10.5.3	297.000	3	99.000	10.083	0.000
	10.5.4	1836.000	3	612.00	41.556	0.000
	11.1	1512.000	3	504.000	51.333	0.000
Fe+Zn	10.5.1	388.000	3	129.333	3.066	0.038
	10.5.3	945.000	3	315.000	21.389	0.000
	10.5.4	1377.000	3	459.000	13.357	0.000
	11.1	1593.000	3	531.000	36.056	0.000
RMSE: Error Sum of Squares		F: Comparison Table Value of Sample Means df: Degrees of Freedom				
MSE: Error Mean Squares		Sig.(p): Significance Level in Comparison				

an increase in disease severity in the early period, and the highest increase was in the Fe+Zn $_{(20+30)}$ application dose. This was followed by Fe+Zn $_{(5+7.5)}$ and Fe+Zn $_{(10+15)}$ doses, respectively (+21.42%, +17.64%). In the early-middle and mid-late periods, a limited increase in disease severity was observed at the Fe+Zn $_{(5+7.5)}$ application dose (+6.25%, +8.70%), and it was determined that there was a decrease in the disease severity at all other doses and application periods (Table 9). In Bayraktar 2000 variety, the highest increase in disease severity (+49.95%) was observed in Fe+Zn$_{(10+15)}$ application in the early-middle period due to increasing fertilizer doseapplications. It was determined that this situation was followe d by Zn15 (+37.49%), Fe5, and Fe10 fertilizer dose applications (+37.49%) in the same period. In the mid-late period, an increase in disease severity was observed in the application of Fe5 and Fe10, and Fe+Zn $_{(10+15)}$ fertilizer doses (+20.03%) (Table 12). Significant reductions in the severity of the disease were determined most in the early-middle and mid-late periods at the Zn30 application dose (- 50.05%, -39.98%) (Table 12 and 14).

Table 12. According to different phenological periods for mineral fertilizer applications (Fe, Zn, Fe+Zn) disease change rates (%) in Bayraktar 2000 variety

	Phenological Periods									
Bayraktar 2000 Variety	25 May 2019 (10.5.1)		06 June 2019 (10.5.3)		15 June 2019 (10.5.4)		23 June 2019 (11.1.1)		Mean	
Application	% DS	% Change	% DS	% Change	% DS	% Change	% DS	% Change	% DS	% Change
No Fertilizer (Control)	6.67	0.00	10.67	0.00	13.33	0.00	0.00	0.00	7.67	0.00
Fe 5g/5 L	8.00	+19.94	14.67	+37.49	16.00	+20.03	0.80	+80	9.87	+28.68
Fe 10g/5 L	5.33	-20.09	14.67	+37.49	16.00	+20.03	0.80	+80	9.20	+19.95
Fe 20g/5 L	5.33	-20.09	10.67	0.00	10.67	+19.95	4.00	+400	7.67	0.00
Zn 7.5g/5 L	4.00	-40.03	10.67	0.00	10.67	+19.95	0.80	+80	6.54	+14.73
Zn 15g/5 L	6.67	0.00	14.67	+37.49	14.67	+10.05	0.80	+80	9.20	+19.95
Zn 30g/5 L	6.67	0.00	5.33	-50.05	8.00	-39.98	4.00	400	6.00	+21.77
Fe+Zn 5+7.5g/5 L	5.33	-20.09	12.00	+12.46	13.33	0.00	4.00	+400	8.67	+13.04
Fe+Zn 10+15g/5 L	7.33	+9.90	16.00	+49.95	16.00	+20.03	4.00	+400	10.83	+41.20
Fe+Zn 20+30g/5 L	9.33	+39.88	10.67	0.00	10.67	-19.95	4.00	+400	8.67	+13.04

When all phenological periods were evaluated together, the effects of Fe applications were found to be statistically significant ($p \leq 0.05$), as were the differences in disease reactions, especially in the early and early-mid periods, were observed to increase in disease severity (Table 13).

High Zn dose applications (Zn30) showed reductions in disease severity in the early-middle and mid-late periods. Significant increases in disease reactions were determined in all phenological development periods in the late period, and the most significant increase was determined in the Fe+Zn fertilizer application dose in the late period (Table 13).

Table 13. Multiple comparison (ANOVA) variance analysis results of the effects of different mineral fertilizer applications (Fe, Zn, Fe+Zn) on disease reaction in Bayraktar 2000 variety

Periods (Feekes)		10.5.1	10.5.3	10.5.4	11.1.1
Bayraktar 2000		25 May 2019	06 June 2019	15 June 2019	23 June 2019
		Disease Severity, % DS (Average ± SD)			
Doses	Rec.	(DAS-185)	(DAS-197)	(DAS-206)	(DAS-214)
0	12	6.67±0.57 ab	10.67±0.57 b	13.33±0.57 b	0.00±0.00 c
Fe5	12	8.00±0.00 a	14.67±0.57 a	16.00±0.00 a	8.00±0.00 b
Fe10	12	5.33±0.28 b	14.67±1.42 a	16.00±0.85 a	8.00±0.00 b
Fe20	12	5.33±0.57 b	10.67±0.57 c	10.67±0.57 c	4.00±0.00 a
Sig.	48	0.136	1.000	1.000	1.000
0	12	6.67±0.57 a	10.67±0.57 b	13.33±0.57 ab	0.00±0.00 c
Zn7.5	12	4.00±0.00 b	10.67±0.57 b	10.67±0.57 bc	8.00±0.00 b
Zn15	12	6.67±0.57 a	14.67±1.42 a	14.67±1.427 a	8.00±0.00 b
Zn30	12	6.67±0.28 b	5.33±0.57 c	8.00±0.007 c	4.00±0.00 a
Sig.	48	0.115	1.000	0.111 / 0.658	1.000
0	12	6.67±0.57 ab	10.67±0.57 b	13.33±0.568 b	0.00±1.28 b
Fe+Zn5+7.5	12	5.33±0.57 b	12.00±0.01 b	13.33±0.568 b	4.00±1.28 a
Fe+Zn10+15	12	7.33±0.29 ab	16.00±0.86 a	16.00±0.852 a	4.00±0.00 a
Fe+Zn20+30	12	9.33±1.14 a	10.67±0.57 b	10.67±0.568 c	4.00±0.00 a
Sig.	48	0.207 / 0.052	0.384 /1.000	1.000	-

Table 14. According to phenological periods Disease Severity *(%DI)* evaluations at repetitive fertilizer application (Fe, Zn, Fe+Zn) doses Anova results in Bayraktar 2000 variety

Bayraktar 2000	Phenological Periods (Feekes)	RMSE	df	MSE	F	Sig. (P)
Fe	10.5.1	58.667	3	19.556	8.963	0.001
	10.5.3	192.000	3	64.000	7.135	0.001
	10.5.4	234.667	3	78.222	18.980	0.000
	11.1	113.280	3	37.760	11.134	0.000
Zn	10.5.1	64.000	3	21.333	9.778	0.000
	10.5.3	528.000	3	176.000	19.622	0.000
	10.5.4	314.667	3	104.889	13.111	0.000
	11.1	113.280	3	37.760	11.134	0.000
Fe+Zn	10.5.1	100.000	3	33.333	5.500	0.003
	10.5.3	229.333	3	76.444	18.549	0.000
	10.5.4	170.667	3	56.889	11.175	0.000
	11.1	144.000	3	48.000	-	-

RMSE: Error Sum of Squares F: Comparison Table Value of Sample Means df: Degrees of Freedom
MSE: Error Mean Squares Sig. (p): Significance Level in Comparison

In Demir 2000 variety, the highest disease severity was observed in the early and mid-late periods, depending on the application of increased fertilizer doses (Table 15). In the early period, Fe_5, Fe_{20}, $Zn_{7.5}$ and $Fe+Zn_{(5+7.5)}$ were found in applications (+71.40%, +7.12%, +28.55%, +28.55%) (Table 15 and 17). In the mid-late period, an increase in disease severity was observed in the application of Fe_{10}, Fe_{20}, Zn_{30}, and $Fe+Zn_{(5+7.5)}$ fertilizer doses (+9.52%, +14.29%, +14.29%, +4.76%) (Table 15 and 16). Significant reductions in disease severity depending on the application of varying fertilizer doses which were determined most at the Zn_{30} fertilizer dose in the early period (-35.73%) and the $Zn_{7.5}$ and Zn_{15} fertilizer doses in the mid- late period (-21.70%, -9.52%). In the late period, increases were found in all fertilizer application doses when compared to plants without disease symptoms (Table 17).

Table 15. According to different phenological periods for mineral fertilizer applications *(Fe, Zn, Fe+Zn)* disease change rates (%) in Demir 2000 variety

Demir 2000	25 May 2019 (10.5.1)		06 June 2019 (10.5.3)		15 June 2019 (10.5.4)		23 June 2019 (11.1.1)		Mean	
Application	% DS	% Change	% DS	% Change	% DS	% Change	% DS	% Change	% DS	% Change
No Fertilizer (0)	18.67	0.00	48.00	0.00	63.00	0.00	75.00	0.00	51.17	0.00
Fe 5g/5 L	32.00	+71.40	48.00	0.00	60.00	-4.76	84.00	+12.00	56.00	+9.44
Fe 10g/5 L	17.33	+7.18	48.00	0.00	69.00	+9.52	81.00	+8.00	53.83	+5.20
Fe 20g/5 L	20.00	+7.12	48.00	0.00	72.00	+14.29	84.00	+12.00	56.00	+9.44
Zn 7.5g/5 L	24.00	+28.55	42.00	-12.50	49.33	-21.70	84.00	+8.00	49.08	+4.08
Zn 15g/5 L	18.67	0.00	42.00	-12.50	57.00	-9.52	81.00	+12.00	50.42	+1.47
Zn 30g/5 L	12.67	-35.73	45.00	-6.25	66.00	+4.76	84.00	+8.00	51.00	+0.33
Fe+Zn 5+7.5g/5 L	24.00	+28.55	42.00	-12.50	66.00	+4.76	84.00	+12.00	54.00	+5.53
Fe+Zn 10+15g/5 L	16.67	-10.71	51.00	+6.25	60.00	-4.76	75.00	0.00	50.67	+0.98
Fe+Zn 20+30g/5 L	17.33	-7.18	48.00	0.00	72.00	+14.29	84.00	+8.00	55.33	+8.13

Table 16. Multiple Comparison (ANOVA) variance analysis results of the effects of different mineral fertilizer applications (Fe, Zn, Fe+Zn) on disease reaction in Demir 2000 variety

Periods (Feekes)		10.5.1	10.5.3	10.5.4	11.1.1
Demir 2000 variety		25 May 2019	06 June 2019	15 June 2019	23 June 2019
		Disease Severity, % DS (Average ± SD)			
Doses	Rec.	(DAS-185)	(DAS-197)	(DAS-206)	(DAS-214)
0	12	18.67±2.842 b	48.00±1.279 a	63.00±0.000 b	75.00±1.279 a
Fe5	12	32.00±0.000 a	48.00±2.558 a	60.00±1.279 b	84.00±1.279 b
Fe10	12	17.33±0.284 b	48.00±2.558 a	69.00±1.279 a	81.00±0.000 b
Fe20	12	20.00±0.852 b	48.00±2.558 a	72.00±0.000 a	84.00±1.279 b
Sig.	48	0.590 / 1.000	1.000	0.103	1.000 / 0.237
0	12	18.67±2.842 a	48.00±1.279 a	63.00±0.000 a	75.00±1.279 b
Zn7.5	12	24.00±0.000 a	42.00±1.279 a	49.33±1.989 c	84.00±1.279 a
Zn15	12	18.67±1.137 a	42.00±1.279 a	57.00±1.279 b	81.00±0.000 a
Zn30	12	12.67±0.000 b	45.00±3.837 a	66.00±1.279 a	84.00±1.279 a
Sig.	48	1.000 / 0.080	0.237	1.000 / 0.402	1.000 / 0.237
0	12	18.67±2.842 ab	48.00±1.279 ab	63.00±0.000 ab	75.00±1.279 b
Fe+Zn5+7.5	12	24.00±0.000 a	42.00±0.000 b	66.00±1.279 b	84.00±1279 a
Fe+Zn10+15	12	16.67±0.284 b	51.00±1.279 a	60.00±1.279 c	75.00±1.279 b
Fe+Zn20+30	12	17.33±0.284 b	48.00±2.558 ab	72.00±0.000 a	84.00±1.279 a
Sig.	48	0.759 / 0.055	0.073 / 0.597	0.103 / 1.000	1.000

Table 17. According to phenological periods disease severity (%DS) evaluations at repetitive fertilizer application (Fe, Zn, Fe+Zn*)* doses Anova results in Demir 2000 variety

Demir 2000	Phenological Period (Feekes)	HKT	df	HKO	F	Sig. (P)
Fe	10.5.1	1642.667	3	547.556	20.533	0.000
	10.5.3	0.000	3	0.000	0.000	1.000
	10.5.4	1080.000	3	360.000	36.667	0.000
	11.1	648.000	3	216.000	14.667	0.000
Zn	10.5.1	869.333	3	289.778	10.305	0.000
	10.5.3	297.000	3	99.000	1.681	0.185
	10.5.4	1948.000	3	649.333	29.927	0.000
	11.1	648.000	3	216.000	14.667	0.000
Fe+Zn	10.5.1	398.667	3	132.889	5.374	0.003
	10.5.3	513.000	3	171.000	4.976	0.005
	10.5.4	945.000	3	315.000	32.083	0.000
	11.1	972.000	3	324.000	16.500	0.000

RMSE: Error Sum of Squares F: Comparison Table Value of Sample Means df: Degrees of Freedom
MSE: Error Mean Squares Sig.(p): Significance Level in Comparison

In the Eser variety, in general, Iron (Fe) applications led to a decrease in disease severity in all phenological periods in the Bread Eser variety. Iron can reduce or moderate the effects of a variety of foliar diseases, including rust infections in wheat and bananas, to variable degrees (Graham and Webb, 1991). Applications of zinc (Zn) led to an increase in the early era, a drop in the middle period, and both an increase and a decline in the late period. Zn treatment, which has a direct toxic effect on pathogens rather than plant metabolism, can frequently lower the severity of disease (Graham and Webb, 1991).

Abd El-Hai et al. (2007), in laboratory and field experiments, stated that nutritional elements (Fe, Zn, Ca, Mn) were promising in controlling both rust and chocolate spot diseases in faba bean. Many traditionally used chemicals are insufficient to control brown spots and rust diseases (Harrison, 1988). In addition, these chemicals are used more limitedly due to the high cost of use and their negative environmental effects on microflora (Khaled et al., 1995).

Therefore, it has become important to develop alternative methods to control plant diseases in soybean. It has been reported that microelement applications from the leaf surface of some plants reduce plant diseases (Abd-El-Karem et al., 2004, El-Gamal et al., 2007). Micronutrients have been applied in many areas of plant production as plant growth stimulators (Scheuerll and Mahafee, 2006). The chlorophyll content was taken as an index for the degree of reduction in effective green areas. Rust diseases reduce photosynthetic activity in leaves and consequently lower yields, increase chlorophyll-a or chlorophyll-b concentrations of Fe and Zn microelements and the total content of leaves (Sinha et al., 1970; Rahhal, 1993). In addition, Abd El-Razek et al., (2012) reported that 4g/L micronutrient administration significantly increased chlorophyll-a compared to control. The same trend was found in chlorophyll b. However, the chlorophyll-b value was significantly lower than the chlorophyll- value. In a study on soybean in corn during the 2010-2011 and 2011-2012 development periods, they found that it reduced rust disease from 15.4% to 62.8% (Morsy and El. Morsy, 2013).

Conclusions

In this study, it was observed that the area 60 cm above the root surface of the plant was affected more, and the application of Fe+Zn+Mn in the first season reduced the rust disease from 16.4% to 6.03% compared to the untreated (control) plant, and as a result, the disease decreased by 62.8%. In the same study, Zinc (Zn) application alone reduced the disease by 7.47%, and Fe+Mn application reduced 8.6%. During the 2011-2012 development period, the best results were obtained from zinc alone (5.1%), Manganese (7.6%) and Iron+Zinc+Manganese (7.9%). Application of Fe+Zn did not result in a decrease in the early period and did not result in a significant change in the middle and late periods. Bayraktar 2000 showed a decrease/increase in the early period, an increase in the early-mid period, an increase/decrease in the mid-late period, and an increase in the late period. While zinc (Zn) applications caused a decrease in the early period, they decreased/increased in the early-middle and mid-late periods, and increased in the late period. Fe+Zn applications, on the other hand, showed an increase/decrease in the early and mid-late period, and an increase in the severity of the disease in the early-middle and late periods. In Kenanbey, Fe applications caused an increase in disease severity in the early and early-mid periods, a decrease in the mid-late period, and an increase in the late period. The increase in Zn applications in the early period showed a decrease in the severity of the disease in all other periods. Fe+Zn applications increased in the early period and decreased in all other periods. In the Demir 2000, Fe applications increased/decreased in the early period, decreased/increased in the mid-late period, and increased in the late period. Zn applications increased/decreased in the early period, decreased/increased in the early-middle period, decreased/increased in the mid-late period, and increased in the late period. Fe+Zn applications increased/decreased in the early and mid- late periods, decreased/increased in the early-middle period, and increased in the late period. In terms of yield, the Bayraktar variety was observed as the least affected variety by disease severity, with yield increases, all other cultivars were significantly affected by disease severity, and yield decreases. In terms of reducing the severity of the disease with fertilizer applications, Iron (Fe) dose applications in the Eser variety and zinc (Zn) dose applications in the Kenanbey variety were both effective in reducing disease severity. Although Fe and Zn applications increased the disease severity in all phenological periods in the Bayraktar variety, they did not cause significant losses in yield. In Demir 2000 variety, Fe and Zn applications caused both an increase and a decrease in disease severity, and losses in yield were observed. When the phenological periods were compared, the change in disease severity was evaluated as the most observed variety after Kenanbey.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that might apper to influence the work reported in this paper.

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Author Contribution

MA: Idea/Hypothesis, Material, Method, Research, Data-Processing, Data-Analysis, Visualization, Executive/Consultant, Thesis Management, Original Drafting, Writing- Reviewing & Editing; KA: Data processing, Executive/Consultant, Writing-Reviewing & Editing. All authors have read and agreed to the published version of the manuscript.

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RESEARCH PAPER

Agricultural land suitability assessment with GIS-based multi-criteria decision analysis and geostatistical approach in semi-arid regions

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Fuzzy model
AHP

Abstract

For sustainable land use planning, evaluating land characteristics and making suitable land use decisions is a priority and critical step. In order to make these evaluations safely, spatial analyzes of many criteria should be made. In this study, the suitability of the land for wheat production was evaluated by Geographical Information Systems (GIS) based Multiple Criteria Decision Analysis (MCDA) in semi-arid conditions. In obtaining the land suitability map; fuzzy set model, Analytical Hierarchy Process (AHP) and GIS are integrated. Ecological criteria weights for agricultural land suitability were determined by AHP. In the suitability analysis, a total of criteria including soil and topographic features were evaluated. Geostatistical analysis approach was applied to determine the spatial variability of soil properties (sand, clay, silt, pH, OM, CEC, ESP, $CaCO_3$, EC). The lowest variation among soil properties was observed in pH (3.8%), while the largest variation was observed in ESP content (107.5%). The nugget/sill ratio is poor for EC and pH, while other soil properties are moderately spatially dependent. According to the results of the analysis, 25.7% (3.226 km^2) of the area is highly suitable, while 27.6% (3.457 km^2) is moderately suitable and 19.5% (2.440 km^2) is marginally suitable for wheat cultivation. In addition, 27.2% (3.415 km^2) of the area is not suitable for agricultural production. The use of geostatistical modeling, MCDA and GIS together is very beneficial in making agricultural land management decisions.

Introduction

In the face of the rapidly increasing world population, the sustainability of agricultural production is one of the most important problems for the future. According to the projection of the United Nations organization, the world population is estimated to be between 8.3 and 10.9 billion by 2050. In this case, the increase in food demand will require an increase in agricultural production by 50 to 75% (Prosekov & Ivanova, 2018). On the other hand; climate change, natural disasters, land constraints make it difficult to achieve optimal production and agricultural sustainability (FAO, 2017; Tóth et al., 2018; Arora, 2019). Increasing environmental constraints gradually increasing the pressure on agricultural lands, which is a

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limited natural resource. In order to reduce the impact of these difficulties, it is necessary to create rational agricultural plans and strategies and to use agricultural lands effectively.

Land suitability assessment is a fundamental data for the sustainable development of agriculture and for accurate land use planning. Therefore, sustainable land use planning and management is important for increasing production and protecting land resources (Baroudy, 2016). Land suitability assessment is a preliminary step in land use planning (FAO, 1993). In agricultural production, it is necessary to determine the land conditions in order to obtain maximum benefit per unit area at the economic level. In agricultural production, it is necessary to determine the land conditions in order to obtain maximum benefit per unit area at the economic level. The suitability of the land for a crop includes the evaluation of many different criteria such as climate, soil, topography, water resources (FAO, 1976; Sys, 1985). Identifying effective land features and obtaining accurate data is a priority to determine the suitability of an area for a particular land use.

Important factors affecting crop production are soil and topographic features apart from climate. Soil features have a heterogeneous structure in the land and show a spatial distribution where variation is seen depending on distance (Zhan et al., 2020). This distribution can be affected by soil management, fertilization, crop rotation, land characteristics and geomorphological structures (Cambardella & Karlen, 1999). Spatial distribution maps of soil properties are one of the basic inputs of agricultural land suitability and sustainable agricultural planning (Aggag & Alharbi, 2022). Spatial variation maps of soil properties can better correlate soil properties with ecological conditions (Goovaerts, 1998). There is spatial dependence for soil variables (Webster, 1985). The spatial dependence of the variables is determined by variogram analysis (Mcbratney & Pringle, 1999). The relationships with the distance between the samples are characterized by the variogram (Trangmar et al., 1985). Kriging is an interestimation technique that can make spatially linear estimation with variogram models (Khan et al., 2019). In the geostatistical approach, spatial variability of soil properties for different land uses is characterized by spatial modeling (variogram) and spatial interpolation (kriging) (Kariuki et al., 2009; Liu et al., 2014; Reza et al., 2016; AbdelRahman et al., 2020). Spatial distribution maps are produced by integrating geostatistics and GIS techniques (Tashayo et al., 2020; Yeneneh et al., 2022).

