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Modeling of The Nitrogen Requirement of Winter Wheat for Protein Content Using Optical Sensor in Central Anatolia Region of Türkiye

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A B S T R A C T

Chlorophyll meters manage both the amount and duration of nitrogen fertilizer application based on the principle that the chlorophyll or nitrogen content of plants should be maintained throughout their development. For smallholders in developing countries, the use of a hand-held meter to manage nitrogen fertilizer in rice and wheat is the most popular method. The adoption of nitrogen management strategies based on close sensing using chlorophyll meters and optical sensors will largely depend on the inclusion of specific economic analysis in future research. The importance of using sensors and chlorophyll meters for nitrogen fertilizer management depends on how successful current practices have been. In this study, five different nitrogen rates (0, 80, 120, 160, 200 kg N ha-1) were applied to two different wheat varieties, and the effect of these different nitrogen rates on wheat protein content was investigated in a randomized block design. A quadratic polynomial model described the relationship between protein content and nitrogen rates.

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Introduction

Nowadays, fertilizer applications for quality and yield increase have recently started. This research aims not to apply fertilizers directly for quality increase but to determine the optimum nitrogen rate used in variable rate fertilizer applications by using optical sensors to reach the maximum protein amount. With the help of the equations obtained as a result of the research, it is aimed to maximize the quality and minimize the nitrogen use as much as possible by determining the most appropriate nitrogen dose for the area. Therefore, the optimum fertilizer dose was determined by applying variable rate nitrogen, an essential part of precision agriculture practices.

As a result of high levels of nitrogen fertilizers, the amount of nitrate that is washed from the soil and mixed with drinking water and rivers increases. Some harmful substances are produced in plants growing in soils with excess nitrogen fertilizer application. As a result of intensive chemical fertilization, the soil becomes poorer in organic matter, leading to decreased biological activities and deterioration of the soil structure. If this continues, soils will deteriorate yearly, plant growth will slow down and stop depending on the intensity of chemical fertilization, and yield will decrease.

As a result of intensive chemical fertilization, the amount of organic matter in the soil's humus ratio will decrease, biological activity will decrease, and the fertilizers given will be washed away because they cannot hold in the soil. The transformation of plant nutrients into the form that plants can take will stop, and thus, the physical and chemical properties of the soil will deteriorate. As a result, the upper parts of the soil will become sandy, and the lower parts will become stony.

One of the most significant factors causing environmental pollution and the deterioration of the natural balance is the intensive use of chemicals in agricultural activities. Moreover, the agricultural method using chemicals causes ecological pollution and disruption of the natural balance and threatens the lives of all living things by reaching them through the food chain. This threat's continuity and rapid progression make it more and more challenging to return to nature.

The part of inorganic fertilizers containing nitrogen and phosphorus compounds that plants do not take up is washed out of the soil by rain and irrigation water and transported to the water environment. Nitrogen and phosphorus are converted into nitrate and phosphate due to biochemical reactions. These reduce the water-holding capacity of the soil. Nitrate in chemical fertilizers mixes with soil water as rainwater seeps through the soil. When nitrate concentration in water taken from wells and used as drinking water exceeds 45 mg L^{-1}, it becomes toxic, and methemoglobinemia occurs in infants. Oxygen consumption and fish deaths occur in lakes and rivers. In addition, it causes low crop potential, quality deterioration in crop production, corrosion of soil fertility, deterioration of soil reaction, and deterioration of the elemental balance in the soil.

As a result of this research, reducing all these adverse side effects will be possible. In addition, one of the critical issues is the economic losses caused to farmers by unnecessary fertilizer use. Considering that the price of 1 ton of DAP (diammonium phosphate) fertilizer is 1500 USD today, it is evident that the farmer will gain if the extra 1 kg of fertilizer to be applied per decare is saved. In our country, there is currently no practical tool for farmers to use this method. The aim is to determine the optimum amount of nitrogen to be applied as a result of the research to be carried out with the help of sensors and to maximize the protein ratio in wheat with the least input.

