Soil Studies 13(2), 74-88
*http://doi.org/*10.21657/soilst.1601778

RESEARCH PAPER

Development and dissemination of precision agriculture practices for wheat in Central Anatolia

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How to cite
Polat, T., Yıldız, H., Aydoğdu, M., Keçeci, M., Aloe A.K., Urla, Ö., Çolak, A., Akdemir, B., Türker, U., & Yegül, U. (2024). Development and dissemination of precision agriculture practices for wheat in Central Anatolia. *Soil Studies, 13(2)*, 74-88. http://doi.org/10.21657/soilst.1601778

Article History
Received 03 October 2024
Accepted 25 October 2024
First Online 28 December 2024

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Keywords

Wheat
Variable Level Fertilizer Application
Yield Mapping
Analytic Hierarchical Process (AHP)
Spatial Change

Abstract
According to the results of the analysis of the soil samples taken from the production field in the Research and Application Farm of the Central Research Institute of Field Crops in 2021, a significant relationship was found between yield and NDVI and between yield and organic matter at 0.01 level. There was a significant negative relationship between lime and NDVI at 0.01 level. Increasing lime content negatively affected plant growth, which resulted in a decrease in NDVI. The positive significant correlation between NDVI, organic matter and yield indicates that NDVI value increases with increasing plant biomass. Increased biomass has added more soil organic matter. In 2021, when the yield change depending on NDVI was examined; it was observed that the yield was higher in the central and western parts of the plots where NDVI was higher, and the yield decreased in the eastern parts where the lakeshore strip was located due to the decrease in NDVI. According to the correlation results between the analysis results of soil samples taken from the farmer's field in 2021, yield values and NDVI data; a significant relationship was found between yield value and NDVI, water saturation, EC, organic matter and potassium at 0.01 level. Again, the relationship between yield and phosphorus was determined at 0.05 level. There was a significant negative relationship between yield and lime at 0.05 level.

Introduction

The effects of fertilizers, one of the indispensable inputs of agriculture, on environmental pollution has become a current issue of intense debate in recent years. It is known that organic and inorganic fertilizers contain some substances that may cause environmental pollution. Some of these substances are essential nutrients for plants, while others are naturally occurring in the raw materials used in fertilizer production and are not absolutely essential for plants. Fertilizers applied to the soil to meet the nutrient requirements of plants carry the risk of environmental pollution when they are used unconsciously and excessively due to the pollutants, they contain

(Köseoğlu, 1995). Today, excessive and unconscious use of chemical fertilizers and pesticides is the most important factor in the pollution of underground and surface water resources. It should not be forgotten that this pollution disrupts human health. As a result, since climate and soil characteristics differ in all regions of the country, it would be useful to carry out such studies in every region in order to prevent fertilizer losses and environmental pollution (Bellitürk, 2008). When any nitrogen fertilizer is added to the soil, some of the nitrogen evaporates away in the form of NH_3 depending on the type of fertilizer, soil conditions and climatic events in the region. Under some circumstances, the amounts lost can reach quite significant values and cause great economic losses. It is neither theoretically nor practically possible to stop the losses completely. However, it is possible to reduce losses at certain rates, in which case the amount of fertilizer to be applied to the soil will decrease and the income to be obtained from the unit area will increase (Sağlam, 2005). Remote sensing methods are widely used for modern agricultural studies and have become an important component of precision agriculture studies aimed at increasing productivity (Idso et al., 1977; Wiegand et al., 1979; Carley et al., 2008). The near infrared region of the electromagnetic spectrum is sensitive to plant structure, and it is possible to study changes in vegetation with satellite systems that include this region (Sabins, 1987; Jensen, 1996).

Remote sensing data can be used to determine plant nutrient levels, areal distribution of plants, whether plants are diseased or healthy, and biomass. Using satellite imagery of different resolutions, areas of high or low crop yields can be easily identified (Morgenthaier et al., 2003). Guozheng and Maohua (1999) worked to develop a yield mapping system for cereals. Three main yield mapping approaches are introduced. The first method is the collection and weighing method. The second method is parceling type yield mapping, and the third method is instantaneous yield mapping. Many different grain flow sensors have been analyzed and their characteristics compared. The quality of grain yield information is influenced by the quality and moisture content of the flowing material. Radiometric sensors are fully accurate and recommended. Vellidis et al. (2000) stated that the most important component of precision agriculture is yield maps obtained by mounting sensors or groups of sensors on a harvester. Yield maps were created using data from the fields and color-coded images were used in the maps to make them more useful for farmers. The system was extensively and fully tested over a period of more than 3 years and evaluated by 11 users during 1999.

Lee et al. (2005) designed a silage yield mapping system using a DGPS receiver, load cells, amaster switch, Bluetooth modules for data transfers and a moisture sensor. In total, 13 cars of silage were harvested from the commercial silage field during the test period. The weights of full and empty cars were measured with the help of a platform before and after harvesting and compared with the values obtained from the load cells of the silage yield mapping system. System yield losses were 5% less in the whole harvested crop than those measured on the platform. Blackmore (1994) stated that precision agriculture interacts with many components and that not all components of the relationships between the various elements that make up precision agriculture serve only one main purpose, and that measures to minimize environmental pollution and cultural practices should be taken into account as well as those that increase productivity. According to Blackmore and Marshall (1996), with the introduction of DGPS systems in the agricultural sector, it has become possible to prepare yield maps using yield and location information. These maps have become important elements of a new management system, called precision agriculture, which allows better use of information to manage variable features in the landscape. Güçdemir et al. (2010) observed that the coefficient of variability in crop yield was more than 19% in their study conducted under farmer conditions in Adana and determined that there were different yield areas ranging between 9 tons/ha and 19 tons/ha. In this study, temporal and spatial information about the physical and chemical properties of soils were obtained and their relationship with yield was examined. In this way, real-time maps encouraging rational fertilizer use were obtained and farmers were encouraged to turn to variable level input applications in terms of business management. As a result, it was recommended to use fertilizer effectively and as much as necessary in agricultural production. With this study, firstly, the nutrient elements in the soil were revealed depending on the location by using soil analysis and sensors, and then, with the variable level fertilizer application method, it was recommended to apply as much fertilizer as needed. In this way, agricultural inputs will be used more rationally, imports will be reduced, profits of enterprises will increase and contribution will be made to the national economy. Therefore, it will be inevitable to put forward adaptation strategies suitable for the region in the dissemination of precision agriculture practices for each region of our country.