Crop production is under the influence of different ecological characteristics. In the MCDA approach, spatial decisions can be made by evaluating many criteria according to the determined purpose (Malczewski, 2006). In eliminating the uncertainty, the values belonging to the objects are assigned to the set membership with functions and converted into a standard scale (Zhang et al., 2015; Nguyen et al., 2015, Tuğaç, 2021). AHP is a decision-making method in which hierarchical structure and criterion weights are determined. AHP is based on pairwise comparisons of factors according to their importance using a comparison scale on the decision hierarchy (Ramamurthy et al., 2020; Everest et al., 2021). In the evaluation of different ecological characteristics in land suitability analysis, the integration of GIS and AHP provides spatial analysis of the data and rational results according to the preferences of the decision maker (Pilevar et al., 2020; Şenol et al., 2020; Shaloo et al., 2022).

Turkey has large production areas of wheat, barley, corn, sunflower, cotton and sugar beet crops. Approximately, 11 million hectares of these areas are cereal fields (TUIK, 2021). One of the main centers of agricultural production in Turkey is the Central Anatolian Region. While this region accounts for 35.8% of the total grain production, wheat (53.2%) and barley (36.7%) are widely produced in the region (TUIK, 2021). Due to the fact that the Central Anatolia Region is in a semi-arid climate regime, it is under the limiting effect of drought and precipitation distribution irregularities. For this reason, it is important to ensure the effective and sustainable use of lands in semi-arid areas. In this context, spatial variability of some soil properties was determined by geostatistical analysis in the study area. Agricultural land suitability for wheat was evaluated with the GIS-based Fuzzy-AHP approach, taking into account soil and topographic characteristics.

Materials and Methods

Study area

The study area is between 31° 49' 10" and 33° 46' 40" east longitudes and 38° 40' 21" and 39° 53' 05" north latitudes. The study area is between 31° 49' 10" and 33° 46' 40" east longitudes and 38° 40' 21" and 39° 53' 05" north latitudes. The area is located between Sakarya river in the west, Kızılırmak river in the east, and Lake Tuz in the south and has a surface area of approximately 12,537 km^2 (Figure 1). The study area consists of Polatlı, Haymana, Gölbaşı and Bala districts of the Ankara province and Kulu districts of the Konya province. The study area has a semi-arid climate regime that typically characterizes the Central Anatolia Region. The average annual temperature is 11.3°C. The monthly average 98 temperature ranges from -2 to 24°C. The coldest month is January with a minimum temperature of -14°C. The hottest months are July and August, when the maximum temperature exceeds 37°C. The average annual precipitation of the area is 378 mm. Steppe vegetation characterizes the region (Öner et al., 2016). The elevation of the study area is between 620 m and 1,865 m and the average elevation is 1010 m above sea level.

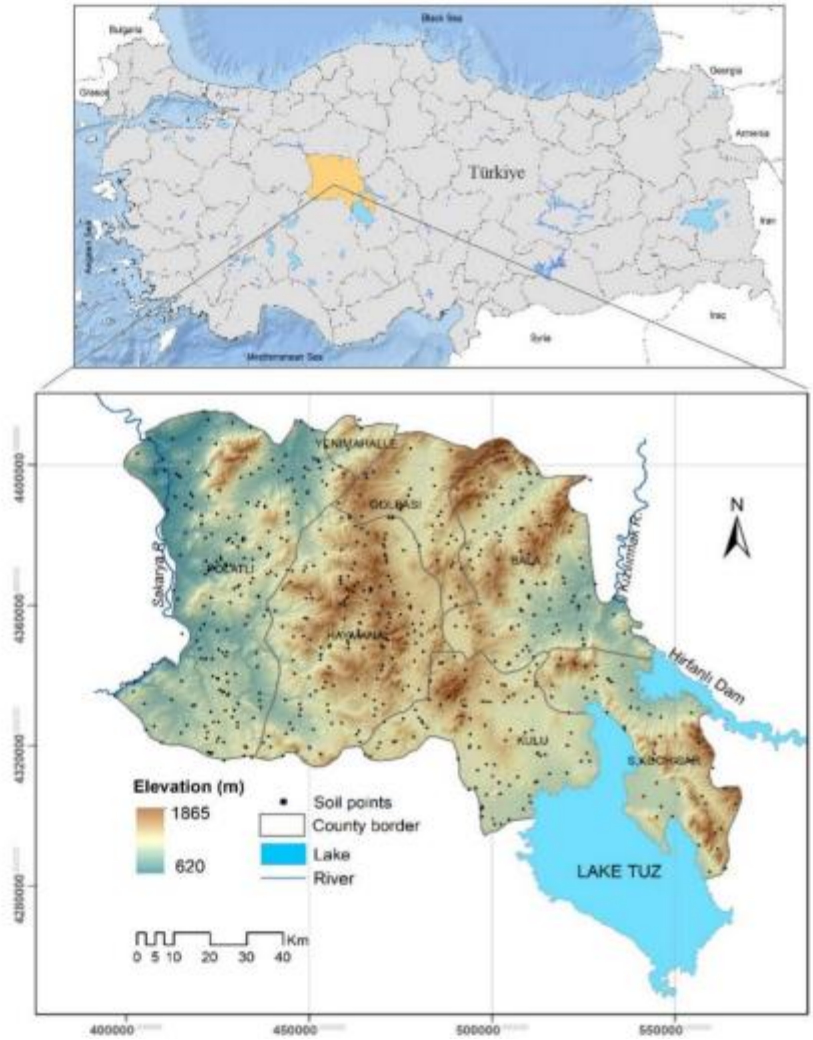

Figure 1. Study Area.

Sandstone, conglomerate and limestone are common in the area as geological formations (Ünalan et al., 1976). Wheat and barley are the main crops in the region, which mainly consists of rainfed agricultural areas. Except for cereals; chickpeas, beans, lentils, sunflowers, safflower, sugar beet and corn are produced throughout the region.

Data sources

The agricultural suitability of the area was evaluated by considering the soil and topographic characteristics. Digital Elevation Model (DEM) was created by combining 1/25,000 scale topographic maps and then slope parameter was obtained. Soil data includes 1/25,000 scaled digital soil database and land evaluation survey data produced by the Ministry of Agriculture and Forestry, and soil samples collected from field studies. Physical and chemical parameters obtained from 640 soil samples were used to determine the spatial changes of the study area. Spatial distribution maps of soil parameters were prepared using Ordinary Kriging (OK) interpolation technique. Geostatistical analysis, parameter maps and land suitability model were produced using ArcGIS 10.4 program.

Geostatistical analysis

Geostatistical analysis provides spatial models of samples taken from the field to make estimations at unsampled locations and evaluate the uncertainty associated with these estimations (Goovaerts, 1998). In the geostatistical approach, mostly variogram functions are used to determine the relationship based on distance (Mousavi et al., 2017). The variogram function is the variance of the difference between two random variables separated by the distance (h) from each other. The variogram function equation (Equation 1) characterizing the spatial variability of a variable is given below (Trangmar et al., 1985).

Eq. (1) $$\Upsilon(h) = \frac{1}{2N(h)}\sum_{i=1}^{N(h)}[Z(x_i) - Z(x_i + h)]^2$$

Where, $Z(x_i)$ is the soil properties measured at the x_i location, Y(h) represents the variogram for the lag distance h between $Z(x_i)$ and $Z(x_i + h)$, and N(h) is the number of data pairs. In the variogram graph, the y-axis is the variance, and the x-axis is the lag distances, in other words, the distance between the pairs of points. One of the kriging methods, OK, is based on taking the weighted average of the points containing the measured value in an area. The estimation equation (Equation 2) for OK is given below (Webster & Oliver, 2001).

$$\text{Eq. (2)} \qquad \hat{Z}(x_o) = \sum_{i=1}^{N} \lambda_i \, z(x_i)$$

Where, Ẑ(x0) is the predicted value, N is the number of observations, λi, z (x_i) is the weight assigned to the measured values. One of the frequently used methods for the determination of variogram model parameters is the cross validation technique. In this method, the difference between the actual values and the estimated value is calculated and the statistics of the estimation errors are checked. The variogram model and parameters that meet the desired criteria for these statistics are determined. The mean error (ME), root mean square error (RMSE) and root mean square standardized error (RMSSE) equations (Equation 3-5) applied in cross validation are given below.

$$\text{Eq. (3)} \quad \text{ME}=\frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)$$

$$\text{Eq. (4)} \quad \text{RMSE}=\sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)^2}$$

$$\text{Eq. (5)} \quad \text{RMSSE}=\sqrt{\frac{1}{n}\sum_{i=1}^{n}[(P_i - O_i)/\sigma_i]^2}$$

Where; P is the estimate, O is the observed value, and n is the number of samples. Low MAE and RMSE represent higher prediction accuracy, while RMSSE is desired to be close to 1.

Land suitability assessment

Land suitability assessment includes criteria standardization, criterion weighting and land suitability map creation in the MCDA approach.

Fuzzy set modelling

Fuzzy set approach was used to define different criteria with a common criterion in agricultural land suitability assessment. In the fuzzy set approach, a function is created to define continuous data and assign membership degrees. With a scale between 0 and 1, objects with high-value membership classes are assigned to a better suitability class (Zadeh, 1965). A fuzzy set (A) can be expressed as follows (Burrough, 1996).

$$A= \{x, MF(x)\}, x \in X$$

Here, x ϵ X belongs to a finite set of points. MF is membership function of x in A. Therefore, a fuzzy subset is defined by the MF, which describes the membership degrees of the objects. The MF of a fuzzy subset determines the degree of membership of x in A. For all A, MF(x) is a value in the range 0 -1. In this context, MF = 0 indicates that the value x does not belong to A and MF = 1 indicates that the value completely belongs to A. On the other hand, if 0 < MF(x) < 1, it is defined as partial A.

There are different models for constructing the MF function. In this study, the Semantic Import (SI) model was applied to grade land features (Burrough & McDonnel, 1998). The attribute values, which are evaluated depending on the phenological development of the product and the land requirements, are converted into common membership degrees (0-1) according to the threshold values determined by taking into account the expert opinions (Zhang et al., 2015; Bagherzadeh & Gholizadeh, 2018; Arab & Ahamed, 2022). In the cellular data structure, 1 indicates full membership or suitability, while 0 indicates unsuitability. For each criterion, a function definition is made in accordance with the data structure. These functions can be defined as linear model, symmetric optimum range model-SFM (Equation 6), left asymmetrical model-ALFM (Equation 7) and right asymmetric model-ARFM (Equation 8) (Figure 2).

$$MF(x_i)=\begin{cases} 1 & (c_1+d_1) \le x_i \le (c_2-d_2) \quad \text{Eq. (6)} \\ 1/(1+(x_i-c_1-d_1)/d_1)^2) & x_i < (c_1+d_1) \quad \text{Eq. (7)} \\ 1/(1+(x_i-c_2+d_2)/d_2)^2) & x_i > (c_2-d_2) \quad \text{Eq. (8)} \end{cases}$$

Where, $MF(x_i)$ represents the membership function value, x_i is the land feature, c_1 and c_2 are the center point value where the MF is 0.5, d_1 and d_2 are the width of the transition region (distance from the center).

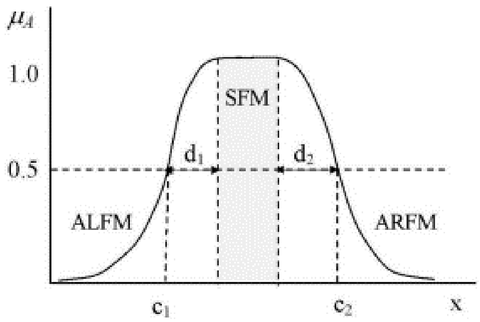

Figure 2. Fuzzy membership functions

According to the variables, an increase in the values of slope, $CaCO_3$, EC and ESP parameters indicates a decreasing suitability value, while a high soil organic matter value indicates an increased suitability value.

Table 1. Fuzzy membership function thresholds of land suitability criteria for wheat

Criteria	Model	Suitable (Complate membership)	Unsuitable (non membership)	Weight
Slope (%)	ARFM	<3	>15	0.182
Elevation (m)	ARFM	<1100	>1500	0.029
pH	SFM	6.5-7.5	>8.5, <5	0.063
EC (dS/m)	ARFM	< 2	>16	0.042
OM (%)	ALFM	> 3	< 0.5	0.077
$CaCO_3$ (%)	ARFM	< 15	> 40	0.052
CEC (cmol/kg)	ALFM	> 24	< 16	0.022
ESP (%)	ARFM	<15	>45	0.013
Depth (cm)	Linear	deep	very shallow	0.237
Texture (class)	Linear	medium	very coarse	0.103
Erosion (class)	Linear	none	severe	0.129
Drainage (class)	Linear	good	poor	0.035
Stoniness (class)	Linear	none	high	0.017

ARFM: Right asymmetric model, ALFM: Left asymmetrical model, SFM: Symmetric model, OM: organicmatter, CEC: cation exchange capacity, ESP: exchangeable sodium percentage, EC: electrical conductivity

Therefore, ARFM and ALFM models were applied for these factors, respectively. In addition, symmetric membership function (SFM) was used for soil pH. Among the soil properties, the data with vector data structure are divided into suitability classes. In this context; depth (deep (>90), moderate (90-50), shallow (50-20), very shallow (<20)), erosion (none, light, medium, severe), drainage (good, moderate, insufficient, poor), texture (fine(Sandy clay, Clay>%45, Silty clay), medium (Silt, Silt loam, Loam, Clay loam, Silty clay loam, Sandy clay loam, Clay<%45), coarse (Sandy loam), very coarse (Loamy sand, sand)) and stoniness (none, light, medium, high) layers were created. The suitability classes of soil physical properties are graded between 1 and 9 according to their importance levels. The threshold values of the parameters for the wheat suitability analysis were developed based on the literature (Sys et al., 1993) and expert opinions (Table 1).

Analytical hierarchy process

A decision problem can be divided into four main parts in the AHP approach. (i) the decision problem is defined, (ii) the comparison matrix between factors is created, (iii) factors weights are determined, (iv) the consistency of the comparison matrix is measured.

In defining the decision problem, the factors affecting the determination of the agricultural suitability of the land are determined. In particular, the correct determination of the effective factors is important in terms of making pairwise comparisons consistent.

The Original Matrix (A) was created, comparing the priorities of all criteria with each other. The comparison matrix is an m x n square matrix (Figure 3). It takes the value 1 when the components on the diagonal of this matrix are i=j. Factors are compared with each other according to their relative importance. A scale of 1 to 9 is used to compare variables. In this scale, one factor takes the value 3 if it is more important than the other, and 9 if it is extremely important. If the opposite is true, it is expressed as $x_{ij}=1/x_{ji}$.

$$A = \begin{bmatrix} 1 & x_{12} & x_{1i} & x_{1j} & x_{1n} \\ x_{21} & 1 & x_{2i} & x_{2j} & x_{2n} \\ x_{i1} & x_{i2} & 1 & x_{ij} & x_{in} \\ x_{j1} & x_{j2} & x_{ji} & 1 & x_{jn} \\ x_{m1} & x_{m2} & x_{mi} & x_{mj} & 1 \end{bmatrix}$$

Figure 3. Comparison matrix

Matrix values are normalized. Here, matrix C is formed by dividing the pairwise comparison values of matrix A by the column sum (Figure 4).

$$k_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}$$

$$C = \begin{bmatrix} k_{11} & k_{12} & \cdots & k_{1n} \\ k_{21} & k_{22} & \cdots & k_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ k_{m1} & k_{m2} & \cdots & k_{mn} \end{bmatrix}$$

Figure 4. Normalized pairwise matrix

By using the C matrix, the percent importance values of the factors relative to each other are obtained. For this, the arithmetic average of the sum of the row components forming the C matrix is taken and the priority vector (w) is obtained (Figure 5).

$$w_i = \frac{\sum_{i=1}^{n} kij}{n} = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix}$$

Figure 5. Weighted criteria matrix

The consistency of the pairwise comparison matrix is measured. The Consistency Ratio (CR) is calculated with the equation (Equation 9) given below. In the equation, CI is the consistency index and RI is the random index. The following formula (Equation 10) is used to calculate the consistency index (CI):

Eq. (9) $CR = CI/RI$
Eq. (10) $CI = (\lambda mak - n)/(n - 1)$

Where, λmax is the largest eigenvector of the preference matrix and n is the number of criteria. RI values according to the number of parameters are given in Table 2. If the calculated CR value is less than 0.10, it shows that the comparisons made by the decision maker are consistent. A CR value greater than 0.10 indicates either a calculation error in the AHP or inconsistency in the decision maker's comparisons (Saaty, 1980).

Table 2. Random index (RI) values (Saaty, 1980)

n	1	2	3	4	5	6	7	8	9	10	11	12	13
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56

Land suitability map

In the suitability model, the standardized cellular data values of the variables are weighted according to the importance of the parameters. In the GIS environment, an agricultural land suitability index (ALS) map is generated using the weighted linear combination method (Malczewski, 2011). The linear combination equation (Equation 11) is given below.

$$\text{Eq. (11)} \qquad ALS = \sum_{i=1}^{n} w_i x_i$$

Where, ALS is the land suitability index value, wi is the weight of the criterion, x_i is the standardized criterion value, n is the number of criteria. ALS is divided into suitability classes as suitable (S1), medium (S2), low (S3) and unsuitable (N) areas (FAO, 1985).

Results and Discussion

Soil characteristics

Soil physical properties, depth, erosion, drainage and stoniness maps were obtained from the soil database. Geostatistical analysis was applied to create spatial maps of soil properties (sand, silt, clay, pH, EC, $CaCO_3$, OM, ESP, CEC). Geostatistical modeling and

Table 3. Descriptive statistics of soil parameters

Soil Criteria	Minimum	Maximum	Mean	CV	SD	Skewness	Kurtosis
Sand (%)	9.9	92.5	39.0	34.7	13.6	0.72	3.9
Clay (%)	0.4	72.7	34.5	34.8	12.0	-0.05	2.8
Silt (%)	1.8	56.7	26.5	27.6	7.3	0.28	4.1
CEC (cmol kg^{-1})	10.8	54.7	29.2	26.2	7.7	0.37	3.0
pH	6.6	8.7	7.7	3.8	0.3	-0.33	3.4
$CaCO_3$ (%)	0.8	68.7	18.3	57.2	10.4	1.29	5.9
OM (%)	0.3	5.6	1.3	40.7	0.54	1.88	12.3
ESP (%)	0.1	15.3	1.8	107.5	1.9	2.74	12.6
EC (ds m^{-1})	0.2	8.8	1.0	76.9	0.73	6.18	56.7

CV: coefficient of variation; SD: standard deviation, OM: organic matter; CEC: cation exchange capacity, ESP: exchangeable sodium percentage, EC: electrical conductivity creation of parameter maps are completed in two parts. (i) Descriptive statistics were determined to describe the trends and distributions of soil properties. (ii) Ordinary Kriging (OK) technique was used to determine the spatial dependence and variability of soil parameters.

Descriptive statistics for soil properties are given in Table 3. While the sand, clay and silt values of the soils vary between 9.9-92.5%, 0.4-72.7% and 1.8-56.7%, the averages are 38.9%, 34.5% and 26.5%, respectively. $CaCO_3$ content varies between 0.8% and 68.7%, with an average of 18.3%. Organic matter content varies between 0.3% and 5.6%, with an average of 1.3%. While the pH level in the area ranged from 6.50 (slightly acidic) to 8.70 (strongly alkaline), it was characterized as slightly alkaline with an average value of 7.70. It can be said that the area is suitable for agricultural production in terms of average value. The CEC content varies between 10.8% and 54.7%, with an average of 29.2%. While the EC level varies between 0.2 and 8.8 ds m^{-1}, its average value is 1.0 ds m^{-1}, and it is not at a level that will adversely affect the wheat in the whole area. On the other hand, there is moderate salinity in some areas as irrigated agriculture is intense. The ESP value varies between 0.1% and 15.3%, with an average value of 1.8%.

The normal distribution of the data sets was evaluated according to the skewness values of the variables. Webster & Oliver (2001) stated that if the skewness value is greater than 1, transform can be done. In this context; While Clay, Silt, CEC and pH showed normal distribution, Sand, OM, $CaCO_3$, ESP and EC did not show normal distribution and positive skewness was determined and log-transform was applied. This need for transformation has been consistent with similar studies (Di Virgilio et al., 2007; Liu et al., 2014; Mousavifard et al., 2013; Bogunovic et al., 2017; Sharma & Sood, 2020).

The variability of the datasets is evaluated with the coefficient of variation (CV). A CV value of less than 15% indicates a weak variation, a moderate variation of 16-35%, and a high variation above 36% (Wilding, 1985). Among the variables, pH showed a weak change with the lowest (3.8%) value, while ESP showed the highest change (107.5%). While pH, the parameter with the lowest CV value, is the least affected by the land structure and agricultural practices, OM (40.7%), $CaCO_3$ (57.2%), EC (76.9%) and ESP (107.5%) with a CV value > 35 are the most affected soil properties. On the other hand, there is moderate variability (26.4-34.8 % CV) for CEC, Silt, Sand and Clay. Soil pH value showed a homogeneous distribution with a low CV value (3.8%) and showed similarity with other studies (Emadi et al., 2008; Jiang et al., 2012; Mousavifard et al., 2013; Bogunovic et al., 2014).

Spatial variation of soil properties

The geostatistical analysis showed different spatial distribution patterns and nugget/sill relationships explaining the spatial relationships for the selected soil features. Spatial distributions of soil properties are described by Ordinary Kriging technique and isotropic variogram models. Spatial distribution models and spatial dependence degrees were determined for the variables by geostatistical analysis. The spatial variability of sand, clay, silt, OM, $CaCO_3$, CEC and pH were described by the exponential model, while the ESP and EC variables were best characterized by the spherical model (Table 4). Model type and parameters are given in Table 4, and experimental and model variograms are given in Figure 6.