Materials and Methods

The research was conducted in the experimental fields of Ankara University Faculty of Agriculture Haymana Research and Application Farm (39º37'00.05" N - 32º41'39.09" E) with two different red hard bread wheat varieties under irrigated conditions for two years. The experiment was carried out in a factorial experimental design with four replications in randomized experimental blocks consisting of 2 factors: nitrogen level and wheat varieties. 5 different nitrogen levels were used as 0, 80, 120, 160, and 200 kg N ha^{-1}. One of the varieties used in the experiment was Bezostoya1, and the other was Ahmetağa. Sowing was carried out on the 21st of October in the first year and on the 22nd of October in the second year, known to be the most suitable time for winter wheat sowing in the Central Anatolia Region. After the preliminary studies and soil preparation necessary for sowing, the sowing process was carried out as 5N (nitrogen levels) x 2Ç (wheat seed) × 4T (number of replications) = 40 plots.

Diammonium phosphate (DAP; 18% nitrogen and 46% phosphorus) was used as base fertilizer in Central Anatolia. Therefore, DAP fertilizer was used at a dose of 200 kg ha^{-1} in farmer applications. In the experiment, Ammonium Nitrate (AN; 33% nitrogen) was used as a nitrogen source in top dressing, and (G1;0), (G2;80), (G3;120), (G4;160), (G5;200) kg N ha-1 doses were used. After harvesting, the products obtained from each plot were weighed, and yield values were obtained and sent to the laboratory for protein analysis.

NDVI, Normalized Difference Vegetation Index, has an algorithm based on the principle that a healthy plant absorbs visible light and reflects most of the near-infrared light. In contrast, an unhealthy plant reflects more visible and less near-infrared light. NDVI readings were taken with a GreenSeeker sensor (NTech Industries, INC., USA). Red light is absorbed by the plant during photosynthesis as an energy source. A healthy plant absorbs more red light, while NIR light is largely reflected. The light reflected by the plant is measured by a photodiode located at the front of the sensor. The values obtained vary between -1 and +1. Where healthy and dense vegetation is present, the index value approaches +1, whereas where unhealthy and weak vegetation is present, the index value approaches -1.

The normalized vegetation index is formulated as follows.

$$\text{NDVI} = \frac{\text{NIR}-\text{R}}{\text{NIR}+\text{R}}$$

Normalized vegetation index values, or the ratio of the near-infrared band to the red band, provide information on green vegetation cover and the areas that are poorly vegetated or empty without vegetation. Moreover, the closer the vegetation index is to a value of 1, the denser the vegetation, and the closer to zero, the vegetation cover decreases. When it is negative, the areas are devoid of vegetation.

Flavonol and chlorophyll-to-flavonol ratio readings (Nitrogen Balance Index, NBI) were performed with the Force-A Dualex Scientific Spad Meter optical sensor. Flavonoids are polyphenolic compounds with different skeletal structures found in various plants; these differences in their skeletal structures include flavone, flavonol, flavonone, etc. They take names. The type of flavonoid found in wheat is flavonol. As a result of the research, it was found that the chlorophyll-flavonol content ratio (NBI) can be used in protein estimation. By measuring the NBI value in the plant with the help of this sensor, raw data that can be used to estimate the protein content are revealed.

If nitrogen fertilization is appropriately done, the plant produces chlorophyll, and due to nitrogen deficiency, the plant has flavonol. Flavonoids are found in the epidermis layer of the plant and absorb ultraviolet wavelength rays. The sensor measures the near-infrared rays emitted by the chlorophyll layer from both sides of the leaf. Measurements are carried out with the readings obtained from the leaf during the spike period, called NBI.

Sowing was done in 8 rows with 15 cm row spacing using a single row manual seeder. A plot length of 6 m was used, and 50 cm was left between the blocks.