Material and Methods

Description of the Research Site

The project was carried out in 2 plots in 2021. For the project, the institute production parcel located in the Central Research Institute of Field Crops İkizce Enterprise in Gölbaşı district of Ankara province and a farmer's parcel from Gökçehöyük village representing the farmers' fields within the borders of the same district were selected (Figure 1 and Figure 2).

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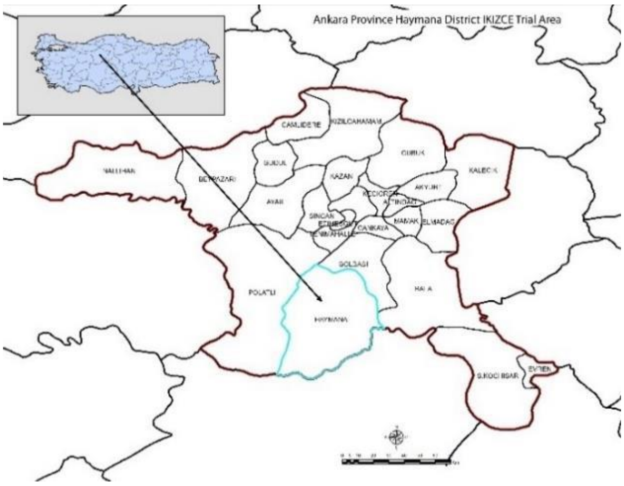


Figure 1. Study area parcels (ANKARA)

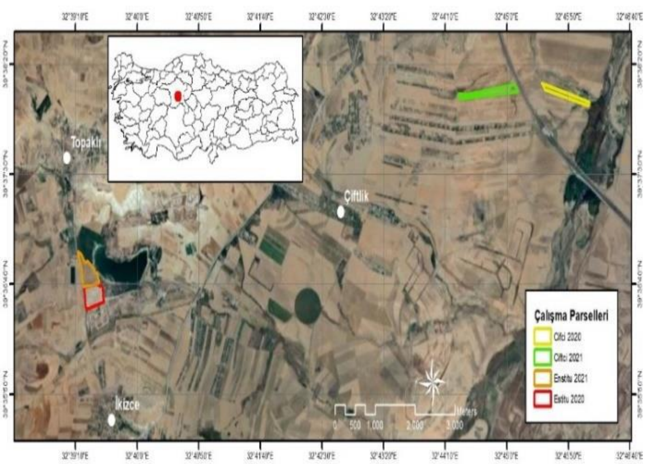


Figure 2. Farmer parcel sampling points in 2021

The climate of Ankara is continental. Generally, summers are hot and dry, winters are cold and rainy. The total annual precipitation of the province is 300-350 mm on average for many years. 32% of the total precipitation falls in winter, 25% in spring, 17% in summer and 26% in autumn. Again, thev average temperature for many years is 13.2.

Sampling Studies

The study was carried out in 2021 in 2 different locations: institute and farmer plots. Gridding method was used for sampling the plots, soil and plant samples were collected at 50x50 m from the institute plots, and 25x50 m from the farmer plots to represent the plots. After the parcels were identified in the study, the parcel boundaries were digitized using ArcGIS, a Geographic Information Systems (GIS) software. In order to reveal the variability within the parcel, 50*50 m and 50*25 m grid sampling patterns were created with the help of ArcGIS 9.2 program Fishnet plug-in (Figure 3, 4).

The coordinates of the sampling points determined in Parcels were uploaded to GPS and made suitable for field studies. Before planting in the field, soil samples were taken from 0-30 cm by going to the sampling points with the help of GPS. At harvest time, samples were collected from the same points with the help of a circle with an area of 0.25 m^2 for yield calculation. Within the scope of the project, 37 soil and yield samples were taken from the institute plots (Figure 3) and 42 soil and yield samples were taken from farmer plots (Figure 4) in 2021. The plots and sampling design is shown below.

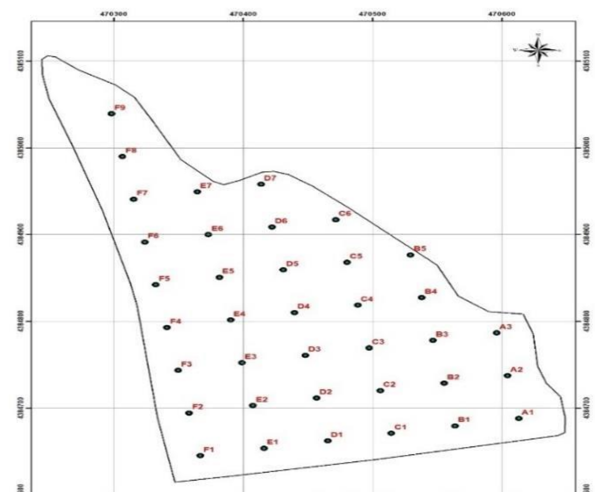


Figure 3. Institute parcel 2021 sampling points

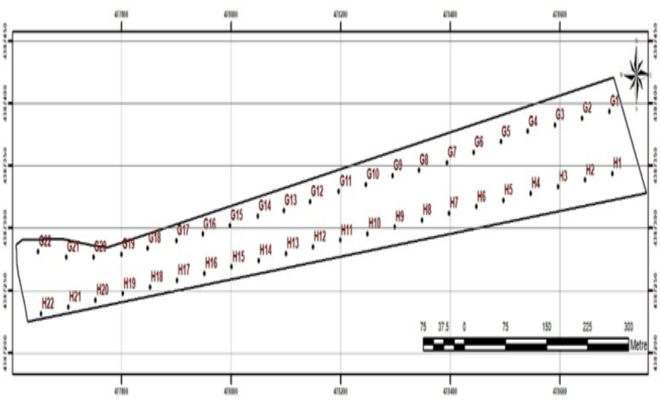


Figure 4. Farmer parcel sampling points in 2021

Modelling of Spatial Distribution of Crop Yield and Soil Characteristics

In the sampling arrangement, which was determined at an average of 50 m grid intervals in the study area, transect application was carried out in lengths varying between 25-28 m at certain locations where there are variability transitions on the naked satellite image of the land. A regular grid pattern covering 79 samples in total was formed and some soil analyses and yield values were determined at the sampling points. Within the scope of geostatistical modelling, firstly, the data structure of each parameter was examined and the parameters requiring data transformation were determined. In line with the descriptive statistics, if kurtosis and skewness are high, the data structure is transformed to transform the data structure into a normal distribution, and spatial distribution surfaces are determined over non-transformed values.