The nugget-to-sill ratio gives a measure of the short-range variability of the variable. It can be said that if this ratio is below 0.25, a large part of the variance is spatially included and there is a strong spatial dependence, if it is between 0.25 and 0.75, it is medium level, and if it is above 0.75, there is a weak spatial dependence due to a high short-distance variability (Cambardella et al., 1994). In this context, there is generally a moderate short-range variability for the study area soils, while there is a weak spatial dependence for EC and pH. Cambardella et al. (1994)

Table 4. Geostatistical model and model parameters of soil parameters

Soil Criteria	Model	Nugget	Sill	Nugget/ Sill	Spatial Dependence	Range (km)	Cross Validation		
							ME	RMSE	RMSSE
Sand (%)	Exponential	90	160	0.56	Moderate	18	-0.15	12.2	1.05
Clay (%)	Exponential	66	140	0.47	Moderate	16	0.014	11.1	1.05
Silt (%)	Exponential	26	50	0.52	Moderate	15	0.012	6.64	1.02
$CaCO_3$ (%)	Exponential	0.12	0.43	0.28	Moderate	23	0.54	8.49	0.91
CEC (cmol kg^{-1})	Exponential	34	63	0.54	Moderate	50	-0.015	6.73	1.03
OM (%)	Exponential	0.07	0.16	0.43	Moderate	13	0.001	0.51	1.06
ESP (%)	Spherical	0.45	0.75	0.60	Moderate	4	0.007	1.79	0.96
EC (ds m^{-1})	Spherical	0.17	0.20	0.85	Weak	4	-0.032	0.73	1.50
pH	Exponential	0.072	0.086	0.84	Weak	16	0.002	0.29	1.01

ME: Mean error, RMSE: root mean square, RMSSE: root mean square standardized error

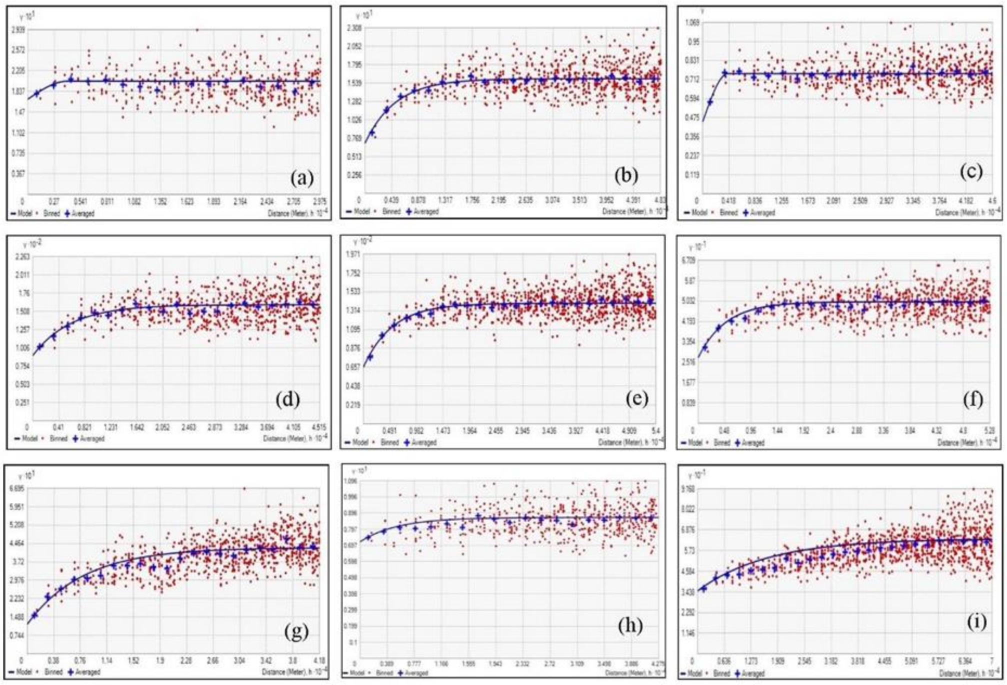

Figure 6. Experimental variogram models of soil properties (a) EC, (b) OM, (c) ESP, (d) 396 sand, (e) clay, (f) silt, (g) $CaCO_3$, (h) pH, (i) CEC

stated that the dependence of soil properties is closely related to topography, climate, parent material and land use. In the variogram model, the structural distance (range) value represents the maximum distance of the relationship depending on the distance, and beyond that, there is no autocorrelation between the variables (Behera et al., 2018). The highest range value was observed in the CEC (50 km) content, while the lowest was determined at 4 km in the EC and ESP variables.

Distribution maps of soil and topographic features are given in Figure 7. In terms of soil texture characteristics, while the clay content in the area varies between 30-40%, the areas with higher clay content are mostly located in the middle part of the area. It was observed that the clay content decreased to 25-30% around Lake Tuz and along the river, which also constitutes the boundaries of the area in the west and east. In the areas where the clay content is low, the sand content rises to 45%. While the clay content drops below 30% around Lake Tuz, the sand content rises above 50%. In a general approach, it can be said that the sand content is low in areas with high clay content. The negative relationship between the clay and sand contents of the soils is seen in the distribution maps (Figure 6). This situation was similar to previous studies (Tesfahunegn et al., 2011; Selmy et al., 2022). The widespread distribution of conglomerate and limestone materials can be attributed to the high sand content found in alluvial lands.

Although the EC varies between 0.2 and 8.8 dS m^{-1}, the average salinity in the area is not sufficient to restrict crop growth. Lake Tuz, located in the southeast of the study area, is the second largest lake in Turkey. Lake Tuz is important as a salt source and has a high value both as a natural structure and as a habitat. Lake Tuz and its surroundings are covered with Oligocene aged formations with gypsum and salt layers. Although the lake is closed, it is fed by underground and surface waters (Dengiz & Baskan, 2009). In addition, the Hirfanlı Dam is located on the Kızılırmak river in the east of the study area. It has been observed that moderate saline soils are present in the irrigated agriculture areas around Lake Tuz and Hirfanlı Dam. EC is one of the soil properties with the shortest distance range. Similar studies have also stated that EC has the shortest range compared to other soil properties (Emadi et al., 2008; Kılıç et al., 2022). The OM content ranges from 0.3% to 5.6%, while the coefficient of variation value has a high variation of 40.7%. It was observed that the OM content was higher than the average (1.3%) in the southwestern and central parts compared to other areas. The $CaCO_3$ content in the study area increases from east to west. While the $CaCO_3$ rate varies between 15-30% throughout the area, moderately calcareous areas are common. Depending on the parent material, the $CaCO_3$ has moderate short-range variability in the area. While the CEC is 25-28 cmol/kg in the western and eastern part of the area, it decreases to 20 cmol/kg in the southern part. In the central part of the area, as in the clay distribution, it increases and exceeds 35 cmol/kg. The pH content showed a weak spatial dependence, ranging from 7.4 to 7.8 (slightly alkaline) over a wide area (Figure 7).

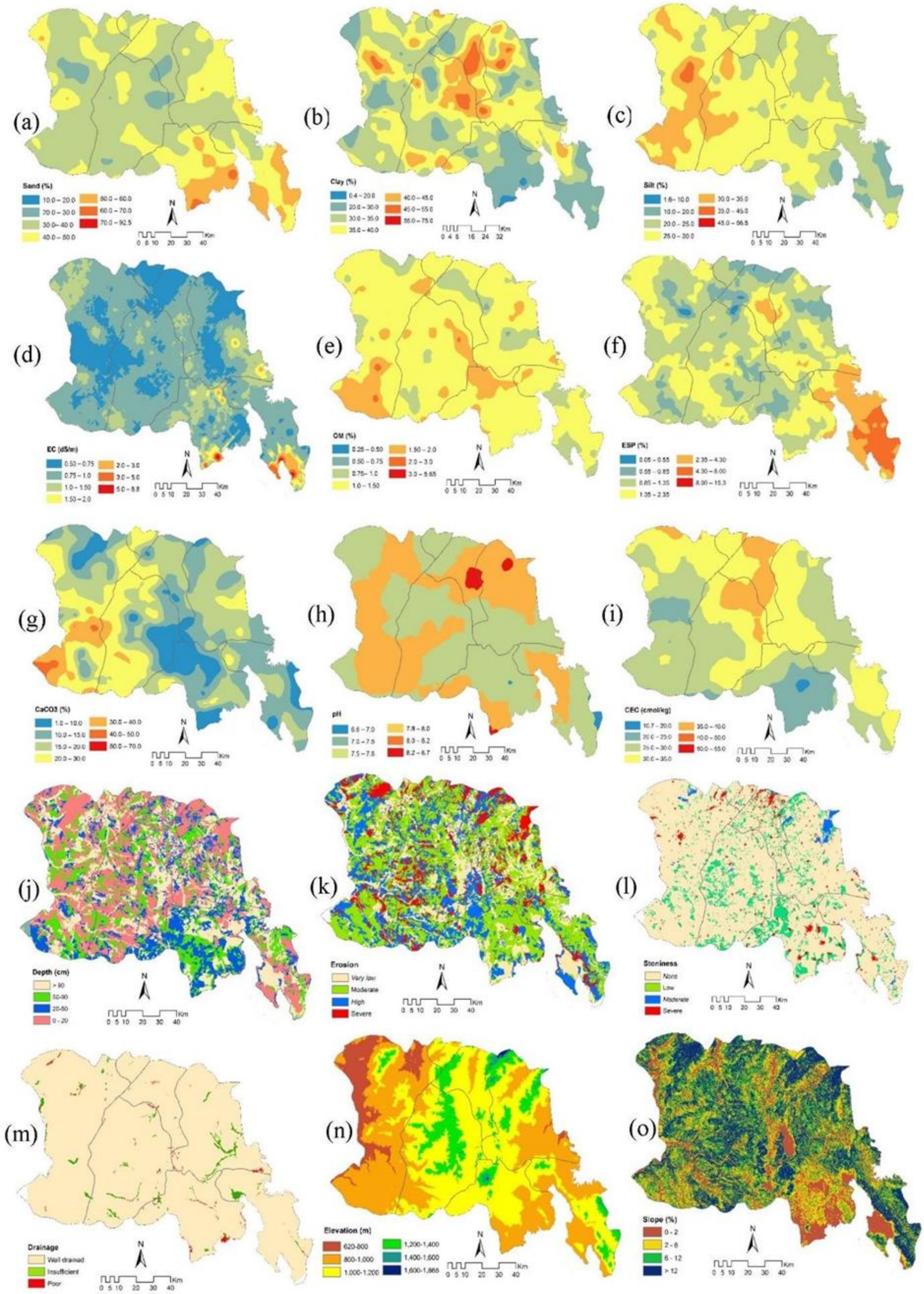

Figure 7. Soil and topographic parameter distribution maps (a) Sand, (b) Clay, (c) Silt, (d) EC, (e) OM, (f) ESP, (g) $CaCO_3$, (h) pH, (i) CEC, (j) depth, (k) erosion, (l) stoniness, (m) drainage, (n) elevation, (o) slope

Table 5. The correlation coefficients matrix of the studied soil attributes

	Clay	Silt	Sand	OM	ESP	CEC	$CaCO_3$	pH
Silt	-0.077*							
Sand	-0.843**	-0.471**						
OM	-0.008	0.200**	-0.101**					
ESP	0.009	-0.110**	0.052	-0.204**				
CEC	0.406**	0.052	-0.388**	-0.037	0.023			
$CaCO_3$	0.067	0.165**	-0.148**	0.131**	-0.100*	-0.140**		
pH	0.225**	-0.126**	-0.131**	-0.114**	0.066	0.008	0.007	
EC	-0.019	0.034	-0.002	-0.014	0.236**	-0.005	-0.020	-0.034

∗ $P < 0.05$, ∗∗ $P < 0.01$

The interpolation method used in spreading soil samples over the area is important. Soil properties values in unsampled areas were produced by kriging according to spherical and exponential variogram models. Spatial variation maps of soil parameters were produced using the OK method based on variogram models. It has been reported that the OK method performs well in mapping different soil properties (Tesfahunegn et al., 2011; Piccini et al., 2014; Pham et al., 2019; Dengiz, 2020). The cross-validation results of the prediction maps produced with OK are given in Table 4. The OK method produced lower RMSE errors to predict pH, EC and OM, while the highest RMSE errors were observed to predict sand and clay.

In the study area, the relations of soil properties with each other were evaluated. A strong negative relationship was observed between clay and sand (r = -0.843**), while a significant positive relationship was found between clay and CEC (r =0.406**) and pH (r = 0.225**). A significant negative relationship was found between sand and CEC (r = - 0.388**), OM (r = -0.101**), $CaCO_3$ (r = -0.148**), and pH (r = -0.131**). In the correlation analysis, a negative significant relationship was observed between OM and ESP (r = - 0.204**) and pH (r = -0.114**). In addition, there was a negative significant relationship between $CaCO_3$ and CEC (r = -0.140**), while a positive significant relationship was found between ESP and EC (r =0.236**) (Table 5).

In the findings obtained in similar studies; the relationships between clay and sand (Mustavifard et al., 2013; Kılıc et al., 2022), clay and CEC (Selenay et al., 2022; Usowicz & Lipiec, 2021) and ESP and EC (Selenay et al., 2022) variables consistent with the results of the study. The spatial variation of soil parameters and their interrelationships can affect soil management, fertilization, crop rotation, land characteristics and geomorphological structures (Cambardella & Karlen, 1999). In this context, the relationships between some soil properties in the literature could not be observed in the study area. In these studies, a positive relationship was determined between OM and clay and CEC (Saidian et al., 2016; Azadi & Baninemeh, 2022; Mishra et al., 2022). Soil organic matter content can be affected by climate, topography and land use (Durdevic et al., 2019), intensive tillage (Lopez-Fando & Pardo, 2011), and crop residue removal (Raffa et al., 2015). The low biomass of the steppe vegetation in the semi-arid climatic conditions in the Central Anatolian Region caused the soil organic matter to become poor (Öner et al., 2016). The study area is also under the influence of the steppe ecosystem and intensive agricultural activities for many years.

Land suitability evaluation

Multiple criteria analysis was applied to determine the suitability of agricultural land. In the suitability model, criterion weights were determined by the AHP approach (Table 6). Depth, which is among the soil physical parameters, has the highest weight with a value of 0.237. This criterion was followed by slope (0.182), erosion (0.129) and texture (0.103). Among the soil chemical properties, OM (0.077) has the highest weight. OM was followed by pH (0.063), Lime (0.052) and EC (0.042) parameters. The CR values of the criteria matrix were calculated as 0.059.

In the study area, the depth is the most effective factor with the highest weight value (0.237). Depth is an important criterion for moisture and plant nutrient intake (Dedeoğlu & Dengiz, 2019). Soil depth has different depth levels throughout the field. This situation creates a limiting effect for crop growth. Slope is the second most influential and weighted (0.182) factor in the study area. In areas where the slope is high, plant growth is limited with the decrease of plant root depth and the effect of erosion increases. In addition, these areas may have indirect negative effects on agricultural practices, mechanization and yield. In the Central Anatolian Region, depth and topographic parameters have significant weight in suitability studies for large areas (Özkan et al., 2020; Kılıc et al., 2022). In the field-specific evaluations, depth and slope factor were determined as the most important factors and showed similarities with other studies.

The steppe ecosystem is dominant in the Central Anatolia Region and it is a region with a high risk of land degradation and erosion due to topographic and anthropogenic conditions in semi-arid climate conditions (FAO-TOB, 2020). In the study area, there is erosion effect throughout the area due to the high sloping lands. In this respect, the weight value of erosion was determined as 0.129. The weight of the soil texture was calculated as 0.103. It has good and medium class soil structure throughout the Central Anatolian Region (Özkan et al., 2020). In the study area, there is a medium and clay loam texture, which is mostly suitable for wheat cultivation. Among the soil chemical parameters, OM has the highest weight (0.077). OM has an important effect on soil fertility in terms of both soil structure and plant nutrients (Obalum et al., 2017). A calcareous soil structure is common in the area and the pH value is between 7 and 8. These soils are in the slightly alkaline class due to their lime content and insufficient rainfall. pH, which is the basic soil criterion in land suitability analysis, plays an important role in the availability of plant nutrients. Therefore, pH has the highest weight value (0.066) after OM among the soil chemical properties. EC is not at a level that will adversely affect wheat production in the whole area, except around Lake Tuz and local areas where irrigated agriculture is made. In large areas, more sampling of areas with extreme soil properties or evaluation with sub-zoning can provide more accurate results for the area.

The land suitability class map was obtained by classifying the agricultural land suitability index (ALS) (Figure 8). According to the suitability map, 25.7% (3,226 km^2) of the area is highly suitable, 27.6% (3,457 km^2) is moderately suitable, 19.5% (2,440 km^2) is marginally suitable and 27.2% (3,415 km^2) is not suitable for wheat cultivation (Table 6).

Table 6. Spatial distribution of wheat suitability classes

Suitability classes	Area (km^2)	(%)
Highly suitable	3,226	25.7
Moderately suitable	3,457	27.6
Marginally suitable	2,440	19.5
Not suitable	3,415	27.2

Suitable class (S1) lands do not have a significant barrier to agricultural production. These lands are flat and nearly flat alluvial areas with 0-3% slope. These areas have deep soil structure and medium texture. Moderately suitable (S2) lands is important for

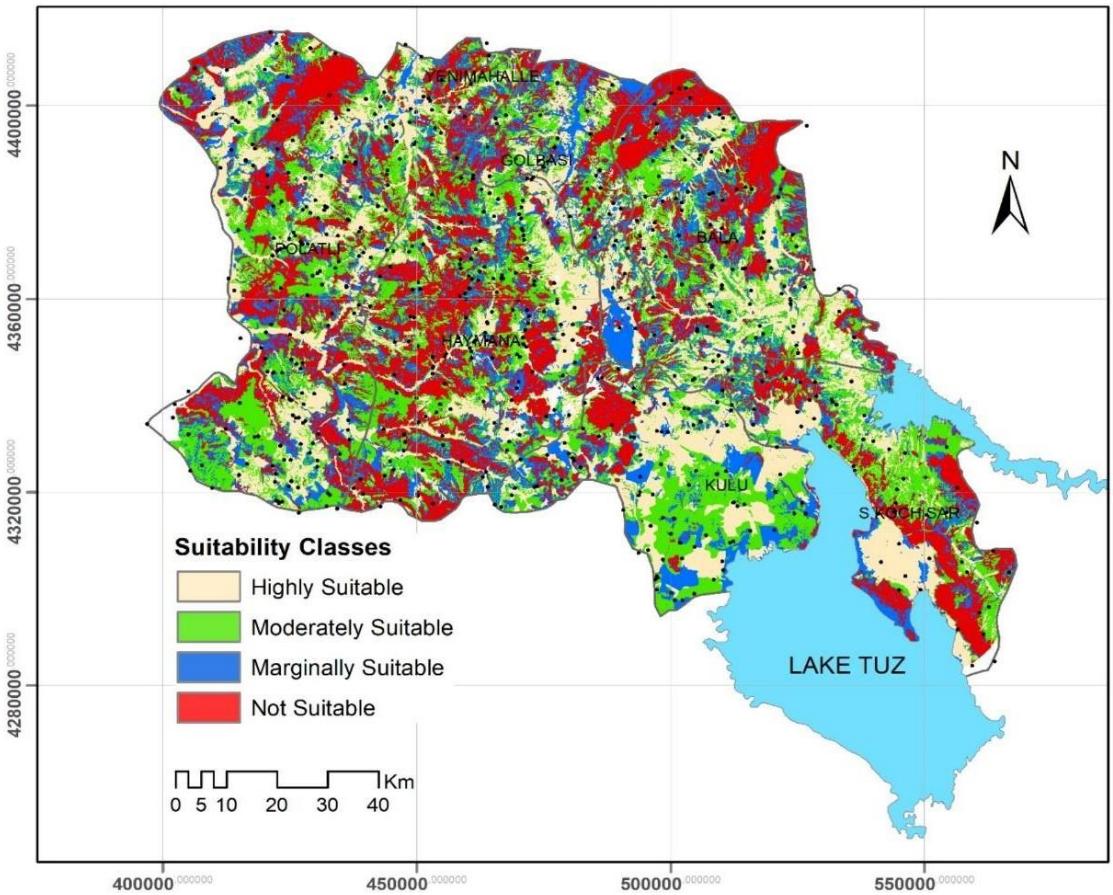

Figure 8. Land suitability classes for wheat

agricultural production, although it has several limitations for land use. This class covers 27.6% of the study area. Intensive agricultural activities are carried out on the soils in this class. The slope in these lands varies between 0-6% and they are medium deep soils. The less suitable (S3) lands, covering 19.5% of the area, have serious limitations. These lands have low agricultural potential due to negative features such as shallow soil depth, erosion risk, stoniness, low organic matter and protection measures are required. 27.2% of the area is not suitable for agriculture. These lands have very serious limitations due to insufficient soil depth, steep slope and severe erosion.

Conclusion

For semi-arid regions, wheat production is mainly preferred in dry agricultural areas. Due to the limited rainfall in these areas, the effects of soil and topographic conditions on production are high. Identifying effective land features among many variables is a priority for suitability analysis. Geostatistical modeling was applied to determine the spatial changes of soil parameters. Fuzzy-AHP and GIS integrated approach were applied in land suitability assessment. Potential areas for wheat production were determined by land suitability analysis. As a result of the study, 25.7% (3,226 km^2) of the area for wheat production is highly suitable (S1), While 27.6% (3,457 km^2) is mederately suitable (S2), 19.5% (2,440 km^2) is marginally suitable (S3) and 27.2% (3,415 km^2) is not suitable (N). In the preliminary stage of land use planning, it is important to evaluate land characteristics and develop land use alternatives. Since ecological needs differ in land use decisions, it is necessary to compare land characteristics with ecological demands and select the most optimum area. The relative importance of different parameters for land suitability was defined with AHP and integrated into the decision-making process with GIS techniques. MCDA has played an active role in evaluating many criteria and making the right choices. In the MCDA process, it is necessary to determine the relative importance or weight of the factors. At this stage, determining the effective criteria by evaluating the field conditions and expert opinions increases the accuracy of the result map. In the study area, it has been observed that the spatial variability of soil properties is high, but this variability is also effective in climate and topographic structure, as well as land use and agricultural practices. The results of the study can be an example for land planning studies in relation to the impact of ecological data on crop development in semi-arid and large areas. The land suitability maps produced in this context can be used as base data in current and future planning studies. In land use preferences, sustainability should be ensured by taking into account the balance of protection and use of the land, as well as the increase in production.

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Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that might apper to influence the work reported in this paper.

Author Contribution

MGT: Conceptualization, investigation, methodology, validation, software, carried out the field study, collected the soil samples, resources, data curation, writing (original draft preparation), writing (review and editing), visualization, supervision, statistical analysis, project administration; **AET:** Conceptualization, investigation, geostatistical analysis, writing (review and editing); **HT:** Carried out the field study, collected the soil samples, software, validation, investigation, data curation; **EK:** Carried out the field study, collected the soil samples, validation, investigation, data curation; **MU:** Investigation, validation, soil analysis, data curation. All authors have read and agreed to the published version of the manuscript.

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RESEARCH PAPER

Changes in some physical properties of the soils tread with wheat straw and rice husk under the rotation of white-head cabbage, tomato and wheat

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Abstract

This study was carried out silty clay (SiC) textured soil and silty land (SiL) textured soil in order to reveal the changes in some physical properties of the soil in white-head cabbage (WHC), tomato (T) and wheat (W) rotation after the application of wheat straw (WS) and rice husk (RH). Soil organic matter (OM), bulk density (BD), total porosity (F), aggregate stability (AS), mean weight diameter (MWD), field capacity (FC), volumetric water content (ϴ), penetration resistance (PR), relative saturation (RS) and initial infiltration (In) values were determined, after harvest of each plant. As the results of the experiments pointed out, soil OM contents and F values increased, while BD values decreased after WHC, T and W harvest with WS and RH application. With a higher C/N ratio, WS application increased soil OM content more than RH application. The lowest BD, AS, and MWD values were generally obtained after the WHC and T harvest, and the highest BD, AS, PR and in values after the W harvest. Soil OM content showed very significant negative relationships with BD (-0.561**), MWD (-0.680**) and RS (-0.528**) in the silty clay (SiC) textured soils, while it showed very significant negative relationships with BD (-0.809**), AS (-0.543**), MWD (-0.830**), PR (-0.555**) and very significant positive relationships with FC (0.728**), ϴ (0.814**), RS (0.767**) in the silty loam (SiL) textured soils.