NDVI and NBI readings

According to the Zadoks convention (Zadoks et al., 1974), NDVI readings were taken with the GreenSeeker device at Z21, Z30, Z37, Z50, Z55, and Z60, and these values were used to calculate RI (Response Index) and INSEY (In Season Yield Estimation) values. RI and INSEY equations were used in the evaluation of NDVI readings. Accordingly, the $RI_{(NDVI)}$ values obtained by dividing the NDVI value of the plots giving the maximum NDVI value by the NDVI values of the unfertilized control plots were compared with the $RI_{(HARVEST)}$ value obtained by dividing the maximum yield obtained at harvest by the yield obtained from the control plots as a result of the correlation analysis the $RI_{(HARVEST)}$ value and the $RI_{(NDVI)}$ value gave the highest R^2 value from which period readings were obtained. Readings were taken in that period in the subsequent studies for recommendation. Force-A Dualex

Scientific Spad Meter sensor was used to take ten readings from each plot during the wheat spike period. When both readings were evaluated statistically, a very close relationship was found. Therefore, these NDVI values were used as the average of the NDVI readings obtained with the GreenSeeker and Force-A Spad Meter to estimate protein and to find the optimum point in the yield-protein relationship. Image 1 and Image 2 show pictures of different reading periods.

Evaluation of The Data

Analysis of variance was used in the statistical evaluation of the data obtained from the research, and the Tukey multiple comparison test was applied to determine the difference between groups. The SAS package program was used for this purpose. The analysis results were evaluated regarding different nitrogen rates and seed varieties. Image 3 shows the harvesting process and samples obtained from each plot.

A quadratic polynomial model was used to predict yield and protein versus applied nitrogen rate:

$$f(N) = c + b.N + a.N^2$$

$$g(N) = \beta + \alpha.\mathrm{N}$$

Where;
f(N) : Yield (tons/ha),
g(y) : Protein content (%),
N : Fertilizer rate and
A, b, c: regression coefficients of yield and protein response functions to nitrogen.

The models obtained for yield and protein were used for the economic optimum nitrogen rate. Determination of the optimum nitrogen rate in nitrogen fertilizer consumption is vital in wheat production due to its effect on quality and yield. The average yield and protein results obtained were used to determine this rate.

RI (Response Index) was used to determine the optimum fertilization time. This index was calculated for NDVI and yield values. Accordingly, RINDVI values obtained by dividing the NDVI value of the plot's NDVI value by the NDVI values of the other plots were compared with the RIharvest value obtained by dividing the maximum yield obtained at harvest by the yield obtained from the different plots. As a result of the correlation analysis, the RINDVI value giving the highest R^2 value with the RIharvest value was obtained from which period readings were obtained. Then, readings will be taken in that period in the studies for variable rate nitrogen application. In the experiment, RINDVI and RIhasat are calculated using the following equations Mullen et al. (2003):

$$RI(NDVI) = \frac{\mathrm{NDVI(max)}}{\mathrm{NDVI(control)}}$$

$$RI(harvest) = \frac{\mathrm{Yield(max)}}{\mathrm{Yield(control)}}$$

After determining the optimal fertilization time, the relationship between NDVI values and fertilizer rates for that period was defined, and the nitrogen status of the plant was determined by using the regression equation obtained by the linear regression method. INSEY values were used to estimate potential yield with the GreenSeeker sensor (Franzen et al., 2013). INSEY (Season Yield Estimation) is the value obtained by dividing the NDVI reading in any period by the cumulative growing degree days (CGDD) from planting to the reading date (Lukina et al. 2001; Teal et al. 2006).

a b c d e f

Image 1. 1st year, 1st reading period (a), 2nd year, 1st reading period (b), 1st year, 2nd reading period (c), 2nd year, 2nd reading period (d), 1st year, 3rd reading period (e), 2nd year, 3rd reading period (f)

a b c d e f

Image 2. 1st year, 4th reading period (a), 2nd year, 4th reading period (b), 1st year, 5th reading period (c), 2nd year, 5th reading period (d), 1st year, 6th reading period (e), 2nd year, 6th reading period (f)

Growing-degree days (GDD) integrate excess temperatures on days with temperatures bounded by maximum and minimum values. GDD is defined by the following equation:

$$GDD = (T_{max}+T_{min})/2-T_{basic}$$

GDD : Growth-degree-days,
T_{max} : Daily maximum air temperature,
T_{min} : Daily minimum air temperature and
T_{basic} : The basic threshold temperature at which crop development begins.

The equation obtained as a result of regression analysis in which INSEY values are taken as independent variable (x) and wheat yields obtained from the same plots as dependent variable (y) can be used as a calibration equation in variable rate fertilizer application.