Creation of Fertilisation Zones for Variable Level Fertilisation

Yield, Normalized Difference Vegetation Index (NDVI), lime, water saturation, organic matter and EC layers were used to create fertilization zones. In determining the fertilization classes of these layers, expert opinions were used to determine the weight ratio for each layer. Analytic Hierarchy Process (AHP) method was used to determine the importance of the layers (Bouzekri and Benmessaoud 2015; Negaresh et al., 2016; Arami and Ownagh, 2017). The AHP is a powerful mathematically based multi-criteria decision-making technique that enables the organisation and analysis of complex decisions and ensures consistency in decision-making (Saaty, 1977). The scale of preference between 1-9 developed by Saaty (2008) was utilized in the weighting of the layers relative to each other (Table 1). Consistency Ratio is calculated to test the reliability of experts' decisions. In order to accept the weight value obtained for each indicator because of the evaluations made by decision makers with the AHP method, the consistency ratio must be less than 10% (Satty, 2008; Negaresh et al., 2016).

In the analytical hierarchy process, the objective of the problem is at the top of the hierarchy. In the lower step, there are main criteria related to the problem, and in the lower step of the main criteria, there are sub-criteria of the relevant criterion. At the bottom step of the hierarchy, there are options related to the problem. After the hierarchy table of the decision problem is formed, the next step is to determine the weights of the criteria with the same degree of importance relative to each other (Table 1).

For the plots, 4 different fertilization classes were formed. In the 1st group the most fertilizershould be used while in the 4th group the least fertilizer should be used. While forming the regions, it was thought that the highest fertilizer should be applied to the region with the highest yield, NDVI, water saturation and organic matter. Again, in the 1st group, the regions with the lowest lime and EC were included. In the region where the least fertilizer should be applied, the opposite values of the layer values were taken according to the 1st group. These values change gradually from group 1 to group 4 (Table 2).

Table 1. 1–9-point preference scale (Saaty, 2008)

Importance Rating	Definition	Description
1	Equally Important	Both factors are of equal importance
3	Moderately Important	One factor is slightly more important than the other
5	Strongly Important	One factor is strongly more important than the other
7	Very Strongly Important	One factor should be strongly preferred over another
9	Absolutely Important	One factor is very highly important relative to the other
2-4-6-8	Intermediate Values	Used when there are small differences between two factors

Results

Descriptive statistics

Descriptive statistics were made on soil analysis results and yield values obtained from four plots in two different years. In the evaluation, it was found that the yield variability was high in the parcels. It was determined that the CV value was 31.41 in the Institute 2021 parcel and 47.1 in the farmer 2021 parcel. In this case, it is seen that it is economical to carry out precision agriculture practices in these parcels.

Descriptive statistics of the Institute 2021 study parcel

Descriptive statistics of soil analysis results and yield values taken from 37 points in the institute parcel in 2021 are shown in Table 3. In the parcel, yield value (31.4%), water saturation (16.18%), lime (19.36%), available phosphorus (27.4%) and available potassium (22.2%) showed moderate variability, while EC (8.1), pH (0.69), Organic matter (12.4) showed low variability.

Farmer 2021 study plot descriptive statistics

Descriptive data of soil analysis results and yield values obtained from 42 points in farmer parcel in 2021 statistics are shown in Table 4. Yield (47.1%), EC (123.85 Ds/m), available phosphorus (66.3%) and available potassium (41.9%) were classified as high variability. pH, lime and organic matter were classified as low variability.

Table 2. Determination of the amount of fertiliser to be applied according to soil, yield and NDVI parameters

Parameter	Class Range	Fertilization Region Code
Yield (kg da^{-1})	400 <	1
	300 - 400	2
	200 – 300	3
	< 200	4
NDVI	0.65<	1
	0.55-0.65	2
	0.5-0.55	3
	<0.5	4
Lime (%)	<20	1
	20-25	2
	25-30	3
	30<	4
Water Saturation (%)	65<	1
	62-65	2
	58-62	3
	<58	4
Organic matter (%)	1.7 <	1
	1.6 -1.7	2
	1.5 -16	3
	<1.5	4
EC (dS m^{-1})	<0.92	1
	0.92-0.95	2
	0.95 -0.98	3
	0.98 <	4

Table 3. Descriptive statistics of the Institute 2021 study parcel

STAT n=37	Yield (kg da^{-1})	Water Saturation (%)	EC (dS m^{-1})	pH	Ca_2CO_3 (%)	Organic Matter (%)	Available (P_2O_5) (kg da^{-1})	Available (K_2O) (kg da^{-1})
Mean	295.71	0.65	0.94	7.75	24.28	1.63	3.66	141.81
Std. D	92.87	0.11	0.08	0.05	4.70	0.20	1.01	31.57
CV (%)	31.41	16.18	8.13	0.69	19.36	12.40	27.45	22.26
CV class	Medium	Medium	Low	Low	Medium	Low	Medium	Medium
Kurtosis	-0.07	-0.66	0.27	-0.83	0.24	-0.11	0.96	0.39
Skewness	-0.18	-0.16	-0.31	2.32	0.12	-1.02	1.85	-0.67
Variance	8625.22	0.01	0.01	0.00	22.09	0.04	1.01	996.64
Lowest	72.80	0.37	0.81	7.58	16.16	1.24	2.04	92.70
Highest	490.40	0.79	1.14	7.88	36.30	1.96	6.95	209.10

CV=%0-15 low, CV=%16-35 medium, CV= %> 36 high (Wilding 1985; Mulla ve McBratney 2000; Karabulut 2010).

Geostatistical model parameters

Geostatistical techniques were used to determine and map the variability of soil properties in the study area. Geostatistics is an applied science that quantifies the spatial structure and spatial dependence of a measured property and predicts the value of that property at unsampled points using the relationship obtained (Goovaerts, 1999; Mulla and McBratney, 2000). The percentage expression of the ratio of nugget semivariance to total semivariance is used to classify the areal dependence of soil variables. If this ratio is ≤25%, the variable is classified as strongly are dependent, if it is between 25% and 75%, it is classified as moderately areally dependent. If this ratio is more than 75%, the variable is classified as weakly spatially dependent (Cambardella et al., 1994; Trangmar et al., 1985). The ordinary kriging method was applied to produce the maps with a maximum of 12 neighbouring points. Maps belonging to the semivariogram models tested for each feature were produced, the error values of the maps were recorded, and these values were compared with each other in the selection of the correct model. These operations were performed with - ArcGIS 9.2. Geosatistical Extension‖ programme.