Introduction

Improving the physical properties of the soil is important for sustainable plant growth and other living organisms in the soil. Poor soil structure leads to poor water and aeration conditions that restrict root growth, limiting the efficient use of nutrients and water by plants. It also affects the storage of organic carbon in the soil (Blanco-Canqui and Lal, 2004). Soil properties such as bulk density and aggregate stability are affected by the amount of organic C in the soil and the composition of organic matter (Martin, 1971; Dormaar, 1983; Lal, 2009). Organic matter directly absorbs water and increases the formation and stabilization of the structure containing abundant pores that keep the water under medium tension, increasing the water holding capacity of the soil (Magdoff and Weil, 2004; Varela et al., 2013). The longevity of changes in soil properties due to additional waste is related to decomposition rates. The amount, chemical composition and decomposition rate of wastes cause differences in soil properties and soil organic carbon (OC) content (Martens, 2000; Demir and Gülser, 2008; Gülser et al., 2015). However, the maximum amount of soil C is also determined by various factors including climate, parent material in soil, physiography, drainage, land management practices, and soil properties such as clay content, minerals and nutrient reserves (Lal, 2008; Gülser at al., 2020).

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Wheat and paddy are the most important agricultural products of the Bafra Plain, where there are large amounts of WS and RH wastes. Continuous tillage is carried out, and intensive chemical fertilizers are utilized as well as intensive agriculture in the Bafra Plain. The usage of organic wastes as soil conditioners helps to improve soil quality and enables economical disposal of these materials (Ic and Gülser, 2008; Gülser et al., 2010; Candemir and Gülser, 2011).

There is a bulk of research on the decomposition of wheat straw; the deterioration process of straw has been reported to be slower in the field conditions compared to greenhouse experiments, and it has been underlined that this difference is caused by different atmosphere, precipitation and physico-chemical properties of the soil, as well as soil cultivation and microorganisms in the soil (Nielsen et al., 2019). Straw mainly contains lignin, cellulose, hemicellulose, N, P and K, and so forth (Wang et al., 2019). Once the straw is returned to the soil, some nutrients are easily converted into CO_2 by the mineralization of microorganisms in the soil. Wang et al. (2020) have revealed that wheat straw components and nutrients are rapidly released in the natural environment under different tillage practices - without additives such as biomass and organic fertilizers- between 0 and 90 days. However, lignin remaining in the straw, cellulose and straw organic carbon in the hemicellulose remain in the soil longer because macromolecules such as lignin cannot be easily assimilated and converted by bacteria in the soil (Yang et al., 2019). Therefore, the remainder of the straw may have unique surface morphology and mechanical properties likely to have a sustained impact on tillage and soil compaction (Holthusen et al., 2018).

Rice husk contains carbon (C), oxygen (O), hydrogen (H), nitrogen (N), sulfur (S), silicon (Si), iron (Fe), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K) and phosphorus (P) (Jenkins et al., 1998), making it a useful source of main nutrients for crops. C (37.8-39.1%) and N (0.5-0.6%) are the two essential nutrients of rice husk (Jenkins et al., 1998; Demir and Gülser, 2021). The ash content of rice husk varies between 16-23% and consists mostly of silica (90-95%) together with other elements (Kapur, 1985; Jenkins et al., 1998; Natarajan et al., 1998). As indicated by these properties, Rice Husk (RH) can potentially be used as a soil conditioner (Verala et al., 2013). Furthermore, RH and its compost can be used as a soil conditioner to improve the physical properties of the soil as reported by some researchers (Jeon et al., 2010; Demir and Gülser, 2021), especially by increasing the soil porosity. Therefore, this study aims to examine the effects of WS and RH applied to silty clay and silty loam textured soils as an organic matter source on some physical properties of the soils in white-head cabbage, tomato, and wheat rotation systems.

Materials and methods

The experiment was carried out on two different lands in the Bafra Plain with silty clay textured soil and on silty loam textured soil. The geology of the research area is formed by the bottom and slope lands. Bottomlands are IV. geological time alluviums. These alluviums are mixtures of sand, silt, clay and some gravel. Sedimentary rocks of the Neogene period (marl, claystone, siltstone and pebbly series) and Eocene flysch (sandstone, claystone, marl and partially limestones) were found on the slopes. The soils in the experimental area have been defined as “Typic Udifluvent” because they display little pedogenetic horizon development and are located in the alluvial flood plains brought by Kızılırmak (Yüksel and Dengiz, 1996). Bafra Plain has a warm and temperate climate. Bafra Plain receives much more precipitation in winter than in summer. It can be classified as CSA (Mediterranean climate) according to the Köppen-Geiger climate classification. The annual average temperature of Bafra district is 13.6°C and its annual average precipitation is 730 mm (Anonymous, 2022). The climate data of the Bafra district between 2007 and 2009, when the experiment was conducted, are given in Figure 1.

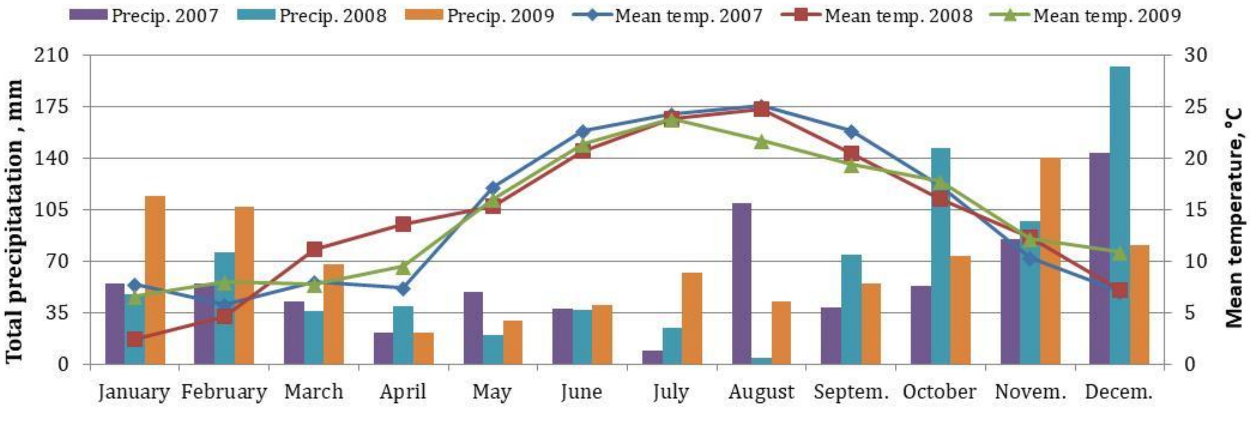

Figure 1. Climatic data of Bafra District (2007-2009)

Trials were carried out in three replications between July 2007 and July 2009 in accordance with the randomized blocks experimental design with the "white head cabbage (WHC) + tomato (T) + wheat (W)" rotation system in both fields where wheat was the previous crop. The WS used in the trials was obtained from the wheat harvested from the field where the experiments were set up, and the RH was obtained from the rice mills in Bafra. Trial subjects have been determined as C: Control, WS: Wheat straw+ Optimum NPK, and RH: Rice husk + Optimum NPK. In the experiments, row spacing and in-row spacing were determined as 100 cm-75 cm (5 rows) for white-head cabbage, 140 cm - 60 cm (4 rows) for tomatoes, and 12 cm (47 rows) for wheat respectively.

The wheat planted in November 2006 in both fields was harvested in the first week of July 2007. All of the WS obtained from this harvest (225 kg da^{-1} silty loam textured soil, and 300 kg da^{-1} clay textured soil) and RH, which was transported from the factory site equivalent to this amount of straw, were applied to the soil using goble discs on July 09, 2007, according to the trial subjects. Organic materials were applied to the field with their original dimensions. Sowing, planting and harvesting processes were carried out between the dates of August-November 2007 for white-head cabbage, May-September 2008 for tomatoes, and November 2008-July 2009 for wheat plants. According to the soil analysis results, all of the phosphorus and potassium fertilizers were applied at once before planting and half of the nitrogen fertilizer was applied before planting wheat, white cabbage and tomatoes. The second nitrogen application was done in the middle of tillering in wheat, on the first hoe in white head cabbage, and between the rows when the fruits began to appear in tomatoes (Deniz and Özdemir, 1980; Özdemir and Güner, 1983a and 1983b). Ammonium sulfate (21%) was used as nitrogen fertilizer, diammonium phosphate (18-46%) as phosphorus fertilizer and in Ağıllar location potassium sulfate (50%) fertilizer was used as potassium fertilizer needed. Sprinkler irrigation was used to provide germination in wheat and White head cabbage. The first irrigation water was applied to the opened furrows with middle breaking in tomatoes. Other irrigations were made according to the observations made on the soil and plants. Irrigation was done in the form of row irrigation and care was taken to give equal water to the parcel in each irrigation. After the harvest of each rotation plant, measurements were made at 0-20 cm depth in each plot in the trial areas, and analyses were made on disturbed and undisturbed soil samples taken from the plots.

The organic carbon (OC) value of organic wastes was determined by the dry-ashing method (Nelson and Sommers, 1982), total N was determined by the Kjeldahl method (Bremner and Mulvaney, 1982), and pH and electrical conductivity (EC) were determined by the suspension obtained by shaking the samples diluted with 1:10 (weight:volume) pure water in a mechanical shaker for 1 hour (Kacar, 1984). General soil properties such as; texture was determined by the hydrometer method (Demiralay, 1993); soil reaction (pH) was determined by pH meter in saturation paste; electrical conductivity ($EC_{25°C}$) was determined by EC meter in the same paste; and organic carbon (OC) content was determined using the modified Walkley-Black method (Kacar, 1994). Bulk density, total porosity, gravimetric and volumetric moisture contents and relative saturation values in the soil samples taken from the field with an undisturbed sampling cylinder were determined according to Demiralay (1993). Aggregate stability values of the soil samples were determined by the “wet sieving” method (Kemper and Rosenau, 1986). The initial infiltration values, which refer to the entry of water into the soil from the soil surface, were determined according to the single cylinder infiltrometer method (Soil Quality Ins. Staff., 1999). Field capacity and wilting point values of the disturbed soil samples were determined after the soil samples reached the hydraulic equilibrium state under 1/3 atm and 15 atm pressures in the pressure table instrument (Black, 1965). Penetration values were determined by Cone Penetration Testing using Eijkelkamp penetrometer with a surface area of 2 cm^2. Air-dried soil samples were sieved from different sieve apertures, and the mean weight diameter values were calculated by using the amount and percentage of aggregates remaining on each sieve (Demiralay, 1993).

Statistical analysis was carried out according to randomized blocks experimental design by using 3 subjects, 3 replications and 3 alternation plants in the JMP statistical program and the significant ones were grouped with the LSD test (Yurtsever, 1984).

Results and discussion

Some physical and chemical properties of the experiment soils are given in Table 1. Silty Clay soil contains 6.73% sand, 51.94% clay and 41.33% silt, while silty loam soil contains 30.50% sand, 7.20% clay and 60.30% silt. Both trial fields were found to be neutral in terms of soil reaction and salt-free, and poor in organic matter content (Soil Survey Staff, 1993). Some features of WS and RH used in the experiment are shown in Table 2. The C/N ratios in the experiment materials were determined as 105.46 for WS and 83.22 for RH, and the pH values as 6.93 and 7.73.

According to the results obtained from both experimental areas, it was found that WS and RH applications to the soils increased the organic matter content of the soils compared to the control application at the end of different rotation periods (Figure 2). Applying organic waste to the soils increased the organic matter content in silty loam soil more than in the control application. Many researchers have stated that different organic wastes and compost applications from wastes

Table 1. Some physical properties of the experiment soils

	Sand, %	Clay, %	Silty, %	Texture class	pH(1:1)	EC,dS.m^{-1}	OM, %
Silty Clay	6.73	51.94	41.33	SiC	7.55	0.58	0.62
Silty Loam	30.50	7.20	62.30	SiL	7.65	0.56	0.41

Table 2. Some properties of the experiment materials

Material	C, %	OM, %	N, %	C/N	pH	EC, dS.m^{-1}
Wheat straw	44.19	88.61	0.419	105.46	6.93	7.54
rice husk	40.78	81.56	0.490	83.22	7.43	1.20

increase the OM content of soils (Candemir and Gülser, 2011; Barus, 2016; Abdallah et.al., 2019; Gülser et al., 2017; Cercioğlu, 2017; Demir and Gülser, 2021). The fact that the WS application caused a marked increase in the OM contents of the soils in all rotation periods compared to the RH application in both experiment sites can be attributable to the fact that the WS (105.46) is wider than the RH (83.22) in terms of C/N ratio. Candemir and Gülser (2011) reported in their study that as the C/N ratio of different organic materials added to the soil widened, the mineralization rates in the soil slowed down, and the increased OM content of the soil was more durable. Cultivation of tomato plants by tillage following white-head cabbage and the application of additional tillage such as hoeing and middle breaking during plant development led to an increase in mineralization in the soil and a decrease in the amount of OM in all applications. Gülser et al. (2020) reported that organic carbon had been retained in the soil with reduced tillage, and the total amount of OM was approximately 10% to 30% higher than conventional tillage.

The effects of organic waste applications on some physical properties of soil in the trial areas in different

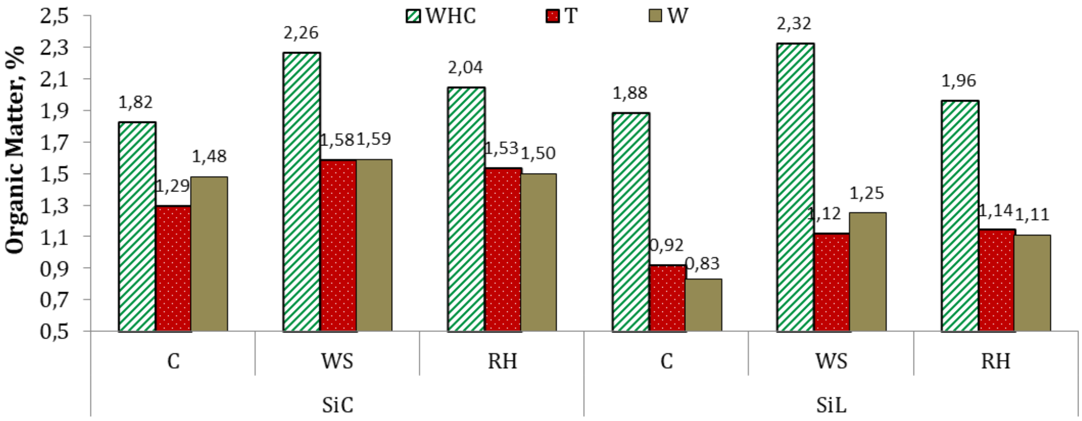

Figure 2. The effect of wheat straw (WS) and rice husk (RH) treatments on organic matter content of the soils compared to control (C) at the end of the rotation periods (WHC: White head cabbage; T: Tomato; W: Wheat)

alternation periods are given in Tables 3 and 4. A statistical difference was determined between organic waste applications according to the variance analysis values performed with BD (P<0.01) and in (P<0.01) in silty clay soil. According to the analysis of variance performed with PR (P<0.05), In (P<0.01) and MWD(P<0.01) values in silty loamy soil, a statistical difference was found between waste treatments (Table 3). A statistical difference was determined between the harvest periods of alternation plants in all parameters (except FC in silty clay soil) in both silty clay and silty loam soils (P<0.01) (Table 4). As shown in Table 5, there were significant negative relationships between OM contents and BD (-0.561** in SiC; -0.809** in SiL) values of soils with different textures, and significant positive relationships between OM contents and F (0.560** in SiC; 0.810** in SiL) values. WS and RH applications decreased the BD values of the soils compared to the control in both applications. The BD values of the soils were found lower in the WS application compared to the RH application (Table 3). Given the BD values according to the rotation periods, the lowest values of bulk density in both soils were obtained after the WHC harvest. In contrast, the BD values increased during the tomato and wheat harvest periods (Figure 3). The highest BD values in both soils were obtained from the control application during the wheat harvest period. Parallel to the decreases in the BD values of the soils, the F values of the soils also increased (Figure 3). Many studies have found that the addition of organic matter to the soil

Table 3. Changes in some physical properties of the soils according to the organic waste treatments

	BD, $g.cm^{-3}$	PR, Mpa	In, $cm.h^{-1}$	AS, %	MWD, mm	FC, %
Silty Clay						
Control	1.42 A	1.75	22.88 B	54.18	0.98	36.55
Wheat straw	1.36 B	1.79	55.36 A	55.00	1.00	36.16
Rice husk	1.38 B	1.74	53.56 A	57.98	0.98	35.44
$LSD_{(*0.05;\ **0,01)}$	0.030^{**}	ns	2.77^{**}	ns	ns	ns
Silty Loam						
Control	1.42	1.58 B	22.04 B	11.30	0.55 A	18.59
Wheat straw	1.40	1.84 A	39.14 A	9.65	0.55 A	19.38
Rice husk	1.41	1.61 B	33.75 A	10.65	0.52 B	18.63
$LSD_{(*0.05;\ **0,01)}$	ns	0.119^{*}	6.32^{**}	ns	0.034^{**}	ns

ns = not significantly different, * Significant at P< 0.05, ** Significant at P <0.01.

Table 4. Changes in some physical properties of the soils according to the harvest periods of the rotation crops (WHC: White head cabbage T: Tomato W: Wheat)

	BD, $g.cm^{-3}$	PR, MPa	In, $cm.h^{-1}$	AS, %	MWD, mm	FC, %
Silty Clay						
WHC (5.7mo.)	1.29 C	1.39 B	40.61 B	52.25 BC	0.94 B	35.66
T (14.06 mo.)	1.33 B	0.84 C	54.96 A	50.54 C	1.00 A	36.87
W (23.9 mo.)	1.54 A	3.05 A	39.76 B	64.42 A	0.87 C	35.61
$LSD_{(*0.05,\ **0,01)}$	0.033^{**}	0.065^{**}	6.55^{**}	2.23^{**}	0.047^{**}	ns
Silty Loam						
WHC (5.7 mo.)	1.29 C	1.00 C	22.11 B	3.48 B	0.47 D	20.10 A
T (14.06 mo.)	1.41 B	1.29 B	18.84 BC	4.95 BC	0.60 AB	19.00 AB
W (23.9 mo.)	1.55 A	2.74 A	53.97 A	23.17 A	0.54 C	17.50 BC
$LSD_{(*0.05,\ **0,01)}$	0.07^{**}	0.16^{**}	3.61^{**}	3.97^{**}	0.035^{**}	1.58^{**}

ns = not significantly different, * Significant at P< 0.05, ** Significant at P <0.01.

reduces the BD value and increases the total porosity (Candemir and Gülser, 2011; Barus, 2016; Abdallah et al., 2019; Gülser et al., 2017; Cercioğlu, 2017; Demir and Gülser, 2021).

Organic waste applications did not have a statistically significant effect on the AS and MWD values of the soils (Table 3). However, the application of RH, compared with WS, resulted in higher AS in silty clay soil than the control. Factors affecting aggregate stability can be grouped as abiotic (clay minerals, sesquioxides, exchangeable cations), biotic (soil organic matter, activities of plant roots, soil fauna and microorganisms) and environmental (soil temperature and humidity) (Chen et al., 1998). As many studies have pointed out that, there is a positive relationship between the organic carbon content of the soils and the aggregate stability; therefore, the addition of organic matter to the soil increases the aggregate stability (Tisdall and Oades, 1982; Rasiah et al., 1993; Cercioglu et al., 2014; Gülser et al., 2015). In silty loam soil, AS values increased with WS and RH applications in WHC rotation period compared to control but decreased in T and W rotation periods. The MWD values of the soils increased in the W rotation period when compared to the WHC rotation

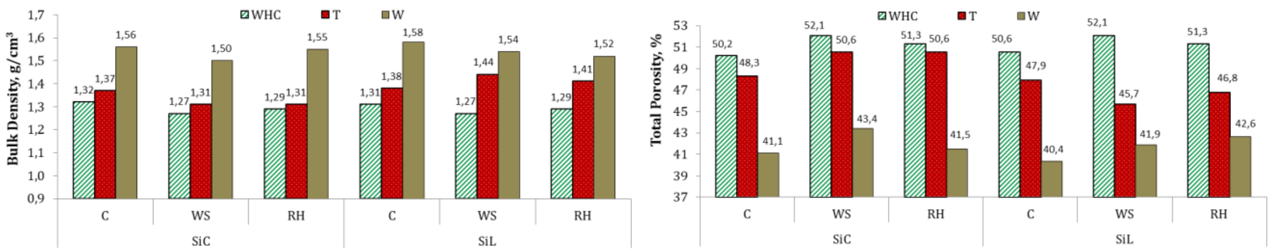

Figure 3. Effects of wheat straw (WS) and rice husk (RH) treatments on bulk density and total porosity of the soils compared to the control (C) at the end of the rotation periods (WHC: White head cabbage; T: Tomato; W: Wheat)

period (Figure 3). MWD values of the soils generally decreased in parallel with the AS values with the addition of organic matter. Significant negative relationships were found between the OM contents of the soils and the AS (-0.208** in SiC; -0.543** in SiL) and MWD (-0.680** in SiC; -0.830** in SiL) values (Table 5). This decrease may be due to the increase in microbial activity after the application of organic materials in addition to tillage during the rotation periods, the inability to meet the increasing nutritional need due to this increase, and the fact that the use of some organic compounds that provide aggregation as nutrients by microorganisms. Aşkın et al. (2000) reported that the increase in the microbial activity of soils reduced AS, and they explained the reason for this, suggesting that microorganisms, previously producing the products that enable aggregation, consumed these products. Considering the sampling times, the highest AS values

Table 5. Relationships between identified properties of silty clay (SiC) and silty loam textured soils (SiL) (n= 27)

	Texture	BD	F	AS	MWD	FC	Θ	PR	RS	In
OM	SiC	-0.561**	0.560**	-0.208	-0.680**	-0.362	0.016	-0.156	-0.528**	0.187
	SiL	-0.809**	0.810**	-0.543**	-0.830**	0.728**	0.814**	-0.555**	0.767**	-0.246
BD	SiC		-1.000**	0.865**	0.666**	-0.151	-0.746**	0.893**	-0.111	-0.301
	SiL		-1.000**	0.887**	0.532**	-0.833**	-0.937**	0.929**	-0.880**	0.738**
F	SiC			-0.865**	-0.667**	0.152	0.745**	-0.893**	0.111	0.303
	SiL			-0.888**	-0.531**	0.835**	0.937**	-0.929**	0.880**	-0.738**
AS	SiC				0.560**	-0.595**	-0.943**	0.942**	-0.539**	0.009
	SiL				0.166	-0.838**	-0.753**	0.941**	-0.685**	0.840**
MWD	SiC					0.011	-0.478**	0.497**	-0.045	0.106
	SiL					-0.329	-0.632**	0.232	-0.624**	-0.041
FC	SiC						0.606**	-0.473**	0.745**	-0.238
	SiL						0.817**	-0.755**	0.775**	-0.586**
Θ	SiC							-0.917**	0.745**	-0.169
	SiL							-0.835**	0.990**	-0.676**
PR	SiC								-0.471**	-0.210
	SiL								-0.784**	0.915**
RS	SiC									-0.566**
	SiL									-0.668**

were obtained in the third sampling period, coinciding with the summer period, in both soils. As pointed out in some other studies, AS values are generally higher in summer than in winter (Özdemir, 1994; Layton et al., 1993; Erel et al., 2010). Blackman (1992) suggested that aggregate stability also changes seasonally depending on soil moisture content. Some researchers have found that macroaggregate stability decreases with increasing soil water content (Rasiah et al., 1992; Caron and Kay, 1992; Chan et al., 1994). This study found the moisture content of both soils was also lower in the third sampling period, when the highest AS values were obtained, compared to the moisture contents of the other periods.