Image 3. Harvesting process and products obtained from each plot

Table 1 Effect of different fertilizer applications on protein at the experimental location

1st year	
Fertilizer Dose	Protein (P=0.006)
1	15.280±1.273 B
2	15.747±1.381 AB
3	16.717±1.086 B
4	17.712±1.132 B
5	18.018±1.805 B
2nd year	
Fertilizer Dose	Protein (P=0.025)
1	15.530±0.524 B
2	15.01±2.82 AB
3	17.015±0.925 A
4	17.713±1.921 A
5	17.517±0.658 A

*Means marked with the same letters are not different from each other (P<0.05).

Table 2. Yield and protein response functions and regression curves and R2 values corresponding to nitrogen in wheat

Seed variety	Protein response function		
	α	β	R^2
Bezostaya	0.6765	14.105	0.6746
Ahmetağa	0.935	14.427	0.5684
Ave.	0.8057	14.176	0.535

Results and Discussion

Laboratory Results and Statistical Analysis

The analysis of variance showed that the difference between the parameters was statistically significant in terms of different fertilizer rates. The results obtained from the analysis are given in Table 1.

The experiment obtained $p<0.05$ statistically significant results between fertilization levels and protein values. p values were determined as 0.006 and 0.025 for the 1st and 2nd years for protein in terms of fertilization levels, respectively. In addition, according to the results obtained, the effect of seed varieties used in the experiment on protein was statistically significant. Based on the results obtained at the experimental location, the 5th fertilizer dose (20 kg N da^{-1}) in the 1st year and the 4th fertilizer dose (16 kg N $da-^{1}$) in the second year were determined as the appropriate fertilizer rate for the highest protein content.

Determination of Optimum Fertilizer Rate

Determining the optimum nitrogen rate in nitrogen fertilizer consumption is important because of its effect on quality and yield in wheat production. On the other hand, as nitrogen is a mobile element, its unnecessary use causes groundwater pollution. Therefore, it is necessary to determine the optimum and economical fertilizer rate. The average of the protein results obtained was used to determine this rate. The results are shown in Table 1. Table 2 shows the protein response functions corresponding to nitrogen in wheat, regression curves, and R^2 values. The protein response functions corresponding to nitrogen in wheat are also given in Image 4.

Quadratic polynomial and linear models were used to predict yield and protein against applied nitrogen rate, respectively (Cerrato and Blackmer 1990);

$$f(N) = c + b.N + a.N^2$$

$$g(N) = \beta + \alpha.N$$

f(N) : Yield (tons/ha),
g(y) : Protein content (%),
N : Fertilizer rate and
a, b, c: regression coefficients of protein response functions to nitrogen.

The obtained models were used for the economic optimum nitrogen rate. Determination of the optimum nitrogen rate in nitrogen fertilizer consumption is essential in wheat production due to its effect on quality and yield. The average yield and protein results obtained were used to determine this rate. The additional price given according to the protein ratio in wheat with less than 1% of wheat fly damage is defined as follows.

Protein 12-12.5% to 1
Protein between 12.5-13% 2.5
Protein between 13-13.5% 3
Protein 13.5-14.5% to 4.5%
6% protein between 14-14.5%
7% on 14.5% protein.

Table 3. Relationships between RINDVI and RIHarvest obtained after fertilization.

RI_{NDVI}	RI_{hasat} (R-sq%)
1.RI_{NDVI}	8.82
2.RI_{NDVI}	11.22
3.RI_{NDVI}	69.38
4.RI_{NDVI}	77.52
5.RI_{NDVI}	76.58
6.RI_{NDVI}	65.31

Table 4. Effect of different fertilization rates on post-fertilization NDVI readings

Fertiliser doze	1st NDVI values	2nd NDVI values	3rd NDVI values	4th NDVI values	5th NDVI values	6th NDVI values
0 kg N ha^{-1}	0.40±0.08 A	0.61±0.09 A	0.68±0.067 B	0.62±0.04 B	0.65±0.10 AB	0.57±0.11 A
80 kg N ha^{-1}	0.46±0.15 A	0.64±0.09 A	0.68±0.04 B	0.70±0.07 AB	0.61±0.04 B	0.55±0.09 A
120 kg N ha^{-1}	0.50±0.10 A	0.65±0.06 A	0.73±0.07 AB	0.72±0.07 A	0.70±0.06 AB	0.49±0.11 A
160 kg N ha^{-1}	0.47±0.18 A	0.71±0.06 A	0.78±0.03 A	0.75±0.02 A	0.71±0.09 AB	0.47±0.06 A
200 kg N ha^{-1}	0.43±0.19 A	0.69±0.04 A	0.75±0.05 AB	0.77±0.02 A	0.74±0.05 A	0.58±0.10 A