Institute 2021 Study Parcel Geostatistical Model Parameters

In 2021, Kriging interpolation method was used to make maps of the analysis results of 37 soil samples in the Institute parcel. The models and parameters in Table 5 were used to create Kriging interpolation maps. Available potassium (18.0%), pH (12.9%), available phosphorus (14.6%), water saturation (13.5%) and EC (24.8%) show strong spatial dependence with nugget/sill ratio. Yield (27.7%), lime (25.7%), organic matter (25.0%) shows moderate areal dependence (Table 5).

Table 4. Descriptive statistics of farmer 2021 study parcel.

STAT n=37	Yield (kg da^{-1})	Water Saturation (%)	EC (dS m^{-1})	pH	Ca_2CO_3 (%)	Organic Matter (%)	Available (P_2O_5) (kg da^{-1})	Available (K_2O) (kg da^{-1})
Mean	288.45	60.71	1.16	7.54	25.13	1.71	3.86	131.49
Std. D	135.86	4.63	1.44	1.20	5.20	0.26	2.56	55.11
CV (%)	47.10	7.62	123.85	15.95	20.68	15.00	66.30	41.91
CV class	High	Low	High	Low	Low	Low	High	High
Kurtosis	1.29	0.42	5.88	-6.29	1.13	0.10	1.56	0.40
Skewness	1.83	-0.64	36.37	40.37	2.15	0.59	2.30	-0.80
Variance	18457.16	21.43	2.07	1.45	27.00	0.07	6.56	3036.59
Lowest	63.60	54.00	0.53	0.00	16.50	1.05	0.59	56.60
Highest	706.80	72.00	9.96	8.23	43.05	2.26	11.52	244.10

CV=%0-15 düşük, CV=%16-35 orta, CV= %> 36 yüksek (Wilding 1985; Mulla ve McBratney 2000; Karabulut 2010)

Table 5. Geostatistical model parameters for Institute 2021 study parcel

Ordinary Kriging									
Parameter	**Transform**	**Model type**	**Major range**	**Lag size**	**Number of lags**	**Nugget (C0)**	**Partial sill (C0+C)**	**RMSE**	**ABD (%) (C0/C0+C)**
Yield (kg da^{-1})	-	Exponential	499.7	41.64	12	3299.8	8813.2	86.06	27.2
Water Saturation (%)	-	Exponential	338.6	28.23	12	1.52	9.76	2.41	13.5
EC (dS m^{-1})	-	Exponential	504.5	42.04	12	0.041	0.124	0.079	24.8
pH	-	Exponential	973.9	49.9	12	0.0016	0.0108	0.05	12.9
Ca_2CO_3 (%)	log	Gausian	4426	14.1	12	0.205	0.593	3.43	25.7
Organic Matter* (%)	-	Spherical	4454	15.39	12	0.065	0.195	0.2	25.0
P_2O_5 (kg da^{-1})	log	Exponential	1370	14.27	12	0.047	0.275	1.05	14.6
K_2O (kg da^{-1})	-	Gausian	1072	14.1	12	0.041	0.187	27.04	18.0

Geostatistical Model Parameters for Farmer 2021 Study Parcel

In 2021, Kriging interpolation method was used to make maps of the analysis results of 42 soil samples in the farmer's parcel. The model and parameters in Table 6 were used to create Kriging interpolation maps. Before creating the maps, it was checked whether the data showed normal distribution by considering the kurtosis and skewness values. Transformation process was applied for EC and phosphorus data for the farmer plot. Available potassium (3.1%), yield (12.5%), water saturation (8.5%) and lime (16.0%) showed strong spatial dependence with nugget/sill ratio. pH (29.0%), available phosphorus (34.6%), EC (26.1%), organic matter (25.2%) showed moderate spatial dependence.

Maps of Yield and Some Soil Properties Obtained as a Result of Geostatistical Modelling

One of the most important steps in precision agriculture applications is to determine the variabilityof nutrients in the field. Since the 1970s, geostatistics has been used to determine the variability of nutrients in the landscape (Burgess and Webster, 1980). Accurate determination of the variability of a nutrient element in the field gives us information about how the agricultural land should be sampled for that feature. Accurate mapping of the nutrient content in the field is a necessary step in order to distribute the fertilizer to be applied to the land in an orderly manner. In this way, the farmer will benefit more from unnecessary and inadequate fertilizer use and will prevent environmental problems caused by excessive fertilizer use.

Geostatistical Maps of Some Soil Properties of Institute 2021 Study

The analysis results of 37 soil samples taken from the institute parcel and the maps obtained by kriging interpolation method of the yield values are shown in Figure 5. Yield values decrease from south-west to north-east of the parcel. Water saturation values show a similar distribution. EC is highest in the northwestern part of the plot. pH values are between 7.7 and 7.8 and the variability in the plot is very low. Lime content is relatively lower in the center and east of the parcel and decreases up to 15%. Organic matter decreases towards the north-west.

Table 6. Geostatistical model parameters for farmer 2021 study parcel

Ordinary Kriging									
Parameter	**Transform**	**Model type**	**Major range**	**Lag size**	**Number of lags**	**Nugget (C0)**	**Partial sill (C0+C)**	**RMSE**	**ABD (%) (C0/C0+C)**
Yield (kg da^{-1})	-	Spherical	1544	10.68	12	6200	43500	96.6	12.5
Water Saturation (%)	-	Spherical	444	53.64	12	2.86	30.71	2.71	8.5
EC (dS m^{-1})	log	Exponential	6150	46.13	10	0.06	0.17	1.39	26.1
pH	-	Spherical	141.6	17.7	12	0.0056	0.0137	0.17	29.0
Ca_2CO_3 (%)	-	Circular	188.1	23.5	12	4.4	23.17	3.64	16.0
Organic Matter* (%)	-	Gausian	69.67	8.7	12	0.014	0.0415	0.22	25.2
P_2O_5 (kg da^{-1})	log	Exponential	333.4	25.92	13	0.18	0.34	2.49	34.6
K_2O (kg da^{-1})	-	Spherical	586.1	54.1	12	154.3	4847.6	31.7	3.1

US<25% high, US=25-75% medium, US>75% low areal dependence (Trangmar 1985; Cambardella et al. 1994; Karabulut 2010)

Geostatistical Maps of Some Soil Properties of Farmer 2021 Study Parcel

The results of the analysis of 37 soil samples taken from the institute parcel and the maps obtained by kriging interpolation method of the yield values are shown in Figure 6. In the farmer's plot, the highest yield value (602 kg da^{-1}) is located on the west side and reaches the lowest values in the middle of the plot. Water saturation values are also the lowest in the middle of the plot. Lime content is highest in the central part of the plot. pH and EC also decrease in the central part of the plot. Potassium and phosphorus maps also show that potassium and phosphorus values decrease in the central part of the parcel.