Organic waste applications were found not to have a significant effect on the field capacity values of the soils (Table 3). This may be due to the large particle size of the wastes, resulting in an increase in macroporosity in the soil. Haynes and Naidu (1998) reported that both field capacity and wilting point of

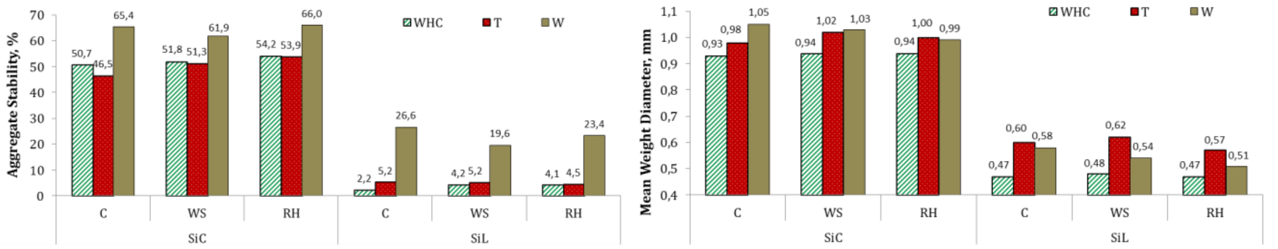

Figure 4. Effects of wheat straw (WS) and rice husk (RH) treatments on aggregate stability and mean weight diameter of the soils compared to control (C) at the end of the rotation periods (WHC: White head cabbage; T: Tomato; W: Wheat)

soils increased with the addition of organic waste, but the available water holding capacity generally did not change significantly. Considering the rotation periods, FC values did not show a significant difference in silty clay soil, while FC (P<0.01) values in silty loam soil decreased significantly from WHC to W harvest (Table 4). The volumetric water content of the soils generally decreased with WS and RH applications compared to the control application in both soils (Figure 5). This can be explained by the decrease in BD values and the increase in the total pore amount as a result of waste applications.

While the penetration resistance (PR) values in silty clay soil were not affected by organic waste applications, significant differences were found between the applications in silty loam soil (Table 3). The decrease in the bulk density of the soils and the increase in the total porosity with organic waste applications caused a decrease in the PR values. OM content in silty loam soil showed a strong negative correlation (-0.561** in SiC; -0.809** in SiL) with PR (Table 5). In both plots, the PR values measured from the first sampling WHC harvest to the third sampling W harvest showed statistically significant increases (Figure 4). PR values above 1.7 MPa, which is the critical level for plant growth in the soil, were determined in the measurements after the W harvest, which coincides with the summer period, when the volumetric water content of the soils was the lowest. Many researchers have found negative relationships between soil PR and moisture content (Gülser et al., 2011; Şeker, 1997; Turgut et al., 2010). The PR values of the soils showed significant positive relationships with BD values and significant negative relationships with volumetric water content and F values (Table 5). Studies have reported that the addition of organic material may cause lower PR values due to low bulk density, high porosity and higher water content (Getahun et al., 2018; Castioni et al., 2018; Unger and Jones, 1998; Vaz et al., 2001).

The increase in the total porosity and the decrease in the volumetric water content in both soils caused a decrease in the RS values compared to the control (Figure 6). Relative saturation values generally showed significant negative relationships with AS (-0.539** in SiC; -0.685** in SiL), OM (-528** in SiC; 0.767** in SiL), and BD (-0.111** in SiC; -0.880** in SiL) (Table 5). The decrease in BD and the increase in AS with the application of waste in the soil caused an increase in macroporosity and a decrease in the RS value as a result. Gülser et al. (2015) reported that they found higher moisture content in the soil in compost and hazelnut husk application, and yet these applications had lower RS values compared to the control.

Waste applications, depending on the decrease in the relative saturation value, also caused an increase in the in values of the soils (Figure 6). The value of both soils was higher in the WS application. In silty clay soil, the initial infiltration increased by 52% with WS application compared to the control, while it increased by 47% with RH application. Similarly, in silty loam soils, there was a 51% increase in WS and a 46% increase in RH. In silty clay soil, the highest in value was obtained after T harvest (Figure 6). This may result from the increase in macroporosity by tilling the soils because of middle breaking of tomatoes. On the other hand, in silty loam soil, the highest in values were determined after

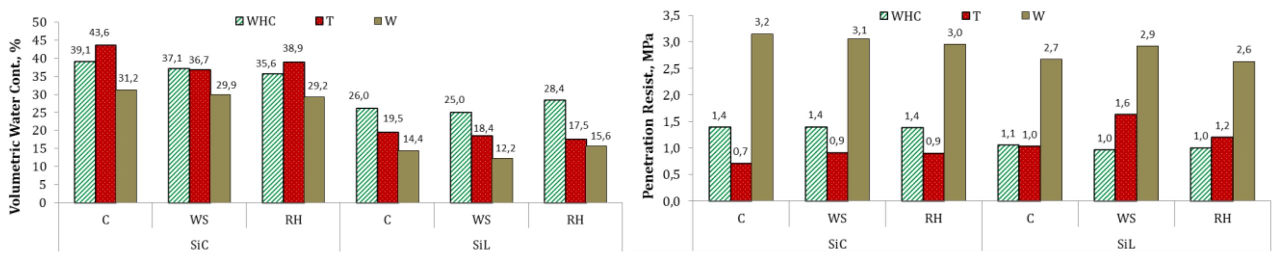

Figure 5. Effects of wheat straw (WS) and rice husk (RH) treatments on volumetric water content and penetration resistance of the soils compared to control (C) at the end of the rotation periods (WHC: White head cabbage; T: Tomato; W: Wheat)

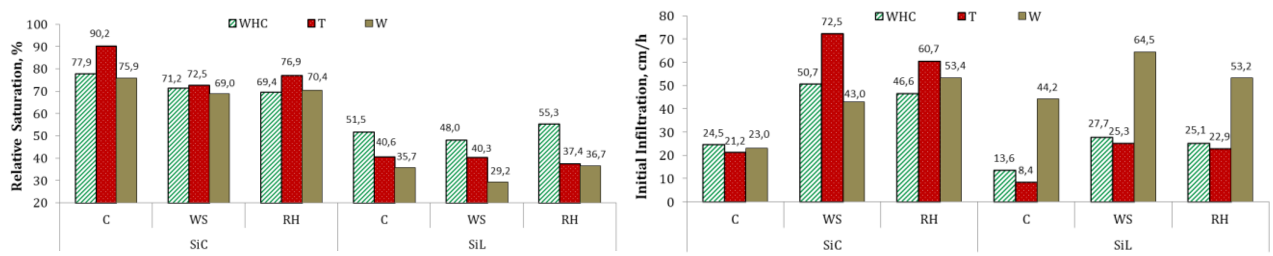

Figure 6. Effects of wheat straw (WS) and rice husk (RH) treatments on the relative saturation and initial infiltration rate of the soils compared to control (C) at the end of the rotation periods (WHC: White head cabbage; T: Tomato; W: Wheat).

the W harvest, which was the last sample with the lowest RH and ϴ contents.

Conclusion

This study was conducted in silty clay and silty loam textured soils in Bafra Plain to find out the effects of WS and RH applications on physical soil properties in whitehead cabbage + tomato + wheat rotation system. In both experiment sites with WS and RH application, OM contents and F values of soils increased after WHC, T and W harvest, while BD values decreased. OM content of soil had greater increase with WS application, which has a wider C/N ratio, compared to RH application, and it decreased in both fields from WHC harvest to W harvest. The lowest BD, AS, and MWD values were generally obtained after the WHC and T harvest with more tillage during the growing season, while the highest BD, AS, PR and the values were obtained after the W harvest without tillage during the growing season. The high in value in this period was due to the soil moisture content and therefore the low RS value. Soil OM content showed very significant negative relationships with BD, MWD and RS in silty clay textured soil (SiC), while it showed very significant negative relationships with BD, AS, MWD, and PR and very significant positive relationships with TK, ϴ, RS in silty loam textured soil (SiL). Measured PR values showed very significant positive relationships with BD and AS, and very significant negative relationships with F, TK, ϴ, and RS. The values of the soils increased with WS and RH applications and showed very significant negative correlations with RS values. The highest in values in the experiment were determined in WS application due to the macroporosity increased after the T harvest in the soils with SiC texture, and because of the low RS in the soil after W harvest in the soils with SiL texture. In this study, it was found that the organic waste with a high C:N ratio increased the OM content of the soil more, the OM content of the soils decreased due to tillage in the multi-rotation system, and the soils contained more OM compared to the control despite these decreases. The effects of different organic wastes on the physical properties of the soil in the rotation system also differed according to the soil texture. With waste applications, AS and MWD values generally increased in silty loam, while they decreased in the soils with silty clay content. The application of WS and RH, residuals after the harvest in the region, to the soil provided positive improvements in the physical properties of the soils within a period of rotation.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that might apper to influence the work reported in this paper.

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Author Contributions

BB: Conceptualization, investigation, methodology, validation, software, validation, formal analysis, investigation, resources, data curation, writing-original draft preparation, writing-review and editing, visualization, supervision, statistical analysis, project administration; **CG:** Conceptualization, investigation, methodology, validation, software, validation, formal analysis, investigation, resources, data curation, writing-original draft preparation, writing-review and editing, visualization, supervision, statistical analysis, project administration.

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RESEARCH PAPER

Detailed soil mapping and classification study for sustainable agricultural land management; Samsun-Vezirköprü example

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Abstract

This study aims to determine basic physico-chemical soil properties, make a classification, create a soil database, and generate a digital soil map for agricultural areas that cover about 111 km^2 ha and includes 18 villages located in Vezirköprü district in the Samsun province. The average annual temperature is 12.52 °C and the annual average rainfall is 518 mm. According to the Newhall simulation model, soil temperature and moisture regimes are *Mesic* and *Typic Xeric*, respectively. Field observations and investigation of topographical, geological, and geomorphological maps, 16 soil pedons were described. Soil samples were taken from each pedon based on the genetic horizon and laboratory analyzes were performed. The detailed field study was carried out by considering the grid method and auger examination. The determination and description of 16 soil series were made by evaluating the findings of analyses and field research. Due to their quick pedological processes, six of them were classified as Entisol, six as Inceptisol, three as Verisol, and one as Alfisol. Vertisols cover about 35.63% of the total area followed by Inceptisols at 22.3%, Entisols at 22.3%, and Alfisol at 13.58%. As for FAO-WRB classification system, soils were classified as Vertisol, Cambisol, Leptosol, and Luvisol. In addition, whereas the Bakçekonak series has the largest area (15.02%), the Yürükçal series was determined as the smallest land (1.65%) in the study area.

Introduction

Throughout history, the production of nutrients for human nutrition, the creation of raw materials for industry, and the fact that it is a large employment area have made agriculture important in every period. The land, which is an indispensable element of agriculture, has been divided for centuries as a result of human intervention, loses its productivity due to its misuse, and is exploited as a continuous production material to feed the existing population. Rapid population growth restricts access to basic food products and complicates access to safe food, paving the way for global food crises.

It is of great importance to prepare soil maps that combine physical and chemical properties in a database to ensure the sustainability of the soil, which takes centuries to form in its natural state. Misuses of irrigation, fertilizer, and other agricultural practices are brought on by failing to take into account the physical and chemical characteristics of soils (Arslan et al., 2018). It has a negative effect on the productivity of soils by creating erosion, barrenness, salinization, and ultimately soil pollution.

With the effect of the increasing population, the division of agricultural lands by inheritance, the fragmentation of agricultural lands, and the intensive use of chemicals to meet the needs of the population in existing lands and to obtain high efficiency from the unit area, soil fatigue, and pollution occur. As a result of unconscious agricultural practices (fertilization, irrigation, etc.), wrong soil management, erosion, barrenness, unintended land use, and soil pollution, the borders of our agricultural lands are narrowing day by day, and their physical, chemical, and biological properties are destroyed. and their quality decreases accordingly. Finding out the soil's physical, chemical, and biological characteristics will make it easier to choose the production models to use and to cultivate the chosen goods.

Digital soil maps are based on very detailed and good coverage of point-based soil profile data together with large-scale data with appropriate resolution (Stoorvogel et al., 2017). The use of morphometric approaches in soils sampled based on the genetic horizon makes it possible to determine the distribution areas in terms of managing the soils following their characteristics. For this reason, with the help of mapping units created for soil survey and mapping purposes, drawing the boundaries of soils that differ in terms of physical and chemical properties provides convenience in the management of soils.

Formerly during the Ministry of Agriculture and Rural Affairs, 30 large agricultural basins were determined, and in the next process under the name of the Ministry of Food, Agriculture and Livestock. Finally, the Ministry of Agriculture and Forestry of the Republic of Turkey, these basins were reduced to the district level and included in the scope of support for the basin-based production model in terms of agricultural products. For the yield and quality of the products supported within the basin borders to be at the desired level, the information to be produced for the soil should be up-to-date and detailed. Agricultural efficiency and productivity are concepts that are often confused. Plant nutrients, which are a reflection of the physical, chemical, and biological values of the soil, are the most basic element that creates productivity and loses their current properties to a certain extent with their exploitation by plants. However, in addition to the physical and chemical properties of the soil, the depth, stoniness, and erosion tendencies, as well as the geological and topographic structure also have a significant effect on the productivity of the soil. According to Heidari et al. (2022), it is possible to have detailed information about the physical, chemical, and weathering properties of soils by classifying them at different taxonomic levels.

In addition to the climate, soil, and plant existence for any basin, revealing the hydrological characteristics is also important in terms of determining the needs of the people in terms of socio-economic terms and the management of natural resources (Dengiz et al., 2015; Coşkun and Dengiz, 2016). Soil maps have the most important place for the sustainable management of soils and the implementation of correct management plans. Produced soil maps and accompanying reports are the most basic material that decision-makers can refer to, with the feature of creating a database in terms of agriculture, forest, and pasture uses, as well as different engineering applications and protection of natural resources (Dengiz and Sarıoğlu, 2011). Soil maps are an important material in terms of the use and management of existing resources by their purpose (Coşkun and Dengiz, 2016). Soil survey and mapping studies carried out in detail not only provide convenience in determining the problems related to soils and propose solutions but also provide an opportunity for sustainable soil management.

The land protection and land use law numbered 5403 adopted in 2005, was enacted by taking it under protection developing protect and develop to protect and develop soil resources and classifying agricultural lands. The lack of a classification of land and soil resources within the scope of the same law by scientific principles in field conditions creates problems in terms of proper use and management of soils. According to Bayramin et al. (2013), one of the most fundamental issues is the lack of adequate soil surveys and mapping studies with detailed information across our nation. According to Kurşun and Dengiz (2018), the information and data on land resources could not be recorded systematically, and the problems experienced during the evaluation and transformation of the recorded data into information were seen as a major deficiency in the country.

Soil maps produced as a result of detailed soil surveys and mapping studies and related reports constitute an important soil database for users. With this study, in the light of detailed numerical and spatial data and information obtained from the area, ensuring the sustainability of the lands and soils in the future, infrastructure, and scientific studies (land consolidation, watershed improvement, erosion, irrigation-drainage planning, land use planning, etc.) constitute an important resource. The study includes determining the basic soil properties, creating a soil database, mapping and classifying the lands covering 111 km^2 of 16 villages within the borders of the Vezirköprü district of Samsun province with the help of Geographical Information Systems.

Material and Method

General characteristics of the study area

The study area is located within the borders of the Vezirköprü district of Samsun province, which is located in the Central Black Sea Region, between 41º 00' - 41º 19' north latitudes and 35º 01'-35º 48' east longitudes. Vezirköprü district, with an area of 1713 km², is 115 km away from Samsun province (Figure 1). The district is surrounded by Boyabat and Osmancık in the west, Havza in the east, Gümüşhacıköy and Merzifon districts in the south, while Alaçam and Bafra districts are located in the north (Anonymous, 2023a). The study area, which is on the southeastern border of the district, includes Ağcaalan, Aydoğdu, Bahçekonak, Bayramköy, Boğazkoru, Çakırtaş, Çalköy, Çekmeden, Esenyurt, Güder, Kızılcaören, Kületek, Meşeli, Pazarcı, Tekekıranı, Yağcı, Yeniçelik, Yürükçal neighborhoods.

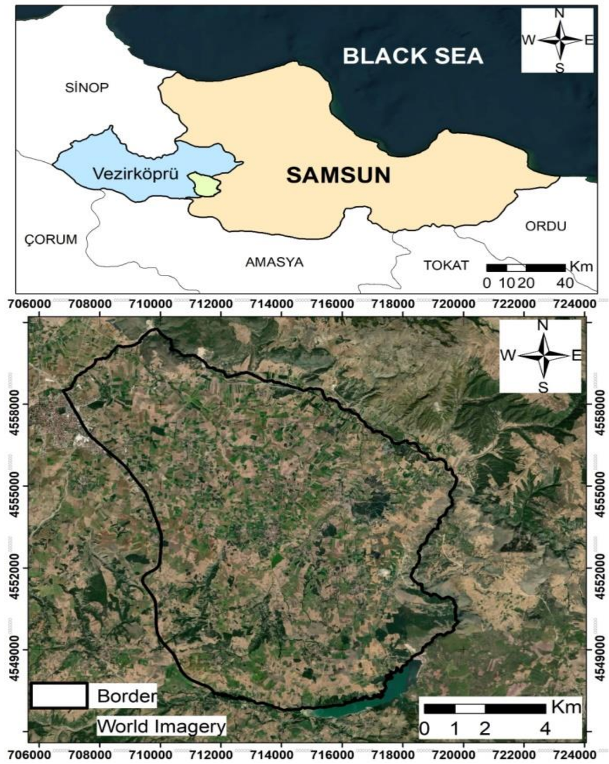

Figure 1. Study area location map

The study area is approximately 111 km^2, and its altitude varies between 240-750 m above sea level. The elevation, slope, and digital elevation model maps of the study area are shown in Figure 2, respectively. Although there are areas with steep slopes of more than 30% in the area's northeastern and southern parts, the majority of them are nearly flat, light, and medium slopes (0-12%) suitable for cultivated agriculture. Also, the majority of the area has north, northeast, and southwest aspects.

Vezirköprü is distinguished between the humid temperate climate type of the coastal zone and the continental climate type of the interior parts in terms of climatic conditions, with the unique thermal and humidity characteristics of the transition zone; winters are colder than the coast and hotter in summers (August monthly average temperature is 22.3ºC). According to long annual averages, the annual temperature is 12.5 °C and, the annual precipitation amount is 518 mm, and it is seen that precipitation in the form of snow is also effective with the increase in precipitation in the surrounding high parts. The distribution of precipitation according to the seasons throughout the year shows a distinctive spring feature (35.5%); summer precipitation reaches 18.6%, and summer drought is effective as a result of increased evaporation (Anonymous, 2023b). In addition, soil and moisture regimes were determined with the help of the Newhall simulation model (Van Wambeke, 2000) of the soils distributed within the boundaries of the Vezirköprü district. The long-term average temperature and precipitation data of Vezirköprü station were taken into account. The soil temperature regime in the determined area was Mesic and the soil moisture regime was Typic Xeric in the Xeric subgroup.

Agricultural lands, which have a share of 72.43% with an area of 8149 ha in the total area, cover the largest area. Agricultural areas are followed by forests with a share of 1353 ha and 12.03%. Non-agricultural lands defined as rocky, bare land, roads, settlements, grasslands and forests within the area cover an area of 591 hectares. The share of non-agricultural lands in the total area is 5.25%.