* Means marked with the same letters are not different from each other (P<0.05)

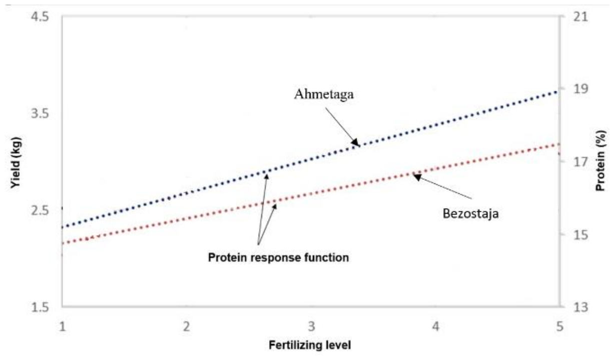

Image 4. Protein response functions corresponding to nitrogen in wheat

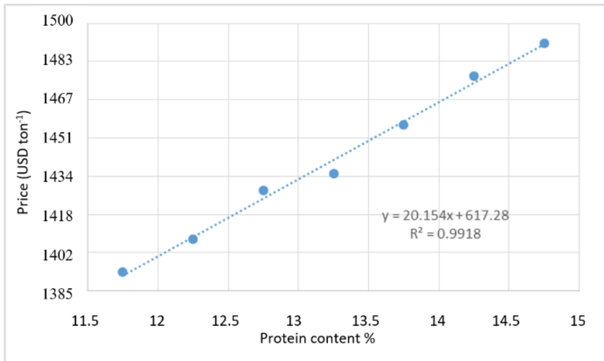

Image 5. Protein content of wheat and price per ton (TL)

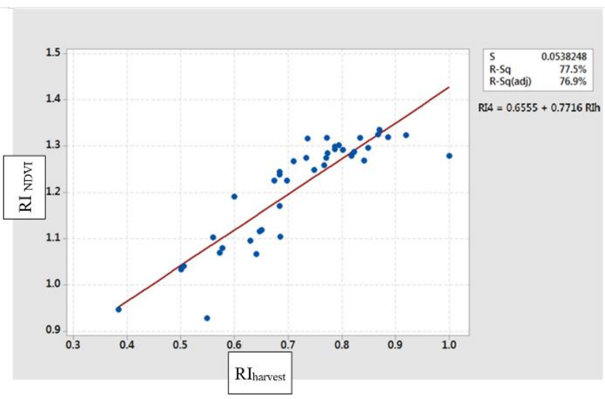

Image 6. Regression curves and equations between RINDVI and RIHarvest obtained from the 4th reading after fertilization

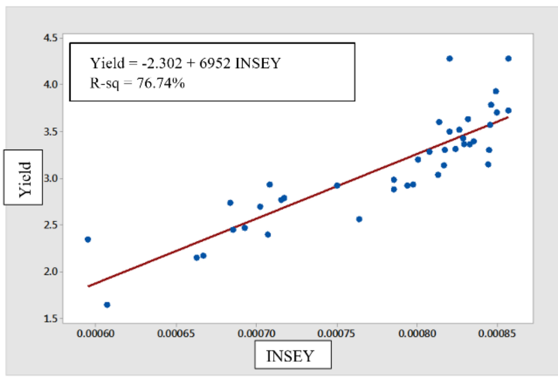

Image 7. Relationship between INSEY and yield values

Since the base price is set at 1500 USD/ton for wheat, the following relationship can be written between price and protein content in the range of 12-15% protein content:

$$F_b(\text{Price}) = 20.154\,\text{Protein\%} + 617.28$$

Image 5 shows protein content of wheat and price per ton (TL). Using equations, we can calculate the net income from wheat production by considering the amount of nitrogen fertilizer used as input (þN=1.74 TL/kg):

$$NR = F_b.f(N) - p_N.N$$

For Bezostaya: $NR = -1.73N^3 - 100.58N^2 + 934.89N + 1036.1$

For Ahmetağa: $NR = -1.64N^3 - 9.66N^2 + 272.6.89N + 511.7$

According to the method proposed by (Cerrato and Blackmer 1990, the optimum nitrogen rate is calculated by setting the first-order derivative of NR equal to zero.