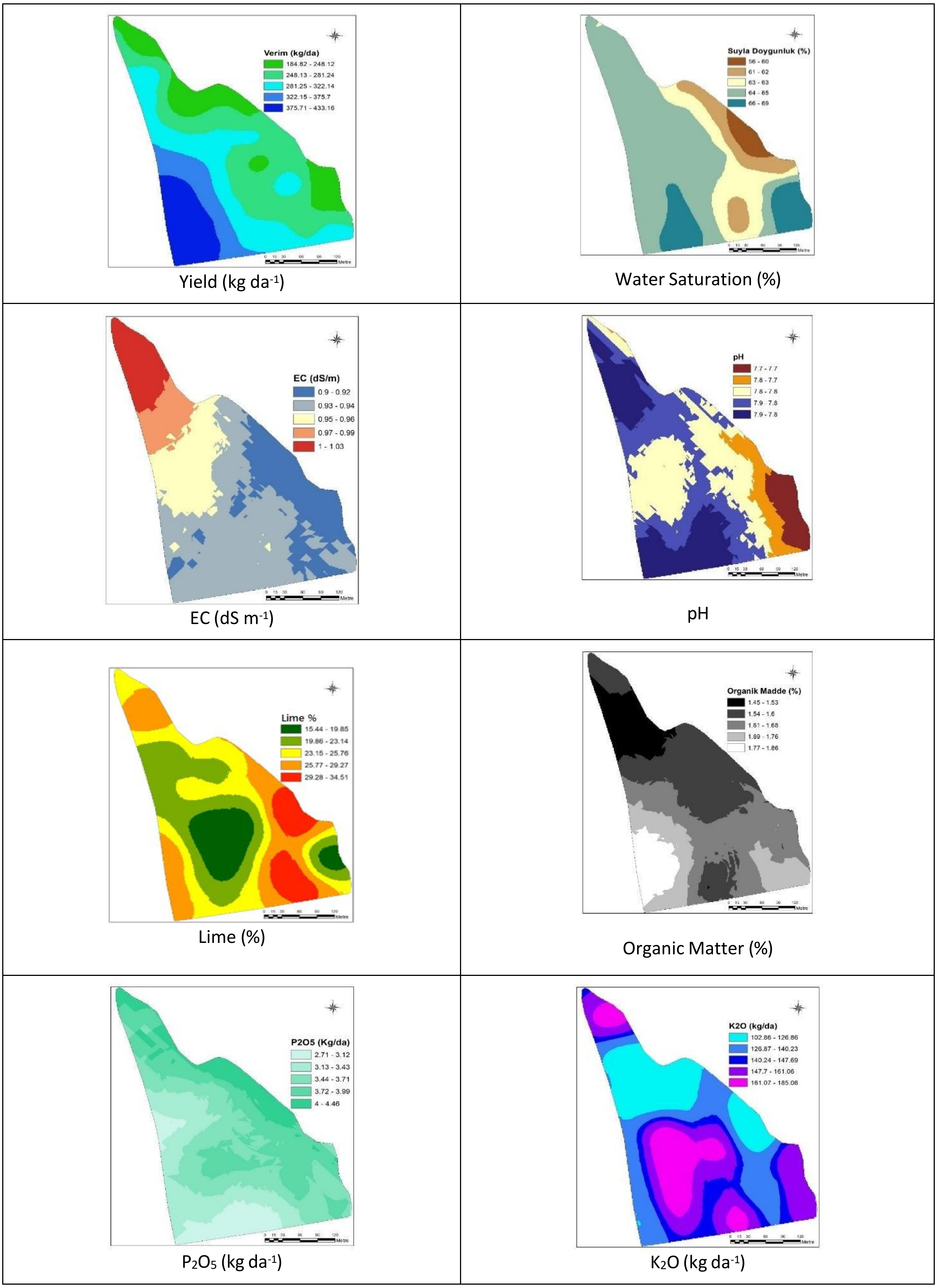
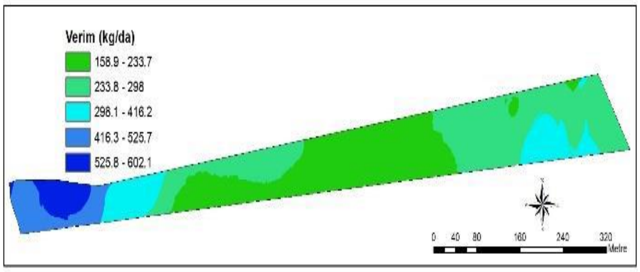
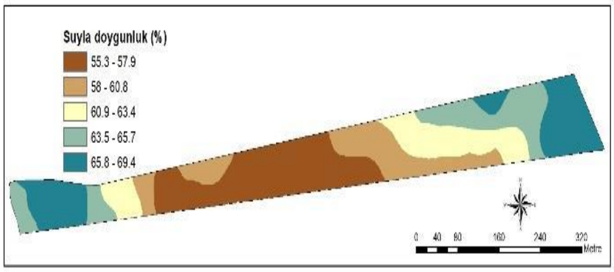


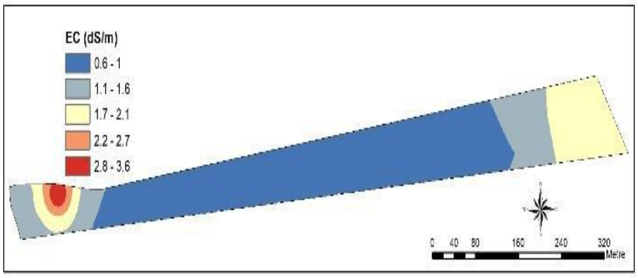
Figure 5. Yield, water saturation, Maps (EC, pH, Lime, OM, P_2O_5, K_2O maps of the Institute 2021 study plot



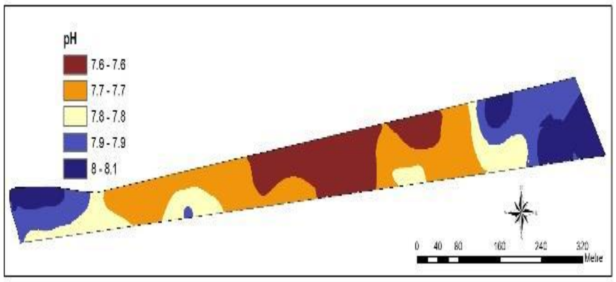
Yield (kg da-1)