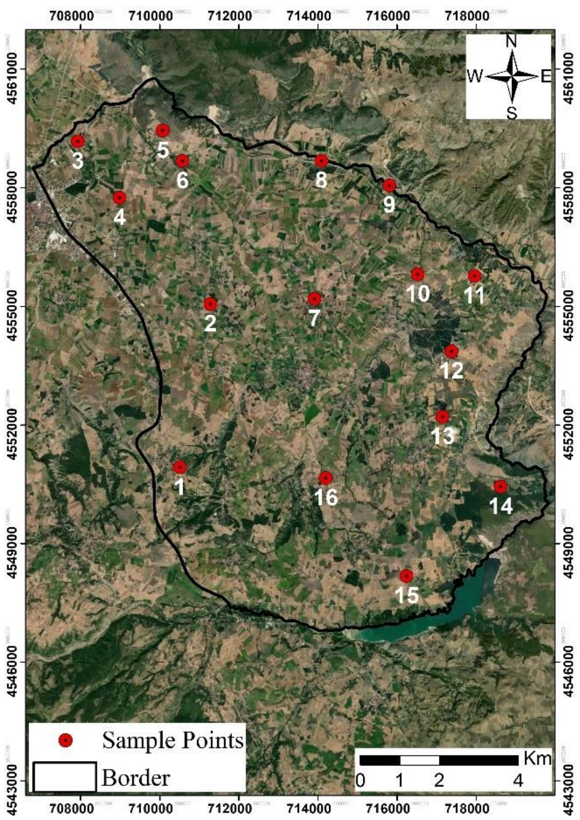

Figure 3. Profile locations showing distribution in the area

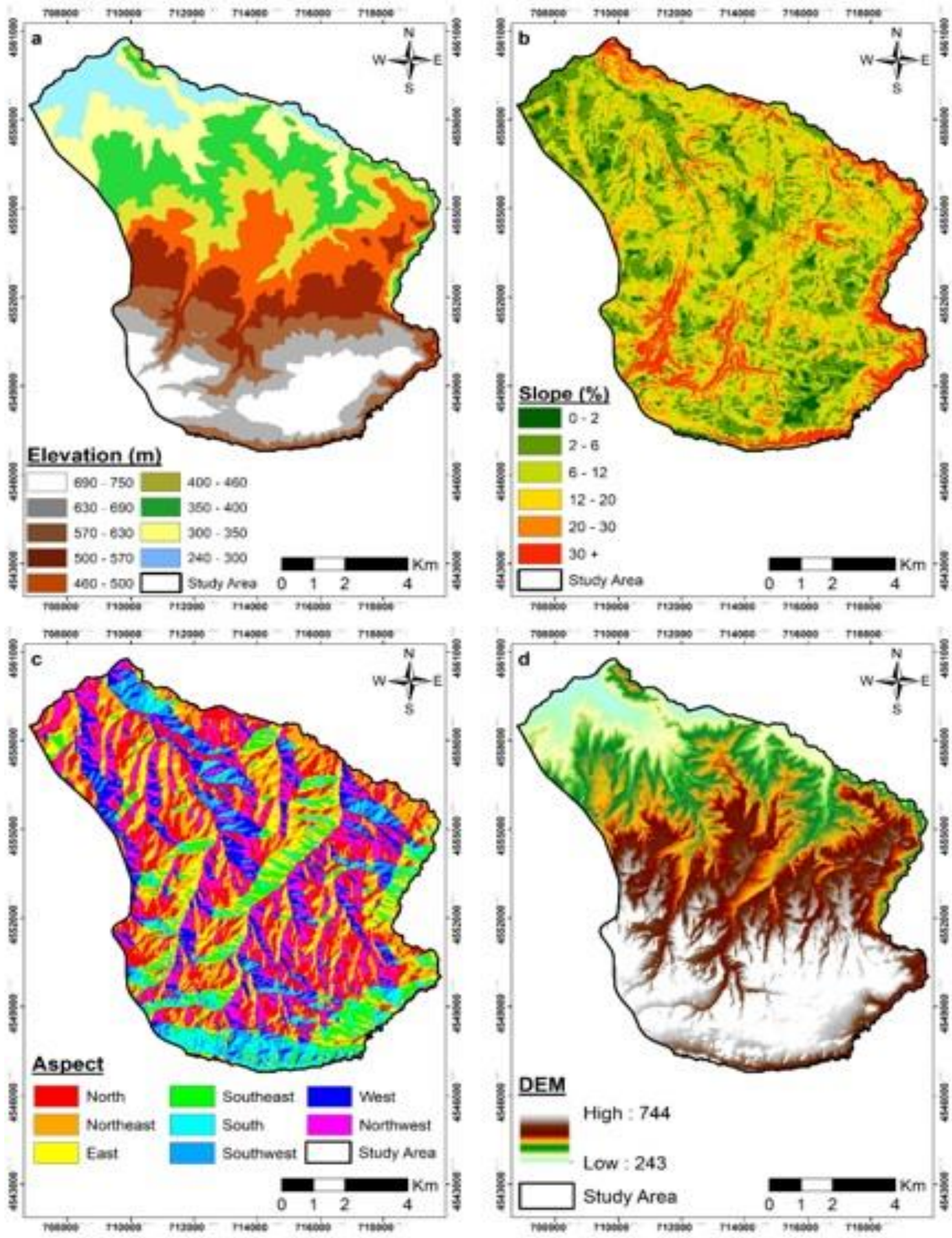

Figure 2. Study area elevation (a), slope (b) aspect (c) and DEM (d) maps

Method

In addition to the determination of the basic soil properties of the soils in the study area and the new soil classification system, their definitions according to the WRB classification system were carried out using 1/25.000 scale topographic maps and satellite images. Thanks to the soil database created by determining the series (physical, chemical, productivity, and morphological) properties of the soils of the study area and classifying them according to soil taxonomy, maps showing the distribution area and spatial status of the soils with different characters distributed in the area were obtained. This process; office, field, laboratory, and reporting studies were carried out in four stages. In this context, first of all, besides determining the vegetation pattern and land use in the area, different slope groups, physiographic units, relief, aspect, and landforms spreading in the area were determined by using DEM.

By combining the determined landform and land cover with numerical geology data, the soil series formed on different parent materials and different physiography were determined, and a draft soil map was created. In the field study, which is the second stage, the coordinates of the soil profile locations were recorded on the draft soil series with different characteristics determined as a result of the previous office work, the location of the profile pits was determined using the GPS device and profile pits were dug in the field.

Soil samples were taken from 16 different soil profiles based on the genetic horizon since 2 of 18 different soil profiles found in the study area showed similar characteristics. Soil Survey Staff (1993 and 1999) were used for the criteria, sampling, and classification to be considered to examine the morphological characteristics of the soils in the field. In the soil samples taken; body Bouyoucous (1962), field capacity, wilting point and available water content Richards (1954), bulk weight Blake and Hartge (1986), exchangeable cations Rhoades (1982), lime content Çağlar (1958), soil reaction (pH), electrical conductivity, salt content, organic matter were analyzed within the framework of the principles reported by Jackson (1958). In the last stage of the study, necessary corrections were made by taking into account the analysis results of soils with different characteristics, and a 1:25,000 scale basic soil map of the basin was prepared. In the study, probing was carried out every 400 m by using the grid system, especially in the finalization of the soil boundaries. Soil series and their phases were used as the mapping unit in the detailed soil survey and mapping studies. The Soil Survey Staff 1993 was also used for the factors such as slope, drainage, stoniness, rockiness, depth, and erosion observed in the separation of the soils into phases. ArcMap 10.8.2, a Geographical Information System Software, was used for digitizing 1:25,000 scale topographic maps, drawing new maps, and preparing soil databases.

Results and Discussion

Some physical, chemical, and morphological properties of soil series

The physical and chemical analysis results of the soil series in the study area are given in Table 1 and Table 2. The Ağcaalan series, covering an area of 8.71% of the total area, the series soils are in the south of the basin and their heights relative to sea level are between 460-630 m. Soils with shallow depth are formed on a mixture of marl and andesite parent material. The texture of the surface soils is clayey and their natural drainage is moderate. While their organic matter content is at a moderate level of 1.62%, their pH is slightly acidic at 6.13. Although they have a clay structure due to their compaction in the surface soils due to field traffic, their bulk density is 1.53 gr/cm^3.

The soils belonging to the Aydoğdu aşağısı series are located in the north of Aydoğdu village and their heights vary between 350-460 m above sea level. It has been determined that the surface soils of this soil series at medium depth are clayey in heavy texture class (61% clay content), while the clay content in the subsurface horizons decreases to 29%. The organic matter content of the series soils is quite low (0.66%), and this rate decreases further towards the depths. While the lime content is 21.81% on the surface, it decreases to 10.91% in the sub-surface horizon, then increases to 15.35% again, exhibiting a wavy appearance. This situation also causes color changes, especially in the horizons formed in the profile, and the color which is 10YR 4/3 on the surface turns into 5 Y 4/2. The pH of the soil varies a little between 8.02 and 8.46, and it is moderately alkaline. In addition, the soils do not have any problems in terms of salinity.

Aydoğdu üzeri series is located in the south of Aydoğdu village, and the soils of this series vary between 400-500 m above sea level. These soils, formed on marl parent material, have medium depth. In soils dominated by clayey texture throughout the profile, the organic matter content is 4.03% at the surface, while it drops to 1.11% under the surface. In addition, the lime content is 13.09% in the surface soils and 48.63% below the surface. No problems were determined in terms of the salinity of the soils in this series soils.

The Boğazkoru series are soils within the steep lands in the southeastern part of the basin and their heights vary between 500-750 m. They are deep soils with clayey textures throughout the profile. The pH of this series of soils varies between 7.33 and 8.13. While the organic matter content is 2.28% on the surface, it decreases by 0.82% towards the deep. In addition, while the surface soils are slightly calcareous in terms of lime content, lime increases with deep washing and turns into a calcareous structure.

Bayramköy series are deep soils with clayey texture, distributed in the southern part of the study area. The clay content increases towards the depths and reaches over 60%. Accordingly, the amount of available water decreases along the profile. While the organic matter on the surface is very rich at 4.46%, this rate decreases towards the depths and becomes very poor at 0.29%. In these soils formed on the marl parent material, while the lime content is 0.81% on the surface without lime, it increases under the surface with the effect of the parent material and becomes very calcareous.

Soils belonging to the Güder aşağısı series are located on topography varying from steep lands with steep slopes to lands with a slight slope of 2-6%. They are deep soils with clayey textures throughout the profile. While the organic matter content is 1.59% on the surface, it decreases to 0.02% under the surface. The lime content of these soils, whose surface is less calcareous, increases towards the depths and becomes very calcareous. The soil reactions of this series of soils range from slightly alkaline to moderately alkaline, and their pH values are between 7.97-8.23.

The Meşeli series spreads in the steep lands in the southwestern part of the basin and areas with heights varying between 450 and 750 m. The soils of this series, which were formed on calcareous parent material, are deep and clayey texture is dominant throughout the profile. Although the soils are formed on the calcareous parent material, the surface soils are lime-free, especially due to leaching. While the soils have a slightly

Table 1. Some chemical analysis results of soil series

Horizon	Depth (cm)	pH	EC ($dS.m^{-1}$)	Lime Content (%)	OM (%)	KDK ($cmol\ kg^{-1}$)	Exchangeable Cations, $cmol\ kg^{-1}$			
							Na^+	K^+	Ca^{++}	Mg^{++}
Ağcaalan										
A	0-30	6.13	1.16	0.81	1.62	47.3	0.33	0.24	27.20	3.85
Aydoğdu aşağısı										
Ap	0-20	8.19	0.23	21.81	0.66	46.2	0.30	0.42	60.30	3.15
Bw	20-58	8.02	0.40	10.91	0.67	49.5	0.34	0.50	57.85	7.25
Ck	58+	8.46	0.21	15.35	0.20	25.6	0.33	0.22	43.90	8.05
Aydoğdu üzeri										
A1	0-20	7.85	0.50	13.09	4.03	73.7	0.33	1.05	64.50	6.70
A2	20-41	7.96	0.29	25.29	1.93	58.0	0.16	0.35	66.85	4.15
AC	41-60	7.63	1.67	48.63	1.11	39.6	0.23	0.29	66.45	4.55
Bahçekonak										
Ap	0-20	8.02	0.28	11.15	1.68	68.9	0.21	0.92	67.30	3.65
A2	20-41	8.06	0.27	12.20	1.12	72.3	0.23	0.59	70.25	4.40
Bt	41-77	8.10	0.31	15.27	0.50	65.8	0.20	0.64	68.80	3.65
Bk	77-136	8.30	0.31	17.13	0.18	71.0	0.95	0.40	62.90	15.75
Ck	136+	8.21	0.35	10.26	0.12	58.5	0.42	0.42	56.80	16.45
Bayramköy										
A	0-30	7.06	0.45	0.81	4.46	62.5	0.23	0.93	37.50	9.15
Bt1	30-54	7.75	0.35	0.81	1.34	62.6	0.23	0.38	45.65	8.75
Bt2	54-95	7.90	0.43	8.00	0.90	58.7	0.30	0.39	57.90	10.95
Ck	95+	8.17	1.99	23.18	0.29	39.2	0.54	0.16	61.75	4.30
Boğazkoru										
Ap	0-17	7.33	0.42	0.89	2.28	74.2	0.22	0.83	48.95	6.20
A2	17-43	7.61	0.33	0.73	0.82	60.7	0.20	0.63	45.10	10.65
Bss1	43-75	7.92	0.31	1.86	1.36	62.9	0.24	0.53	54.20	15.60
Bss2	75-106	8.13	0.27	8.64	1.21	58.0	0.30	0.49	63.80	6.15
Çakırtaş										
Ap	0-24	7.89	0.28	16.32	2.34	54.7	0.26	0.76	28.40	34.75
Bw1	24-58	7.96	0.29	6.62	1.81	56.4	0.20	1.31	33.15	27.45
Bk	58-91	8.21	0.25	25.53	0.59	52.2	0.36	0.32	32.85	34.05
BC	91-127	8.27	0.26	33.93	0.87	50.5	0.28	0.26	32.85	35.65
Ck	127+	8.35	0.26	45.72	0.14	42.9	0.40	0.21	28.40	34.45
Çalköy										
Ap	0-25	8.15	0.26	10.83	1.21	34.0	0.37	0.91	21.60	30.45
Ad	25-55	8.15	0.29	12.84	1.27	43.6	0.68	0.57	23.75	26.25
C1	55-90	8.03	0.73	14.54	0.79	58.1	1.10	0.49	25.45	40.30
C2k	90-123	7.99	1.46	15.35	0.26	44.5	1.96	0.39	31.95	34.90
2C	123+	8.14	1.18	14.22	0.24	31.3	1.79	0.26	43.45	11.20
Çalköy aşağısı										
A	0-20	8.23	0.24	27.47	1.29	37.1	0.39	0.24	30.10	29.85
C	20-56	8.58	0.30	14.14	0.50	37.9	0.41	0.19	24.20	38.80
Çekmeden										
Ap	0-17	7.95	0.28	2.75	2.23	68.1	0.34	1.38	35.45	18.15
A2	17-40	7.97	0.03	3.15	1.59	68.8	0.36	0.56	31.95	28.10
Bk1	40-83	8.09	0.30	3.42	1.04	74.6	0.25	0.53	34.35	24.75
Bk2	83-137	8.17	0.32	7.19	1.18	69.3	0.38	0.45	44.15	25.55
Ck	137+	7.95	0.31	10.02	0.59	75.1	0.53	0.39	46.80	24.55
Güder aşağısı										
Ap	0-20	7.97	0.23	3.64	1.59	67.1	0.36	0.72	56.10	6.80
Bw	20-75	7.98	0.31	5.57	1.03	72.3	0.35	0.53	66.45	5.40
C1k	75-132	8.23	0.28	16.08	0.50	53.9	0.27	0.22	67.35	11.20
C2k	132+	8.05	0.31	17.69	0.02	52.0	0.29	0.35	59.00	2.00
Kületek										
A	0-20	8.05	0.21	9.29	0.29	16.0	0.35	0.37	34.00	0.95
C1	20-40	8.24	0.24	8.89	0.07	11.0	0.30	0.17	27.15	1.85
Meşeli										
Ap	0-27	6.30	0.14	0.89	2.80	80.4	0.23	0.51	30.35	11.30
Bss1	27-72	7.43	0.34	0.73	0.98	65.7	0.36	0.28	39.10	3.90

Bss2	72-116	7.89	0.25	1.86	0.68	66.3	0.27	0.38	56.45	7.75
Ck	116+	8.17	0.29	41.85	0.76	66.2	0.20	0.22	52.75	8.80
Tekekıranı										
Ap	0-16	7.92	0.33	15.43	1.74	53.8	0.27	0.46	61.00	4.75
Bk	16-52	8.11	0.29	21.08	0.39	42.5	0.29	0.28	57.20	3.70
C1k	52-80	8.07	0.31	17.13	0.45	36.7	0.38	0.35	56.70	6.50
C2k	80-105	8.27	0.28	23.59	0.49	51.4	0.33	0.27	65.15	3.90
C3k	105+	8.02	0.38	9.61	0.19	45.4	0.30	0.62	60.10	2.80
Yeşilada										
Ap	0-24	7.95	0.26	13.25	2.22	24.6	0.33	1.09	17.35	31.50
Bw	24-52	8.20	0.24	13.65	1.17	32.6	0.25	0.43	24.20	24.05
Bw2	52-70	8.26	0.26	13.98	1.31	27.4	0.33	0.42	23.30	28.05
Ck	70+	8.30	0.26	14.95	0.30	19.0	0.58	0.26	29.50	24.65
Yürükçal										
A	0-29	7.72	0.35	11.71	3.32	41.2	0.27	0.80	49.65	4.20
C1	29-70	8.20	0.25	12.12	1.27	32.6	0.18	0.58	45.55	11.65
C2	70+	8.21	0.30	12.60	1.74	41.8	0.52	0.47	48.00	15.30

acid reaction on the surface, they turn slightly alkaline, especially with the increase of basic cations and lime towards the deep, therefore pH values show that they vary between 6.30 and 8.17. While the organic matter is 2.80% on the surface, this value decreases towards the depths and decreases to 0.68%. Soils are problem-free in terms of salinity and there is no erosion problem.

The Çekmeden series, the soils of this series, most of which have mild to moderate sloping lands, are deep soils formed on colluvial parent material. The pH values of the soils with clayey texture throughout the profile vary between 7.95 and 8.17. While the organic matter is 2.23% on the surface, it decreases to 1.59%, 1.04%, 1.18% in the sub-surface horizons, and 0.59% in the parent material, respectively. While the surface soil was calcareous with 2.75%, it was determined to be moderately calcareous with 10.02% in the subsurface horizon. Soils are problem-free in terms of salinity and there is no erosion problem.

Yeşilada series is located in the north of the study area and they are medium-depth soils formed on colluvial parent material as in the Çekmeden series. The soils of this series are flat and nearly flat inclined, varying between 240 and 300 m above sea level. The body is clay loam throughout the profile. The pH of the soils varies between 7.95 and 8.30. While the organic matter is 2.22% on the surface, it decreases towards the depths and this value decreases to 0.30%. Lime content varies between 13.25% and 14.95%, and it has a medium calcareous structure. In surface and subsurface genetic horizons, the bulk density does not show much variation but varies between 1.41 and 1.51 gr/cm^3. Soils are problem-free in terms of salinity and there is no erosion problem.

Çakırtaş series are deep soils with a slight slope, formed on calcareous parent material. It is seen that clay dominates the body throughout the profile. The pH values of the soils increase towards the depths and are seen to vary between 7.89 and 8.35. While the organic matter is 2.34% on the surface, this value decreases towards the depths and decreases to 0.14%. There is no salinity problem in the profile. As a result of agricultural activities, the surface soils have a somewhat high bulk density (1.36 gr/cm^3) and this value decreases towards the depths (1.23 gr/cm^3).

Soils belonging to the Çalköy series are deep soils formed on alluvial land. While the soil texture is loamy on the surface, clay is the dominant texture towards the depths. The pH of the soils varies between 8.15 and 7.99. While the organic matter is 1.21% at the surface, it decreases to 0.24% at the depths. Lime content varies between 10.83% and 15.35%, and it is in the medium lime class. On the other hand, Çalköy Lower series, these soils formed on steep lands have a slope of more than 30%. The land cover is mostly in the structure of maquis and covered with forest cover, these soils have a depth of 0-20 cm and show shallow characteristics. While the soil reaction varies between 8.23 and 8.58, it is seen that the organic matter is 1.29% on the surface and down to 0.50% on the C horizon.

Bahçekonak series consists of mostly flat and nearly flat lands in the middle part of the study area and medium-sloping lands with 6-12% slope. The pH contents of the soils dominated by clay throughout the profile show moderate alkalinity with 8.02 to 8.30. Their organic matter varies between 1.68% and 0.12%. Lime content ranges from 11.15% on the surface to the moderately calcareous class, up to 17.13% in the profile, and the highly calcareous class.

The Yürükçal series soils are located in the northern part of the study area and have medium-depth soils dominated by clay throughout the profile. The organic matter content of the soils, whose altitudes vary between 300-350 m above sea level, is rich with 3.32% at the surface, while it decreases to 1.27% under the surface. The lime content of the soils varies between 11.71% and 12.60%. Soil reaction is between 7.72 and 8.21.