$$\frac{\partial(NR)}{\partial(N)} = 0$$

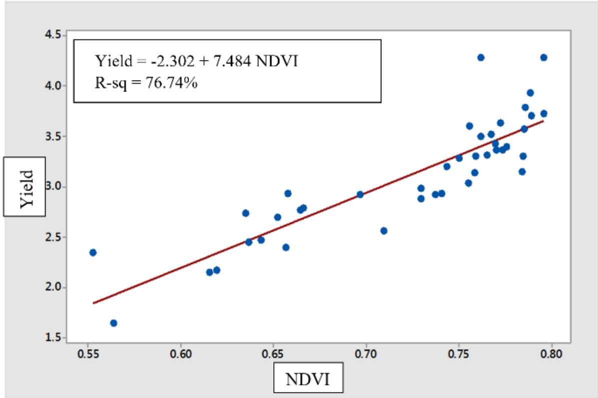

Image 8. Relationship between yield and NDVI values

As a result of this equation, the optimum fertilizer rate was determined as 16.76 and 20.6 kg da^{-1} for Bezostaya and Ahmetağa varieties, respectively.

NDVI and yield values at harvest were used to determine the optimum fertilization time. Response indexes were calculated using NDVI and yield values from different periods. The results of linear regression to determine the relationship between the calculated RINDVI and RIharvest values are given in Table 3. The average of the values obtained from the two locations was used to construct these indices.

As shown in Table 3, as a result of the regression analysis, the R^2 value was obtained in the 4th reading period after fertilization (CGDD=928.9). Therefore, the 4th reading period after fertilization was determined as the most suitable period for the variable rate application regarding NDVI variability. Image 6 shows that regression curves and equations between R_{INDVI} and $RI_{Harvest}$ were obtained from the 4th reading after fertilization.

When the NDVI values obtained were analyzed, NDVI values differed between the plots in some reading periods in both experimental locations. As a result of the analysis of variance, the difference between the plots was found to be statistically significant in Year 1, 3rd, 4th, and 5th readings and in Year 2, 3rd and 4th readings (Table 4).

INSEY values were used to estimate potential yield with the Green Seeker sensor. To create this equation, INSEY values calculated from NDVI readings (with maximum correlation value with RIhasat) obtained from the plots at the 4th reading after fertilization (928.9 CGDD) were used. Image 7 shows relationship between INSEY and yield values. The resulting calibration equation was as follows during the planned period:

Yield = -2.302 + 6952 INSEY R-sq 0 76.74%

Since the CGDD for the period is 928.9 °C and INSEY=NDVI/CGDD, the relationship between yield and NDVI can be calculated with the following equation:

Yield = 7.484 NDVI - 2.302

Image 8 shows that relationship between yield and NDVI values.

The yield obtained with the help of this equation determines the potential wheat yield without using nitrogen fertilizer. To create a calibration equation based on NDVI used in variable rate nitrogen applications, NDVI values obtained from the 4th readings, where the difference was statistically significant and determined at fertilization, were used.

Worldwide, protein deficiency is a significant problem in human nutrition, second only to calorie deficiency (Robinson et al. 1986). In developing countries, 90% of the average diet comprises cereal-based foods (Graham and Welch 1996).

The importance of wheat protein in nutrition and the necessity for Turkey, which is hoped to become a net exporter of wheat and wheat products if it can improve its production to meet and exceed international quality standards, make protein a top priority.

Nitrogen Use Efficiency (NUE) was divided into uptake and utilization efficiency as early as the 1980s (Moll et al. 1982), and this distinction facilitated investigations. Dhugga and Waines (1989) stated that uptake efficiency is more critical than utilization efficiency, especially when nitrogen content is high. Similarly, Van Ginkel et al. (2001) stated that uptake efficiency is more important under conditions with high nitrogen content. In contrast, varieties with higher utilization efficiency may be preferred under low-input farming conditions where nitrogen content is insufficient.