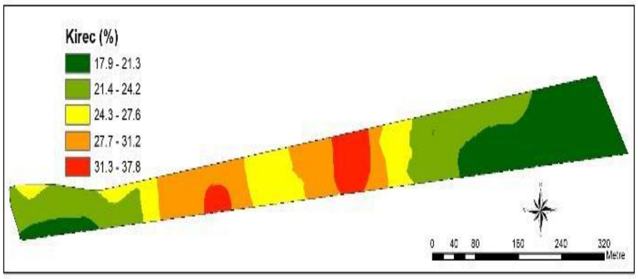
Water Saturation (%)



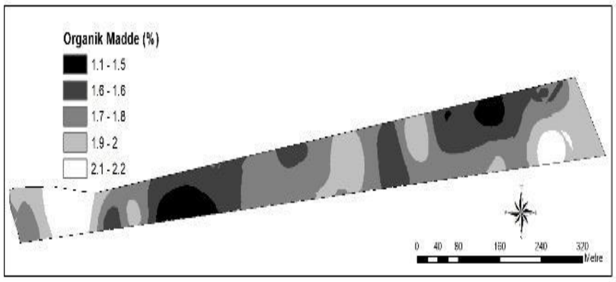
EC (dS m-1)



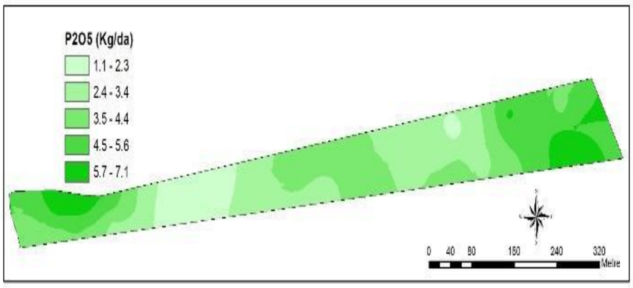
pH



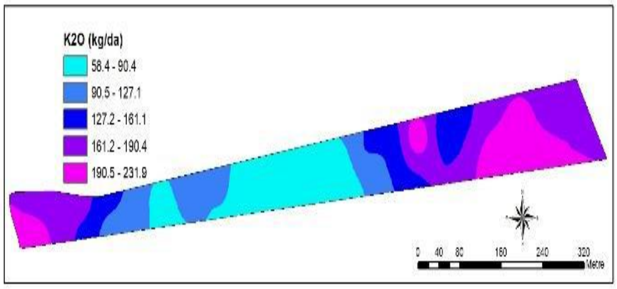
Lime (%)



Organic Matter (%)



P_2O_5 (kg da^{-1})



K_2O (kg da^{-1})

Figure 6. Yield, water saturation, EC, pH, Lime, OM, P2O5, K2O maps of farmer 2021 study plot

Statistical Relationships between Yield, NDVI and Soil Properties

The correlation table between the results of soil sample analysis, yield values and NDVI data obtained from the production field at the Central Research Institute of Field Crops Research and Application Farm in 2021 is given below. The correlation table between the analysis results of soil samples taken from the farmer's field in 2021, yield values and NDVI data is given below (Table 7). According to these results, a significant correlation was found between yield value and NDVI, water saturation, EC, organic matter and potassium at 0.01 level. Again, there was a relationship between yield and phosphorus at 0.05 level. There was a significant negative relationship between yield and lime at 0.05 level.

Table 7. The relationship between soil sample analysis results, yield values and NDVI data for farmer 2021 parcel

	Yield (kg da^{-1})	NDVI	Water Saturation (%)	EC (dS m^{-1})	pH	$CaCO_3$ (%)	Organic Matter (%)	P_2O_5 (kg da^{-1})	K_2O (kg da^{-1})
Yield (kg da^{-1})	1	.618**	.569**	.507**	.009	-.370*	.583**	.389*	.410**
NDVI	.618**	1	.634**	.311*	-.256	-.599**	.271	.254	.588**
Water Saturation (%)	.569**	.634**	1	.514**	- .030	-.518**	.427**	.494**	.681**
EC (dS m^{-1})	.507**	.311*	.514**	1	.040	-.162	.395**	.526**	.212
pH	.009	-.256	-.030	.040	1	.111	-.005	-.026	-.178
$CaCO_3$ (%)	-.370*	-.599**	-.518**	-.162	.111	1	-.245	-.154	-.693**
Organic Matter (%)	.583**	.271	.427**	.395**	-.005	-.245	1	.533**	.344*
P_2O_5 (kg da^{-1})	.389*	.254	.494**	.526**	-.026	-.154	.533**	1	.314*
K_2O (kg da^{-1})	.410**	.588**	.681**	.212	-.178	-.693**	.344*	.314*	1

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

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

One of the most widely used tools for monitoring green vegetation in remote sensing studies is the NDVI data. NDVI is calculated from the near infrared (NIR) and red (RED) light wavelength bands of satellite imagery. NDVI is considered as the main indicator of plant biomass and leaf area index value and is used for monitoring plant development and yield estimation during the growth period (Yıldız et al., 2012).

$$NDVI = (NIR - RED) / (NIR + RED)$$

Here, NIR represents the near infrared wavelength of the light spectrum (0.68 - 0.78 µm), RED represents the red region wavelength (0.61 - 0.68 µm) and NDVI (unitless) represents the vegetation index value (Tucker, 1979). In this study, NDVI data obtained from Sentinel 2 satellite images were utilized. Satellite images of May, when the biomass of wheat covering the field reaches the highest level, were downloaded for both years. NDVI data were truncated according to the classes of the plots where the study was conducted. Maps of yield values obtained from the field and NDVI data obtained from satellite images are shown in Figures 7, 8. In general, where yields are high, NDVI values are also high. This relationship is also seen in the correlation tables above. The most important reason that decreases the relationship between NDVI and yield is the presence of weeds in some parts of the plots. Where weeds are dense, wheat yield decreased while NDVI value was high. When the 2021 yield change depending on NDVI in the institute plots is analyzed; it is seen that the yield is high in the central and western parts where NDVI is higher, and in the eastern parts where the lakeshore strip is located, the yield decreases due to the decrease in NDVI (Figure 9). In 2021, when the NDVI change in the farmer plots was analyzed, it was observed that the yield was generally high in the western and eastern parts where NDVI was high (Figure 10).