These soils formed on the Kületek series alluvial gravel deposits are of medium depth. Organic matter content is very low. The lime content of these soils, which do not have salinity problems, is defined as

Table 2. Some physical analysis results of soil series

Horizon	Depth (cm)	Colour Dry, Moist	Texture (%)				Bulk Density gr/cm^3	Field Capacity (%)	Wilting Point (%)	Useful Water (%)
			Clay	Silt	Sand	Class				
Ağcaalan										
A	0-30	10 YR 3/3, 10 YR 3/3	41.07	41.93	17.00	C	1.53	32.94	21.02	11.92
Aydoğdu aşağısı										
Ap	0-20	10 YR 4/3, 10 YR 3/3	61.29	24.78	13.93	C	1.58	33.30	21.56	11.74
Bw	20-58	10 YR 4/2, 10 YR 4/2	28.94	19.61	51.45	SiCL	1.47	35.80	24.23	11.57
Ck	58+	5 Y 4/2, 5 Y 5/2	52.46	38.75	8.79	C	1.41	20.35	13.58	6.78
Aydoğdu üzeri										
A1	0-20	10 YR 3/3, 10 YR 3/4	44.73	31.15	24.12	C	1.34	39.74	32.37	7.38
A2	20-41	10 YR 3/3, 10 YR 3/4	55.69	15.64	28.68	C	1.26	36.58	28.20	8.38
AC	41-60	10 YR 4/3, 10 YR 4/3	42.57	15.16	42.26	C	1.34	27.45	19.43	8.02
Bahçekonak										
Ap	0-20	10 YR 3/3, 10 YR 3/3	53.98	18.10	27.92	C	1.28	47.14	29.96	17.18
Bss1	20-41	10 YR 3/3, 10 YR 3/3	63.52	8.15	28.33	C	1.24	43.03	29.91	13.12
Bss2	41-77	10 YR 3/3, 10 YR 3/4	60.26	18.72	21.02	C	1.25	47.99	30.79	17.20
Bssk	77-136	10 YR 3/3, 10 YR 3/4	69.72	9.03	21.25	C	1.20	41.02	27.49	13.53
Ck	136+	10 YR 4/4, 10 YR 3/3	60.59	13.95	25.46	C	1.22	43.13	27.86	15.27
Bayramköy										
A	0-30	10 YR 3/2, 10 YR 3/2	51.20	22.89	25.91	C	1.29	42.43	31.17	11.26
Bt1	30-54	10 YR 3/2, 10 YR 3/2	57.91	18.39	23.70	C	1.26	43.88	29.40	14.48
Bt2	54-95	10 YR 3/2, 10 YR 3/2	63.93	18.72	17.35	C	1.27	40.75	26.36	14.39
Ck	95+	10 YR 4/3, 10 YR 4/4	62.73	15.92	21.35	C	1.25	35.52	25.03	10.49
Boğazkoru										
Ap	0-17	10 YR 3/3, 10 YR 3/4	55.58	29.85	14.57	C	1.34	42.72	31.60	11.12
A2	17-43	10 YR 3/3, 10 YR 3/3	67.03	15.90	17.07	C	1.27	44.90	31.04	13.86
Bss1	43-75	10 YR 3/2, 10 YR 3/2	69.55	17.59	12.87	C	1.27	47.64	29.36	18.27
Bss2	75-106	10 YR 3/3, 10 YR 3/4	67.17	15.09	17.75	C	1.26	41.86	28.32	13.54
Çakırtaş										
Ap	0-24	10 YR 3/3, 10 YR 3/4	47.17	28.03	24.80	C	1.36	35.28	22.84	12.44
Bw1	24-58	10 YR 3/3, 10 YR 3/4	50.03	27.33	22.64	C	1.35	41.31	26.16	15.16
Bk	58-91	10 YR 3/3, 10 YR 3/4	60.27	21.55	18.18	C	1.27	33.04	21.98	11.06
Bc	91-127	10 YR 4/4, 10 YR 4/5	63.67	17.95	18.38	C	1.25	31.99	21.18	10.81
Ck	127+	10 YR 5/4, 10 YR 5/5	69.35	14.70	15.95	C	1.23	29.23	19.14	10.09

Çalköy										
Ap	0-25	10 YR 4/4, 10 YR 3/4	25.71	39.36	34.92	L	1.31	26.74	15.97	10.77
Ad	25-55	10 YR 3/3, 10 YR 3/4	54.44	20.77	24.78	C	1.50	35.54	21.30	14.24
C1	55-90	10 YR 3/3, 10 YR 3/4	58.74	18.80	22.45	C	1.26	34.72	23.21	11.51
C2k	90-123	10 YR 3/3, 10 YR 3/4	47.59	27.99	24.42	C	1.39	31.18	21.05	10.13
2C	123+	10 YR 4/3, 10 YR 4/4	33.77	37.93	28.30	CL	1.52	24.90	15.32	9.58
Çalköy aşağısı										
A	0-20	10 YR 5/4, 10 YR 4/4	44.80	20.88	34.32	C	1.35	25.40	15.19	10.21
C	20-56	10 YR 5/4, 10 YR 4/4	46.32	13.25	40.44	SiC	1.58	24.52	13.70	10.81
Çekmeden										
Ap	0-17	10 YR 4/3, 10 YR 3/3	48.70	26.06	25.23	C	1,34	40.40	25.92	14.48
A2	17-40	10 YR 3/3, 10 YR 3/4	56.01	20.80	23.19	C	1,29	44.14	26.55	17.59
Bk1	40-83	10 YR 3/3, 10 YR 3/4	56.03	20.76	23.20	C	1,29	46.22	28.42	17.80
Bk2	83-137	10 YR 3/4, 10 YR 3/3	58.50	20.40	21.10	C	1,27	43.09	26.89	16.20
Ck	137+	10 YR 3/2, 10 YR 3/3	58.19	21.01	20.80	C	1,28	41.53	27.03	14.50
Güder aşağısı										
Ap	0-20	10 YR 3/2, 10 YR 3/3	47.84	27.47	24.69	C	1.36	39.48	31.30	8.18
Bw	20-75	10 YR 3/2, 10 YR 3/3	49.71	21.36	28.93	C	1.33	41.34	30.94	10.40
C1k	75-132	10 YR 3/3, 10 YR 3/4	59.81	20.23	19.96	C	1.25	38.01	27.75	10.26
C2k	132+	10 YR 4/3, 10 YR 4/3	46.28	39.05	14.67	C	1.57	38.69	23.59	15.10
Kületek										
A	0-20	10 YR 4/3, 10 YR 4/3	12.48	74.41	13.11	SL	1.61	13.47	5.85	7.62
C1	20-40	10 YR 4/3, 10 YR 4/3	8.51	86.49	5.00	LS	1.60	8.06	4.09	3.97
Meşeli										
Ap	0-27	10 YR 4/3, 10 YR 3/3	50.36	29.01	20.62	C	1.31	40.27	25.96	14.31
Bss1	27-72	10 YR 3/2, 10 YR 2/2	53.62	27.41	18.97	C	1.29	41.61	23.79	17.82
Bss2	72-116	10 YR 3/2, 10 YR 2/2	57.71	21.18	21.11	C	1.28	47.07	26.30	20.78
Ck	116+	10 YR 6/3, 10 YR 5/3	64.43	16.89	18.68	C	1.27	38.87	22.33	16.54
Tekekıranı										
Ap	0-16	10 YR 3/3, 10 YR 3/4	50.41	27.14	22.45	C	1.35	37.19	24.77	12.42
Bk	16-52	10 YR 5/3, 10 YR 5/4	55.56	25.96	18.48	C	1.32	36.27	24.40	11.87
C1k	52-80	5 Y 5/2, 5 Y 5/2	53.59	27.59	18.82	C	1.34	35.18	24.73	10.45
C2k	80-105	5 Y 5/2, 5 Y 5/3	61.50	20.16	18.33	C	1.30	35.84	24.99	10.85
C3k	105+	5 Y 6/3, 5 Y 6/4	54.05	27.18	18.77	C	1.34	42.44	30.34	12.10

Yeşilada										
Ap	0-24	10 YR 4/3, 10 YR 3/3	31.90	38.02	30.09	CL	1.44	26.39	11.27	13.12
Bw	24-52	10 YR 3/3, 10 YR 3/4	35.98	27.69	36.32	CL	1.43	26.34	13.03	13.31
Bw2	52-70	10 YR 3/3, 10 YR 3/4	36.42	25.49	38.09	CL	1.41	28.59	17.41	11.18
Ck	70+	10 YR 4/4, 10 YR 3/3	30.72	27.16	42.12	CL	1.51	26.90	13.36	13.54
Yürükçal										
A	0-29	5 Y 5/3, 5 Y 4/3	40.46	22.79	36.75	C	1.31	31.18	18.30	12.88
C1	29-70	5 Y 4/3, 5 Y 4/4	44.60	20.84	34.56	C	1.35	29.78	16.64	13.15
C2	70+	5 Y 4/3, 5 Y 4/4	42.61	26.99	30.40	C	1.38	31.12	18.41	12.72

9.29%-8.89% in the low calcareous class. Soil reaction shows moderate alkalinity with 8.05-8.24.

The soils of the Tekekıranı series are found to the east of the study area. These lands, which mostly consist of steep slopes and steep lands, range in elevation from 300 to 500 meters above sea level. These are deep soils with a clayey texture that runs throughout the profile. Organic matter contents vary between 1.74% and 0.19%, Lime contents vary between 23.59%-9.61% and pH values vary between 7.92 and 8.27.

Soil series distribution areas and their phases

The spatial and proportional distributions and maps of the soil series in the study area are given in Table 3 and Figure 4. Bahçekonak series are the dominant soil series in the area of 1664.88 ha (15.02%), Bayramköy series 1506.08 ha (13.58%), and Meşeli series 1259.17 ha (11.36). In addition, with an area of 182.45 ha (1.65%), the Yürükçal series covers the lowest area.

Phases were determined in 58 mapping units belonging to the soil series. The parameters and limit values considered in the separation of soils into phases are given in Table 4. It is the soils expressed by the Bh1.Co1d4t1k4 mapping unit belonging to the Bahçekonak series, which covers the largest area with 983.61 ha (8.47%) in the study area. These soils are deep and have a high lime content. They have a clayey texture and belong to the C slope class. The lowest area is covered with 3.73 ha (0.03%) by the lands expressed by the map unit codded as By1.Ai1d3t1k1 belonging to the Bayramköy series.

Research Area Classification of Soils According to Soil Taxonomy and FAO/WRB

Both physico-chemical and morphological characteristics of soils gain character under ecological

Table 3. Spatial and proportional distributions of soil series in the study area

Series Name	Symbol	Area (ha)	Ratio (%)
Ağcaalan	Ac	965.17	8.71
Aydoğdu aşağısı	Aa	406.42	3.67
Aydoğdu üzeri	Au	451.12	4.07
Bahçekonak	Bh	1664.88	15.02
Bayramköy	By	1506.08	13.58
Boğazkoru	Bk	1025.81	9.25
Çakırtaş	Ct	922.58	8.32
Çalköy	Ck	389.28	3.51
Çalköy aşağısı	Ca	215.45	1.94
Çekmeden	Cd	884.67	7.98
Güder aşağısı	Gd	361.25	3.26
Kületek	Kt	268.82	2.42
Meşeli	Ms	1259.17	11.36
Tekekıranı	Tk	367.39	3.31
Yeşilada	Ya	216.14	1.95
Yürükçal	Yc	182.45	1.65
TOPLAM		11086.68	100.00

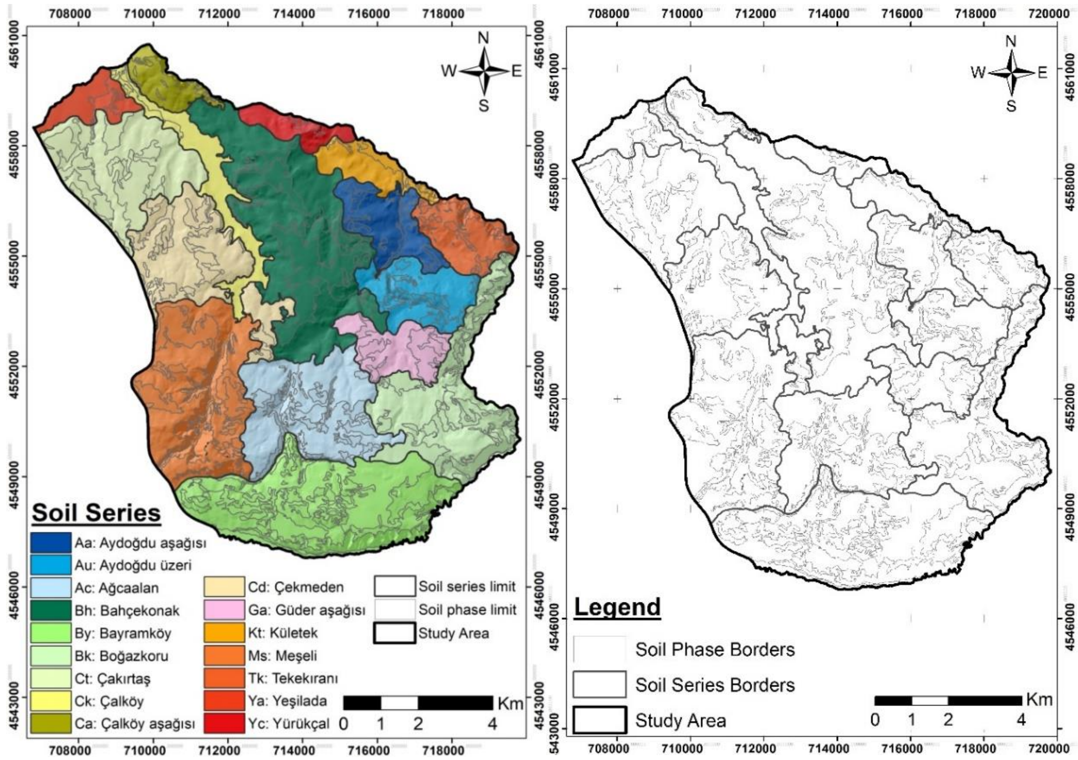

Figure 4. Soil series and phases distributed in the study area

conditions. They are in soil properties, which gain their character according to the contribution and degree of impact of environmental factors and play an important role in the management and productivity of the soil. Veenstra and Burras (2012) stated that soil pH, color, cation exchange capacity, base saturation, and changes in carbonate content are just a few of the soil properties that can cause changes in soil classification and soil fertility. Dengiz et al. (2010), to determine the distribution of the soils formed on the alluvial lands where rice cultivation is carried out in Çorum-Osmancık and to classify the different soils, 12 soil profiles were opened in the study area of approximately 1663 ha and 9 different soil series were defined as a result of the analyzes and field observations. They classified 2 of them in Entisol, 4 of them in Ineptisol, and 3 of tare them in Vertisol order. In addition, Darvishi-Foshtomi et al. (2010), qualitative and economic land suitability assessments were carried out for the Tea plant (*Camellia sinensis* L.) in Guilan province in the north of Iran. The digital elevation model was analyzed by interpreting the outputs obtained from GIS and determining 16 profiles in the study area. They stated 8 soil series with different properties formed on granite and phyllite as the main material. They defined 3 of them in Alisol, 3 in Cambisol, 1 in Umbrisol and 1 in Regosol class. These case studies show that many different soil types can be found in agricultural areas where agricultural activities are located and it turns out that each soil type must take into account its specific management request to make sustainable planning without losing productivity functions of the soils.

The classification of soils in the study area according to soil taxonomy (Soil Survey Staff, 1999) and (WRB, 2014) is given in Table 5. Taking into account the observations made in the field and laboratory results, in the classification of soil series distributed within the study area according to soil taxonomy, their pedogenetic features and upper diagnostic horizons (Epiphone), sub-surface diagnostic horizons and their characteristics should be taken into account. and they are placed in 4 orders, 5 sub-orders, 6 large groups and 7 subgroups (Soil Survey Staff, 2014). Some surface (ocric. vertic) and subsurface (clacic. cambic. clay deposition. slip surfaces) diagnostic horizons formed after the formation process of the soils were determined and placed in Entisol. Inceptisol and Vertisol orders. Among these orders, Vertisol covers the most area with 35.63% followed by Inceptisols at 28.49% Entisols at 22.3% and Alfisol soils at 13.58% respectively. According to FAO-WRB (2014), Leptosol is classified as Cambisol and Vertisol and Luvisol.

Entisol soils consisting of Ağcaalan, Aydoğdu üzeri, Çalköy aşağısı, Yürükçal, Kületek, and Çalköy series do not have any subsurface soils since they have an A/C horizon sequence with the effect of erosion, both because they have not been under the influence of sufficient pedological processes and because they are distributed on slopes that adversely affect this process. It does not have a diagnostic horizon. These series of soils, which are described as young soils, are classified in the Xerorthent large group due to the Xeric moisture regime, in the Orthent suborder due to their location on the slopes, and in the Typic Xerentent subgroup because

Table 4. Parameters and limit values considered in the separation of soils into series and phases

Topsoil Texture (UTT Classes)				
Symbol	General Classes	Secondary Classes	Texture fraction	Texture Class
1	Clays Lands (Heavy)	Fine textured	Clay	C
			Silty clay	SiC
			Sandy clay	SC
2	Loamy Soils (Middle)	Medium fine texture	Clay loam	CL
			Sandy clay loam	SCL
			Silty clay loam	SiCL
3		Medium texture	Silty	Si
			Silty loam	SiL
			Loam	L
			Very fine sandy loam	VFSL
4	Sandy Soils (Light)	Medium rough texture	Sandy loam	SL
			Fine sandy loam	FSL
5		Ruugh texture	Loamy sand	LS
			Sandy	S

Slope			Depth (cm)		
Slope class	Slope degree (%)	Description	Symbol	class	Description
A	0-2	Flat- close to flat	d1	0-20	Too shallow
B	2-6	Slightly sloping	d2	20-50	Shallow deep
C	6-12	Medium slope	d3	50-90	Medium deep
D	12-20	Steep slope	d4	90+	Deep
E	20-30	Very steep slope			
F	30+	Steep			

Drainage		Stoniness		
Symbol	Description	Symbol	Description	Degree (%)
i	Good	t1	Without stones- with few stones	2-10
o	Middle	t2	Medium stony	10-50
f	Bad	t3	Too stony	50-90

Erosion			Lime		
Symbol	Classes	Degree (%)	Symbol	Classes	Degree (%)
1	Light or no	0-25 (A horizon)	k1	Lime free	0-5
2	Middle	25-75 (A horizon)	k2	Less chalky	5-10
3	Severe	75-100 (A horizon)	k3	Medium chalky	10-15
4	Very severe	25-75 (B horizon)	k4	Too much chalky	15-30
			k5	Marn	30+

they contain all the characteristics of the large group. According to the FAO/WRB (2014) classification system; Ağcaalan, Aydoğdu üzeri, Çalköy aşağısı, Yürükçal series are classified as Leptosol. while Kületek and Çalköy series are classified as Fluvisol.

Aydoğdu aşağısı, Yeşilada, Çakırtaş, Çekmeden, Güder aşağısı and Tekekıranı series. with the diagnostic horizon, they contain (cambic) because they show a soil formation more advanced than the Entisols, and because of the Xeric soil moisture regime, secondary calcium carbonate accumulation in 100 cm depth It is classified as Vertic Calcicxerept at the subgroup level due to its vertical characteristics in the surface horizons. According to the FAO/WRB (2014) classification system; It is classified as caloric vertical Cambisol.

Soils belonging to the Meşeli, Boğazkoru and Bahçekonak series were placed in the Vertisol ordo because of the high amount of swelling clays (40% or more along the profile), the cracks extending from the surface to the deep in the dry seasons and the slip surfaces in the profile from time to time. Because the soil moisture regime is Xeric, it is classified in the Xerert lower ordo and Bahçekonak series soils are classified in the Calcixerert large group due to the development of a Calcic horizon as a result of calcification. At the subgroup level, it is classified as Typic Calcixerert because it has all the characteristics of the larger group. Meşeli and Boğazkoru series were classified as Haplxererts at the large group level and as Typic Haplxererts at the subgroup level. These series were classified as Calcic Vertisol and Haplic Vertisol according to the FAO/WRB (2014) classification system. Finally, the Bayramköy series was classified as Mollic Haploxeral, as a subsurface diagnostic horizon and as Calcic Luvisol, according to the FAO/WRB (2014) classification system, due to the development of the argillic horizon and the determination of metallic properties on the surface.

Table 5. Soil classification and FAO-WRB classification of soil series

Series Name	Soil Taxonomy –(2014)				FAO-WRB-(2014)
	Ordo	Subordo	Large Group	Subgroup	
Ağcaalan	Entisol	Orthent	Xerothent	Lithic Xerorthent	Lithic Leptosol
Aydoğdu üzeri	Entisol	Orthent	Xerothent	Typic Xerorthent	Clayic Leptosol
Çalköy aşağısı	Entisol	Orthent	Xerothent	Lithic Xerorthent	Lithic Leptosol
Yürükçal	Entisol	Orthent	Xerothent	Typic Xerorthent	Clayic Leptosol
Kületek	Entisol	Fluvent	Xerofluvent	Typic Xerofluvent	Skeletic Fluvisol
Çalköy	Entisol	Fluvent	Xerofluvent	Typic Xerofluvent	Densic Fluvisol
Aydoğdu aşağısı	Inceptisol	Xerept	Calcixerepts	Vertic Calcixerept	Calcaric vertic Cambisol
Yeşilada	Inceptisol	Xerept	Calcixerepts	Vertic Calcixerept	Calcaric vertic Cambisol
Çakırtaş	Inceptisol	Xerept	Calcixerepts	Vertic Calcixerept	Calcaric Cambisol
Çekmeden	Inceptisol	Xerept	Calcixerepts	Vertic Calcixerept	Calcaric vertic Cambisol
Güder aşağısı	Inceptisol	Xerept	Calcixerepts	Vertic Calcixerept	Calcaric vertic Cambisol
Tekekıranı	Inceptisol	Xerept	Calcixerepts	Vertic Calcixerept	Calcaric vertic Cambisol
Meşeli	Vertisol	Xerert	Haplxererts	Typic Haplxerert	Haplic Vertisol
Boğazkoru	Vertisol	Xerert	Haplxererts	Typic Haplxerert	Haplic Vertisol
Bahçekonak	Vertisol	Xerert	Calcixererts	Typic Calcixerert	Calcic Vertisol
Bayramköy	Alfisol	Xeralf	Haploxeralf	Mollic Haploxeralf	Calcic Luvisol

Conclusion

Sustainable agricultural production is only possible with the effective and efficient use of agricultural inputs. Soil, which is the most important of these agricultural inputs, is subject to deterioration in each production period, that is during the period from planting to harvest. This event, which is defined as soil degradation, defined as the intensive use of agricultural lands, pollution of water resources, and as a result, causing some political and social problems. With the selection of the best soil plant and land management, it is possible to improve many characteristics of the soils, together with ensuring sustainability in agriculture. For this reason, to develop planning strategies that will ensure the sustainable use of agricultural lands and to make models on environmental issues, detailed soil surveys and mapping studies, which will include basic information such as soil, physiography, climate, vegetation and land use, and monitoring, evaluation and updating in the process, a soil database is needed. Most of the soils in the study area consist of deep soils with clayey textures. The establishment of pressurized irrigation systems in the region has a wide product potential in terms of agricultural diversity, and is important for agricultural productivity. Determining the unique physical and chemical properties of soils is the most basic factor that increases productivity and quality in production. For this purpose, the determination of the exact boundaries and distribution areas of the soils after the soil survey carried out in the 11086.68 ha study area in total is a guide that can be taken into account in terms of crop cultivation. The main identified problems of the soils of the study area are tillage, slope, soil depth, erosion, base stone and poor drainage. For example, in the Çalköy and Aydoğdu series the subsurface layer (base stone), which is compressed as a result of continuous plowing at the same depth, needs to be broken with deep plowing. In addition, airless conditions may occur as a result of very slow drainage of water in vertisol soils with dense clay content. For this reason, it is important to take this property of the soil into consideration, both irrigation periods and methods and plant water consumption. Another issue is that in agricultural areas where soils are classified as typic or lithic xerorthent, which are distributed on sloped lands are used, soil cultivation should be carried out perpendicular to the slope to prevent erosion and soil transport. In addition, since organic matter is low in most surface soils distributed within the study area, this ratio should be increased with good agricultural practices.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that might apper to influence the work reported in this paper.

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Author Contributions

FS: Conceptualization, investigation, methodology, validation, software, validation, formal analysis, investigation, resources, data curation, writing-original draft preparation, writing-review and editing, visualization, supervision, statistical analysis, project administration; **OD:** Conceptualization, investigation, methodology, validation, software, validation, formal analysis, investigation, resources, data curation, writing-original draft preparation, writing-review and editing, visualization, supervision, statistical analysis, project administration.

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RESEARCH PAPER

Effects of applications of synthetic polymer and humic acid on resistance to dispersion and mechanical forces

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Abstract

In this study, the effects of the addition of polyvinyl alcohol (PVA), polyacrylamide (PAM), and humic acid (HA) to soils in sandy loam, loam, and clay texture classes on their resistance to dispersion and mechanical forces were examined. The study was performed under greenhouse conditions using surface soil samples and 1.5 kg pots. Furthermore, the study was planned as an incubation experiment and the application of PVA, PAM, and HA at 500, 100, and 500 ppm doses for each soil texture class, respectively. During the incubation times (1 (0), 2 (15), 3 (30) 30, and 4 (45) days), the irrigation process was repeated as half of the available moisture in the soil was depleted. Ultimately, the applications of PVA, PAM, and HA on soils in sandy loam, loam, and clay textures increased the liquid limit/ pF'2 moisture ratio (LL/pF'2) values in them by 6.30%, 5.99%, and 7.30%, respectively, (reducing the tendency to dispersion) compared to the control. Furthermore, the applications increased the plastic limit/pF’2 moisture ratio (PL/pF’2) values (resistance to mechanical forces) by 22.31%, 16.50%, and 9.27%, respectively. Incubation time 1 was more effective in reducing dispersion and increasing resistance to mechanical forces, and the effects decreased over time. PVA was the most effective conditioner for all three soil groups.