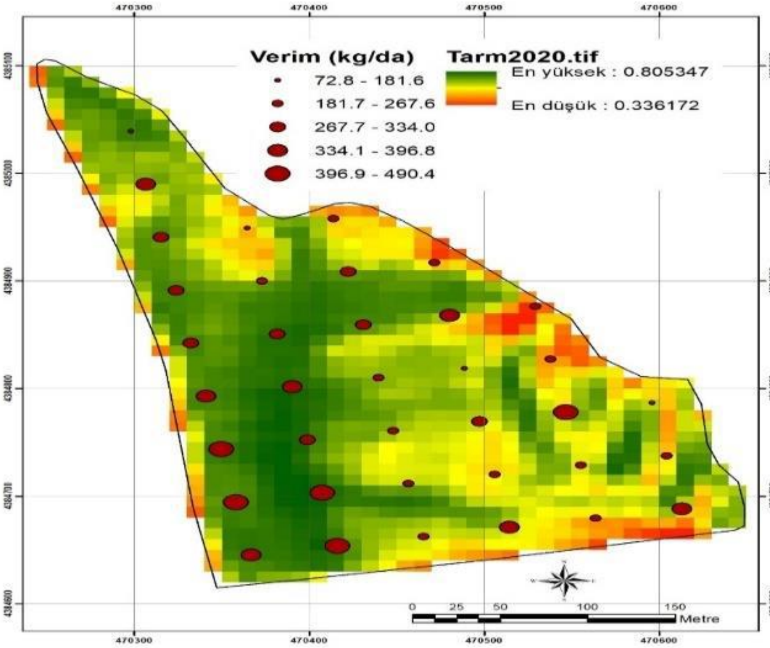


Figure 7. Institute 2021 parcel data- NDVI map Figure

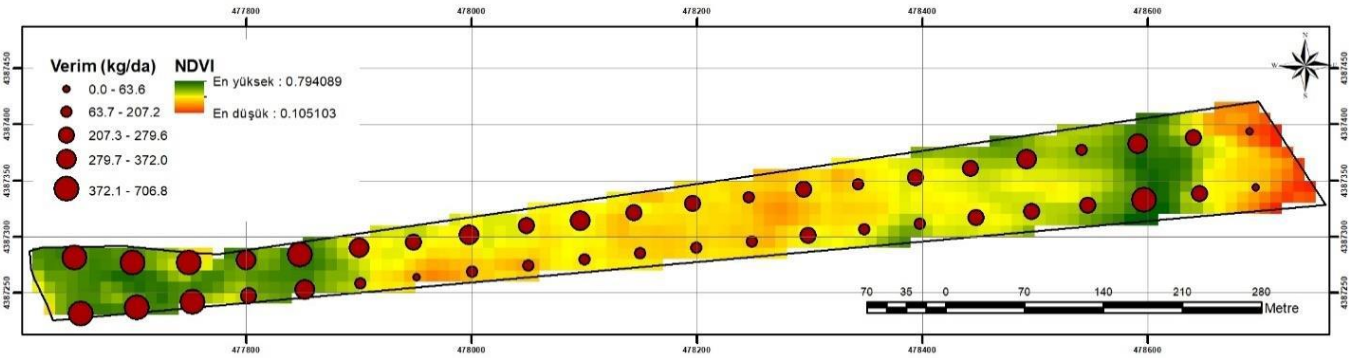


Figure 8. Farmer 2021 parcel yield - NDVI map

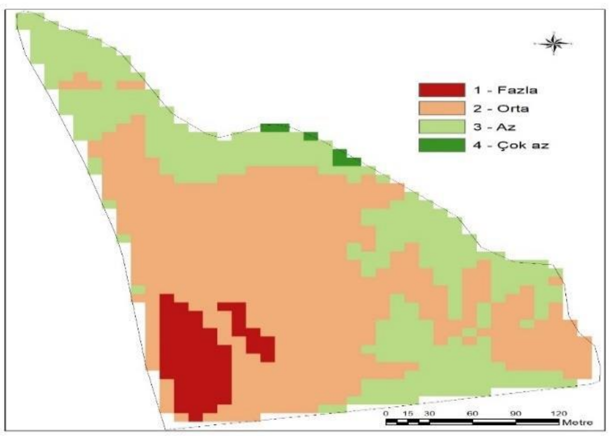


Figure 9. According to Institute parcels fertilization zones (2021)

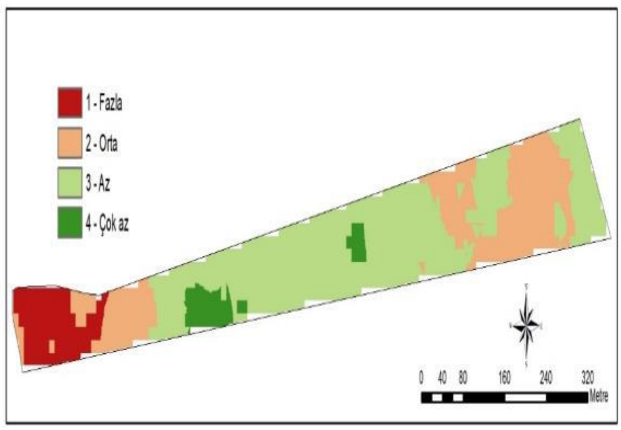


Figure 10. According to farmer parcels recommendation fertilization zones (2021)

Creation of Fertilization Zones for Variable Level Fertilization

In variable level fertilizer application, NDVI, yield, EC, water saturation, lime, pH, organic matter, available phosphorus and available potassium raster layers were created. By scoring, the weight ratios of the layers that will affect the fertilization zones, 4 fertilization classes were formed (Table 8).

The AHP method, which is used to solve a problem that depends on multiple criteria, was used to reveal the effect of layers on the formation of fertilization classes (Özcan et al., 2009). In order to determine the layer weights, the following table was created based on expert opinions (Table 9).

In order to calculate the Consistency Ratio, first the consistency indicator is calculated and then the Consistency Ratio is calculated.

$$Consistency\ Indicator(CI) = \frac{\lambda max\ n}{-1}$$

$$Consistency\ Ratio(CR) = \frac{Consistency\ Indicator(CI)}{Randomness\ Indicator}$$

Consistency Ratio (CR) was checked by pairwise comparison (Table 8). Wind and Saaty (1980) suggest an upper limit of 0.10 for the conservatism ratio. In this study, the consistency ratio was calculated as 0.58. As a result of the calculations made by AHP method, the weight values of the layers were found as lime 0.16, water saturation 0.11, organic matter 0.08, yield 0.36, NDVI 0.24 and EC 0.025, respectively. Because of the calculations made by AHP method, the weight values of the layers were found as lime 0.16, water saturation 0.11, organic matter 0.08, yield 0.36, NDVI 0.24 and EC 0.025, respectively. Layers were created using these weight values, merged using the "overlay" module in ArcGIS 9.2 program, and a map of fertilizer application zones was created. As can be seen in Figures 9 and 10, the maximum fertilizer application was recommended where indicated with 1 and the minimum fertilizer application was recommended where indicated with 4.

Relationships between fertilizer and soil parameters 2021 Institute and Farmer Parcel Evaluation

In 2021 when the data obtained from the sampling points of the Institute's land were evaluated, it was determined that the areas with low fertilization needs were the sampling points taken from the areas close to the pond. It was recommended that moderate fertilizer should be applied where the sampling points are located in the central parts and more fertilizer should be applied where the land falls to the south-west.

In 2021, it was revealed that the least fertilizer should be applied to the areas with the highest yield in the institute lands. There was a need to apply moderate fertilizer to the central parts of the plot and more fertilizer to the western and southern parts. These areas were observed to be the parcel sections falling on the northern parts of the lakeshore. Fertilizer should be applied at medium and higher levels where water saturation is high and at lower levels where water saturation is lowest. Medium and more fertilizer should be recommended where EC is low and less fertilizer should be recommended where EC is high. Medium and high levels of fertilizer should be applied to the northern and southern parts where pH is high, and low levels to the remaining parts. Less fertilizer should be applied to places with high lime content (29.28-34.51%), medium fertilizer should be applied to places with low lime content (15.44%-23.14%) and more fertilizer should be applied to places with medium lime content (23.15%-2-29.27%).

Table 8. Layers affecting the fertilization zones

	Yield (kg da^{-1})	**NDVI**	**$CaCO_3$ (%)**	**Water saturation (%)**	**Organic matter (%)**	**EC (dS m^{-1})**
Yield (kg da^{-1})	1	2	3	3	4	5
NDVI	1/2	1	2	3	3	4
$CaCO_3$ (%)	1/3	1/2	1	2	3	3
Water saturation (%)	1/3	1/3	1/2	1	2	3
Organic matter (%)	1/4	1/3	1/3	1/2	1	2
EC (dS m^{-1})	1/5	1/4	1/3	1/3	1/2	1

Table 9. Randomness Indicator

n	1	2	3	4	5	6	7	8	9	10
RG	0	0	0.58	0.9	1.12	1.,24	1.32	1.41	1.45	1.49

Fertilizer should be applied at a high level to places with high organic matter (1.77-1.86%), at a low level to places with low organic matter (1.45-1.60%), and at a medium level to places with medium organic matter (1.61-1.76%). Where phosphorus is high (3.72-4.6 kg da^{-1}), fertilizer should be applied at low and medium levels, where phosphorus is low (2.71-3.71), fertilizer should be applied at medium and high levels. Medium and high amounts of fertilizer should be applied to the middle of the plot where potassium is high (140.24-185.06 kg ha^{-1}) and low and very low amounts should be applied to the northern and eastern parts of the plot where potassium is low (102.86-140.23 kg ha^{-1}) (Figure 9).

In 2021, more fertilizer should be applied to the areas in the western parts of the parcel where the yield is high, and medium and low fertilizer should be applied to the other parts in the farmer lands. More and medium fertilizer should be applied to the western and eastern parts of the plot where water saturation is the highest and less fertilizer should be applied to the inner and central parts where saturation is low. More and medium fertilizer should be applied to the western and eastern parts where EC (dS m^{-1}) is high and dense, and less and very little fertilizer should be applied to the inner parts where EC is low. More fertilizer should be recommended for the western and eastern parts where pH is high and less and medium level fertilizer should be recommended for the inner parts where pH is low. Fertilizer should be added at low and very low levels to the inner and central parts of the parcel where lime is high, and at high and medium levels to the western and eastern parts where lime is low. Less fertilizer should be applied where organic matter is low and more fertilizer should be applied where it is high. More fertilizer should be applied to the northern and southern parts where phosphorus is high and less fertilizer should be applied to the central parts where phosphorus is low. It was recommended to apply more fertilizer to the southern and northern plots where potassium was high and less fertilizer to the central parts where it was low (Figure 10).

Conclusion

Precision agriculture is an agricultural system based on integrated knowledge and production to increase sustainable production, yield and profitability with minimum impact on the environment. In the world of environmental pollution and environment, precision agriculture is the most important phenomenon that supports environmentally friendly and sustainable agricultural production, especially it enables reduced input applications. For this reason, it is important to support research, publication and infrastructure studies on precision agriculture in all sensitive countries, including our country. Many studies to be carried out in this field within the scope of smart agriculture applications are waiting for the actors of the agricultural ecosystem**.** As a result of the developments in agricultural technologies, studies on the environmental impacts of agriculturblackal production inputs and the reduction of input costs are increasing day by day. These studies show an increasing intensity in the face of physical and geographical variability of agricultural lands, non-uniform soil, crop and environmental factors, environmental impact of inputs and increasing costs.

The most important objective of this study is to establish fertilisation zones for variable level fertiliser application, which is a subject of precision agriculture studies. The agricultural parcels where this study was carried out are heterogeneous in a way that can make a difference in economic terms. Fertilisation zones were created in the study, but fertilisation application could not be made. A variable level fertiliser machine is needed for fertilisation application.

In the study, yield maps were produced by interpolation by cutting the plants within one square metre from the determined sampling points. Although it was aimed to create yield maps with the integrated kit of the yield harvester at the beginning of the study, it could not be done due to impossibilities. In order to carry out such studies in our country, it is necessary to improve the tools and equipment used in precision agriculture.

Author Contribution

The authors declare the contributions to the manuscript such as the following sections: **TP:** Investigation, Review of relevant literatures, **HY:** Methodology, **MA**: Writing, review and editing, **MK:** Review of relevant literatures, **AKA:** Review of relevant literatures, **ÖU**: Review of relevant literatures, **AÇ**: Review of relevant literatures**, BA:** Review of relevant literatures, **UT:** Review of relevant literatures, **UY:** Review of relevant literatures

Conflict of Interest

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

Acknowledgements

This research was coordinated by TAGEM between 01.01.2018 and 31.12.2021 and by the Field Crops Central Research Institute Geographical Information Systems Center "Planning, Development and Dissemination of Precision Agriculture Practices in Crop Production (HAS-TARIM) Haymana/Ankara Example Sub-Application Project Package A.P.İ.P.8.3) data carried out under "Project TAGEM/TSKAD/E/19/A9/P8/1102

(TAGEM/TSKA/16/A13/P08/01/A.P.8") Using "Planning, Development and Dissemination of Precision Agriculture Practices in Crop Production HASTARIM Entegre Project (2018-2021).

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