Introduction

Soil structure is the arrangement and grouping of primary and secondary soil particles in certain shapes along weak surfaces that can be easily separated from each other and is a dynamic characteristic of the soil. This dynamic structure is crucial for creating an environment suitable for plant cultivation and a structure resistant to erosion (Özdemir and Canbolat, 1997; Özdemir and Bülbül, 2021). Soil texture, organic matter content, climatic conditions, land use, and conditioner practices significantly affect the resistance of the dynamic structure to dispersion and mechanical forces. Hacımüftüoğlu (2012) investigated the effects of plants grown under the conditions of the Erzurum region on the structural parameters of the soil and found that the structural parameters of the soil were significantly different depending on the plant pattern cultivated. In research under the conditions of the Turhal region, Bülbül (2019) found that basic soil properties and plant management practices were effective on structural durability and sensitivity to erosion and that the most appropriate parameters were in grassland areas, while the most negative parameters were in the soil in sugar beet cultivation areas.

Different methods can be employed to improve the soil structure and create soils that are resistant to mechanical forces, dispersion, and erosion and suitable for plant cultivation (Demir et al., 2022). These methods include conservation tillage (Busari et al., 2015), the addition of organic matter (Wuddivira and Camps-Roach, 2007) and green manure (Gao et al., 2018), biological fertilization (Lucas et al., 2014), and the addition of organic matter based synthetic environmental conditioners to the soil. Polyvinyl alcohol, polyacrylamide and humic acid are widely used for these purposes because they are effective at low doses (Tejeda and Gonzales, 2007; Hacımüftüoğlu and Canbolat, 2020).

Polyacrylamide application increases aggregate stability (Mamedov et al., 2007; Kassim and Özdemir, 2022), reduces water and soil loss (Bjorneberg et al., 2003; Sojka et al., 2007), prevents crust formation, and reduces plant nutrient loss (Sojka et al., 1998; Özdemir et al., 2014). In their study examining the effects of PAM and PVA applications on soil properties and NPK uptake in coarse and fine-textured soils, Çağlar and Demir (2021) found that the application positively affected the physical structure and NPK nutrition of the jute plant in both (loam, clayey) soil groups. Kassim and Özdemir (2022), on the other hand, evaluated the effect of PVA, PAM, and HA acid applications on aggregate stability and found that PVA was more effective than other conditioners and that the effect was at a proportionally lower level in clay soil.

Today, humic acid, polyacrylamide, and polyvinyl alcohol are the most commonly used synthetic improvers. The effectiveness of these conditioners varies depending on the application doses, application time, application method, climatic conditions, and the effect of soil properties on polymer degradation (Blanco-Canqui and Lal, 2008). Various test techniques may be employed to evaluate the effect of these conditioners on soil structure (Özdemir, 2013). This study examines the effect of the application of humic acid (500 ppm), polyacrylamide (100 ppm), and polyvinyl alcohol (500 ppm) on sandy loam, loam and clayey soil's resistance to mechanical forces and its dispersion in water over time.

Materials and Methods

Three different soil types with sandy loam, loam and clayey textures were used in this study (Table 1). They were obtained from three different locations (41°50'-35°82'; 41°55'-35°86'; 41°36'-36°18') in the research area of Ondokuz Mayıs University. Soils were ready for use after drying and sifting processes. Three different commercial conditioners, namely, polyvinyl alcohol (PVA), polyacrylamide (PAM), and humic acid (HA) were employed in the study. Polyacrylamide ($CH_2CHCONH_2$) was a 98% hydrolysis commercial product with a molecular weight of 10000 mg/mol, and Polyvinyl alcohol (C_2H_4O) was a 98% hydrolysis commercial product with a molecular weight of 72000 g/mol. The humic acid used had a 15% humic and fulvic acid content.

Soils were weighed based on their kiln-dried weights and transferred to 1500 g pots. Afterward, PAM, PVA, and HA were added to the pots at doses of 500, 100, and 500 ppm, respectively (Kassim and Özdemir, 2022; Yakupoğlu and Öztaş, 2016; Yakupoğlu et al., 2019). After the addition process, the pots were left to incubate in the greenhouse (25 ^{0}C) for 0, 15, 30, and 45 days. During this period, irrigation was done when 50% of the ideal moisture in the soil was exhausted. After the end of each period, soil samples were dried in the air and crushed by hand and made ready for analysis.

In the laboratory analyses, texture (% sand, silt, clay) was determined based on the hydrometer method (Demiralay, 1993); soil reaction (pH) based on pH-meter in 1:1 (w/v) soil:pure water mixture (Kacar, 2016);

Table 1. Some of the physical and chemical properties of the soils

Soil num.	Soil properties								
	Sand %	Silt %	Clay %	Tekture	pH (1:1)	EC dS/m	$CaCO_3$ %	OM %	CEC me/100g
1	58.88	29.36	11.76	SL	7.90	0.118	8.23	0.80	31.69
2	36.40	41.60	22.00	L	7.45	0.492	8.42	2.98	38.28
3	31.72	23.17	45.11	C	6.95	0.149	2.20	1.59	65.40
				Parameters					
				LL/pF'2	PL/pF'2				
1				0.70	0.58				
2				0.82	0.64				
3				0.98	0.69				

OM: organic matter, CEC: cation exchange capacity, CaCO3: lime content, EC: electrical conductivity, LL: liquid limit, PL: plastic limit electrical conductivity (EC) based on EC-meter in 1:1 (w/v) soil:pure water mixture (Kacar, 2016); lime content ($CaCO_3$) based on Scheibler calcimeter (Rowell, 1996); cation exchange capacity (CEC) based on Bower method (Kacar, 2016); organic matter content based on Walkey-Black method (Kacar, 2016); field capacity based on pressure table (Demiralay, 1993); PF'2 moisture content based on Pressure table (Demiralay, 1983); liquid limit (LL) based on Casagrande's method, (Demiralay, 1993); plastic limit (PL) based on plastic limit roller method (Demiralay, 1993), and finally, LL/pF'2 and PL/pF'2 moisture contents ratio based on (Özdemir, 2013).

Results and Discussion

Soil Properties

Some of the physical and chemical properties of the soils used in the study conducted under greenhouse conditions are given in Table 1. As can be seen in Table 1, sandy loam (1) textured soil has a moderately alkaline reaction and a moderately calcareous structure with low organic matter content. Loam-textured (2) soil has a slightly alkaline reaction and a moderately calcareous structure with high organic matter content. Clay-textured (3) sample has a neutral reaction and a less calcareous structure with moderate organic matter content. The pH values of the soils are below 8.5 and there is no alkalinity problem in the soils (Soil Survey staff, 1993).

Dispersion and Resistance to Mechanical Forces

The following parameters were used to evaluate the effects of the applications and processes on the soil's dispersion and resistance to mechanical forces.

LL/pF'2 Moisture Ratio

Table 2 shows the effects of PVA, PAM, and HA added to soil samples with sandy loam, loam, and clay textures on soil resistance to dispersion (LL/pF'2 moisture ratio) and the results of the variance analysis test for related of this resistance values over time (0, 15, 30, 45 days), while Table 3 shows the average changes related to these values and the results of the multiple compare test. The changes in the said ratio compared to the control are shown in Figures 1 and 2. As can be seen in the variance analysis test results, the mean value of the squares of the LL/pF'2 moisture ratio values were significant ($p<0.01$). In other words, the soils differed in terms of their sensitivity to dispersion at the end of the experiment.

The same data indicates that the effects of the three conditioners and the application times are also significant ($p<0.01$). The results of the analysis also indicated that the interactions between soil x conditioner (A*B), soil x period (A*C), conditioner x period (B*C), and soil x conditioner x period (A*B*C) for LL/pF'2 values were significant.

Significant changes were observed in LL/pF'2 value compared to control (Table 3). The change varied depending on the time, conditioner type, and soil texture. Considering the increases compared to control, PVA was the most effective conditioner in all three soil classes.

A multiple compare test (Duncan) was performed using the values to compare the effects of soils, conditioners, and application periods on the LL/pF'2 moisture ratio at the end of the experiment. These test data indicate that the soils are significantly different from each other in terms of the average LL/pF'2 moisture ratio at the end of the experiment. The said evaluation also indicated that the conditioner periods were ranked, as shown in Table 3, based on the average LL/pF'2 moisture ratios at the end of the experiment. In this multiple-compare test, the differences between the application times were significant ($p<0.01$), and the effectiveness decreased over time (Table 3).

On the other hand, according to the same test results, the differences between PVA, PAM, and HA were significant ($p<0.01$) in terms of average LL/pF'2 moisture contents at the end of the experiment.

Considering the rate changes (%) in LL/pF'2 moisture contents compared to the control (Figure 1), PVA, PAM, and HA caused increases in LL/pF'2 moisture rate

Table 2. The results of the variance analysis of LL/pF'2 moisture ratio values

Sources	Degrees of freedom	Sum of squares	Mean of squares.	F value	Level of significance
A*	2	0.176	0.088	220.121	0.000
B	2	0.185	0.092	230.992	0.000
C	3	0.211	0.070	175.502	0.000
A*B	4	0.022	0.006	14.017	0.000
A*C	6	0.276	0.046	114.877	0.000
B*C	6	0.013	0.002	5.403	0.000
A*B*C	12	0.056	0.005	11.573	0.000
Mistake	72	0.029	0.000		
General	108	108.992			

A: Soils, B: Conditioners, C: Periods

Table 3. LL/pF'2 moisture ratio values of soils and multiple comparison test (Duncan) results

Soils	Conditioners	Periods				Soil averages
		1	2	3	4	
	PVA	0.826	0.782	0.750	0.746	
SL	PAM	0.765	0.741	0.730	0.726	0.745 a
	HA	0.756	0.738	0.690	0.685	
	PVA	0.950	0.930	0.897	0.850	
L	PAM	0.919	0.862	0.842	0.839	0.869 b
	HA	0.896	0.845	0.819	0.781	
	PVA	1.164	1.193	1.099	1.033	
C	PAM	1.068	1.062	1.002	0.996	1.050 c
	HA	1.035	1.015	0.987	0.965	
Period averages		0.931 a	0.908 b	0.868 c	0.847 d	
Conditioners averages	PVA	0.935 a				
	PAM	0.879 b				
	HA	0.851 c				

The difference between the mean values shown with different letters are significant at the 1%.

depending on the application times. The change was 6.30 in SL class soil, 5.99 in L class soil and 7.30 in C class soil. In other words, the activities of the conditioners changed depending on the texture and the effect on the soils was C>SL>L in this respect. On the other hand the respective effect of different conditioners were: PVA: C soil (14.51)> SL soil (10.85)> L soil (10.58); PAM: SL soil (5.78)> L soil (5.54)> C soil (5.30); HA: SL soil (2.46) >C soil (2.09) >L soil (1.86) (Figure 1). Conditioners may have been more effective in increasing the stability in clay soils due to the combined effects of the clay and the conditioners.

PVA, PAM, and HA applications created significant time-dependent differences in the LL/pF'2 moisture ratiot of the soil compared to the control (%) (Figure 2). As the figure shows, the differences varied depending on the texture of the soil, and the ranking of the periods based on the effectiveness was, 1st period (12.36) > 2nd period (9.03) > 3rd period (4.12) > 4th period (1.82).

The LL/pF'2 moisture content value reflects the resistance of the soils to dispersion when wet, and if the ratio is greater than 1, there is no risk of deterioration of the structure through dispersion when wet. On the other hand, the soil will be easily dispersed when wet if the said value is less than 1 (de Boodt et al., 1967; Demiralay, 1983; Karagöktaş and Yakupoğlu, 2014; Özdemir and Bülbül, 2021). An evaluation of the research data would suggest that the soils were structurally sensitive to dispersion before the

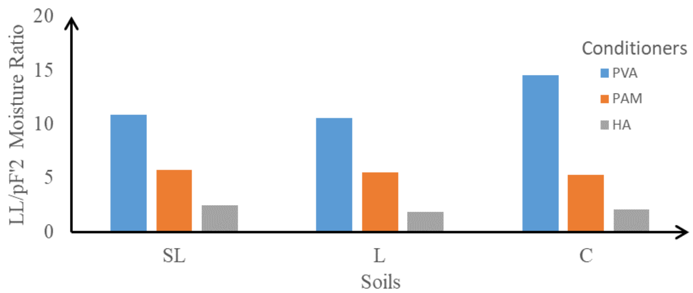

Figure 1. Changes in LL/pF2' moisture ratio values of soils depending on conditioners

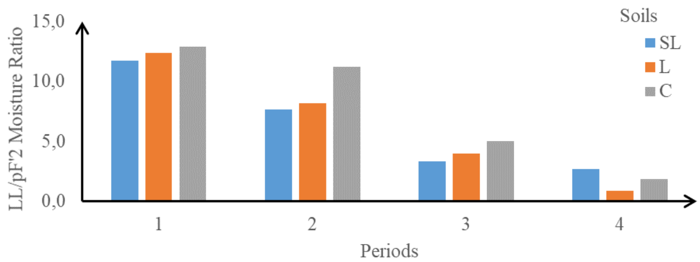

Figure 2. Changes in LL/pF'2 moisture ratio values according to periods

experiment, PVA, PAM, and HA added to the soils increased the LL/pF'2 moisture ratio, thus making them more stable compared to the initial conditions, the effectiveness decreased over time, and the applications were insufficient in terms of limit value in the two soil groups, except those in C class. In a study examining the effects of PVA, PAM, and HA applications on structural stability, Aksakal and Öztaş (2010) emphasized that synthetic conditioners increase stability and PVA is more effective within this scope. In a similar study, Kassim and Özdemir (2022) indicated that synthetic conditioner applications increase stability and their effect varies depending on the textural structure of the soil.

PL/pF'2 Moisture ratio

Table 4 shows the effects of PVA, PAM, and HA added to soil samples with sandy loam, loam, and clay textures on soil resistance to mechanical forces (PL/pF2 moisture content) and the results of the variance analysis test performed to examine the change of this resistance values over time (0, 15, 30, 45 days), while Table 5 shows the average changes related to these values and the results of the multiple compare test. The changes in the said ratio compared to the control are shown in Figures 3 and 4. As can be seen in the variance analysis test results, the mean value of the squares of the PL/pF'2 moisture ratio values were significant ($p<0.01$). In other words, the soils differed in terms of the ratio at the end of the experiment.

The same data indicates that the effects of the three conditioners and the application times are also significant ($p<0.01$). The results of the analysis also revealed that the interactions between soil x conditioner (A*B), soil x period (A*C), conditioner x

Table 4. The results of the variance analysis of PL/pF’2 moisture ratio values

Sources	Degrees of freedom	Sum of squares	Mean of squares.	F value	Level of significance
A	2	0.073	0.037	218.640	0.000
B	2	0.056	0.028	168.497	0.000
C	3	0.035	0.012	70.031	0.000
A*B	4	0.010	0.003	15.271	0.000
A*C	6	0.057	0.010	56.854	0.000
B*C	6	0.006	0.001	6.201	0.000
A*B*C	12	0.023	0.002	11.579	0.000
Mistake	72	0.012	0.000		
General	108	58.146			

A: Soils, B: Conditioners, C: Periods

Table 5. PL/pF'2 moisture ratio values of soils and multiple comparison test (Duncan) results

Soils	Conditioners	Periods				Soil averages
		1	2	3	4	
SL	PVA	0.783	0.745	0.707	0.682	0.709 a
	PAM	0.748	0.727	0.716	0.673	
	HA	0.742	0.711	0.657	0.622	
L	PVA	0.800	0.787	0.777	0.752	0.746 b
	PAM	0.785	0.745	0.711	0.692	
	HA	0.776	0.721	0.717	0.685	
C	PVA	0.827	0.787	0.768	0.747	0.754 c
	PAM	0.769	0.761	0.742	0.727	
	HA	0.739	0.722	0.755	0.707	
Periods averages		0.774 a	0.740 b	0.727 c	0.698 d	
Conditioner averages	PVA	0.763 a				
	PAM	0.733 b				
	HA	0.713 c				

The difference between the mean values shown with different letters are significant at the 1%.

period (B*C), and soil x conditioner x period (A*B*C) for PL/pF'2 values were significant.

Significant changes were observed in PL/pF'2 value compared to the control (Table 5). The change varied depending on the time, conditioner type, and soil texture. Considering the increases compared to control, PVA was the most effective conditioner for all three soil texture classes.

A multiple compare test (Duncan) was performed using the values to compare the effects of soils and application periods of PVA, PAM, and HA on the PL/pF'2 moisture ratio at the end of the experiment. An evaluation of the test results indicates that the soils are significantly different from each other in terms of the average PL/pF'2 moisture ratio at the end of the experiment. The said evaluation also indicated that the conditioner periods were ranked, as shown in Table 5, based on the average PL/pF'2 moisture ratios at the end of the experiment. In this multiple-compare test, the differences between the application times were significant ($p<0.01$), and the effectiveness decreased over time. On the other hand, according to the same test results, the differences between PVA, PAM, and HA were significant ($p<0.01$) in terms of average PL/pF'2 moisture contents at the end of the experiment.

Considering the rate changes (%) in PL/pF'2 moisture contents compared to the control (Figure 3), PVA, PAM, and HA caused increases in PL/pF'2 moisture rate values depending on the application times. The mean change was 22.31 in SL class soil, 16.50 in L class soil, and 9.27 in C class soil. In other words, the activities of the conditioners changed depending on the texture and the effect on the soils was SL>L>C in this respect. On the other hand the respective effect of different conditioners were: PVA; SL soil (25.73)> L soil (21.71)> C soil (13.32); PAM: SL soil (23.47)> L soil (14.53)>C soil (8.70); HA: SL soil (17.73)>L soil (13.28)>C soil (5.80) (Figure 1). Conditioners may have been less effective in increasing the mechanical resistance in clay soils due to the combined effects of the clay and the conditioners.

PVA, PAM, and HA applications created significant time-dependent differences in the PL/pF'2 moisture content of the soil compared to the control (%) (Figure 4). As can be seen in Figure 4, the differences varied depending on the texture class of the soil and conditioner type, and the ranking of the periods based on the effectiveness was, 1st period (12.80) > 2nd period (9.71) > 3rd period (9.27) > 4th period (5.22), meaning that the effects decreased over time.

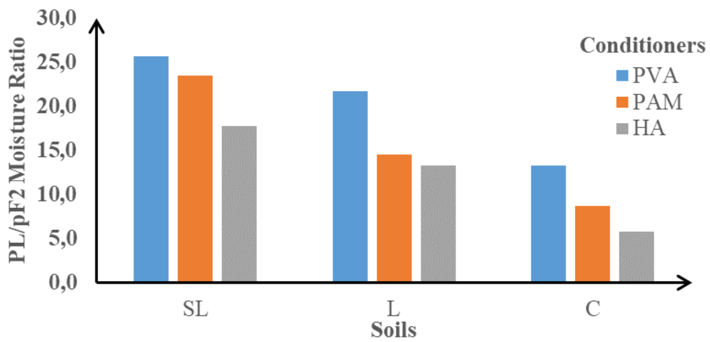

Figure 3. Changes in PL/pF2' moisture ratio values of soils depending on conditioners

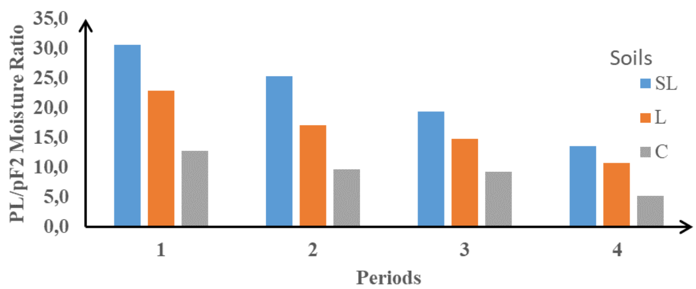

Figure 4. Changes in PL/pF'2 moisture ratio values according to periods

The PL/pF'2 moisture content ratio reflects the resistance of the soils to mechanical forces, and if the rate is greater than 1, the soil is considered to be resistant to mechanical forces, while values less than 1 (0.6-0.7) indicate sensitivity to the mechanical forces (de Boodt et al., 1967; Demiralay, 1983; Karagöktaş and Yakupoğlu, 2014; Özdemir and Bülbül, 2021). An evaluation of the research data would suggest that the soils were sensitive to mechanical forces before the experiment, PVA, PAM, and HA added to the soils increased the PL/pF'2 moisture ratio, thus making them more stable compared to the initial conditions, the effectiveness decreased over time, and the conditioners were insufficient in terms of limit value in all three soil groups. In a study examining the effects of PVA, PAM, and HA applications on structural stability, Aksakal and Öztaş (2010) emphasized that synthetic conditioners increase stability and PVA is more effective within this scope. In a similar study, Kassim and Özdemir (2022) indicated that synthetic conditioner applications increase stability and their effect varies depending on the textural structure of the soil. Examining the durability of the soil against grazing, Sönmez (1978) found that there was a positive relationship between the PL/pF moisture ratio and the criteria based on structural stability.

Conclusions

As a result of this study performed under greenhouse conditions to determine the effects of synthetic polymer and humic acid applications on dispersion and resistance to mechanical forces, it was found that;

Polyvinyl alcohol, polyacrylamide, and humic acid applied to the soil samples significantly increased the resistance to dispersion values of the soil, PVA was more effective than other conditioners, and the said increases in resistance were affected by the texture, and the soils were ranked as C>SL>L in this respect. On the other hand, the effectiveness of conditioners decreased as the period length increased. The applications were insufficient in terms of the recommended limit value for durability in two soil groups, except in the clay (C) texture class.

The application of polyvinyl alcohol, polyacrylamide and humic acid significantly increased the resistance to mechanical forces values of the soils, PVA was more effective than other conditioners, the said increases were affected by the texture and the soils were ranked as SL>L>C in this respect. On the other hand, the effectiveness of conditioners decreased as the period length increased, and the conditioners were insufficient in terms of the limit value related to durability in all three soil groups.

In conclusion, the effects of polyvinyl alcohol, polyacrylamide, and humic acid applications improved the resistance to dispersion and mechanical forces values of soils, and the effectiveness varied depending on the properties of the conditioners, soil texture class, and duration. It would be helpful to pay attention to these issues in practice.

Conflict of Interest

There is no conflict of interests at all.

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