Protein contents in wheat grain are determined not only by genotypic but also by environmental sources of variation, which makes it necessary to test the ability of cultivars selected for high protein contents to maintain these traits under different environmental conditions, as well as the significant environment x genotype interaction, which makes it difficult to use molecular marker techniques reliably in large breeding programs (Pena, 2002).

In most cases, grain protein concentration increases with increasing temperature and decreasing rainfall. A study conducted in the Western Transition Zone in Turkey observed that rainfall during the active growth period negatively correlated with grain protein content of all cultivars (Kalaycı et al. 1996). It is stated that drought and high-temperature decrease carbohydrate accumulation and relatively increase nitrogen accumulation (Panozzo and Eagles, 1999).

It is stated that bread quality is highly affected by climatic conditions, especially during grain filling, and if cool and humid weather prevails during this period, bread quality decreases (Johansson and Svensson 1998, 1999; Johansson et al. 2002). Among the literature findings, temperatures above 20 °C during grain filling provide high protein concentration (Altenbach et al. 2003, Gooding et al. 2003), and weather conditions affect protein polymerization and baking quality (Johansson et al. 2003).

Many researchers have reported the effect of soil inorganic nitrogen content on grain protein. In the trials conducted in Eskisehir and the Western Gateway Region, soil nitrogen was essential for protein. Grains containing more than 13% protein were obtained only when the total inorganic nitrogen (nitrate + ammonium) content at 120 cm depth of the soil profile exceeded 10-11 kg ha^{-1}, and slightly more nitrogen was used than required for optimal yield. In fields where soil inorganic nitrogen was below 10 kg/ha, no protein above 11% could be obtained even at the highest dose (12 kg N ha^{-1}) (Kalaycı et al. 1996).

Regarding the effect of soil nitrogen on plant nitrogen uptake, it has been reported that the available nitrogen in the soil is vital for nitrogen uptake (Ortiz-Monasterio et al. 1997) and that there is a high correlation between soil nitrate content and nitrogen uptake of barley.

Smil (1997) stated that it is only possible to reduce the use of nitrogen fertilizers by finding more suitable fertilization methods and increasing their efficiency. However, it is noted that the uptake rate of applied nitrogen by wheat under dry farming conditions is below 50%, mainly due to evaporation losses from surface applied nitrogen fertilizer (Fillery and McInnes 1992). It has been reported that volatilization losses in the form of ammonia can exceed 40%, especially when urea fertilizer is applied to the surface without mixing with the soil in this way (Flower and Brydon, 1989) and that these losses are generally more significant in the presence of high temperature, high pH and stubble residues on the surface (Raun and Johnson, 1999).

It has been reported that there is a relationship between leaf nitrogen concentrations and maximum photosynthesis values, i.e., some nitrogen is present in the leaves even when photosynthesis is zero, possibly indicating non-photosynthetic nitrogen accumulation, but that this is more limited in C3 plants, which is evident in C4 species, possibly as a result of selection pressures for yield (Zhang et al., 2020). In this case, it seems to be the best way to carry out the calibration studies mentioned above separately for yield and protein.

In the evaluation of NDVI readings, the concepts of RI (Response Index) (Mullen et al. 2003) and INSEY (In Season Yield Estimation) (Raun et al. 2002) are utilized. Accordingly, in calibration studies, $RI_{(NDVI)}$ values obtained by dividing the NDVI value of the plots giving the maximum NDVI value by the NDVI values of the unfertilized control plots are compared with the $RI_{(HARVEST)}$ value obtained by dividing the maximum yield obtained at harvest by the yield obtained from the control plots (Johnson et al. 2002) and as a result of the correlation analysis, the $RI_{(NDVI)}$ value that gives the highest R^2 value with the $RI_{(HARVEST)}$ value is compared with the $RI_{(NDVI)}$ value obtained from which period readings are received. Then, readings are taken in that period for recommendation studies to be carried out in farmers' fields.

In the study conducted in Oklahoma, according to the Feekes convention (Large, 1954), readings obtained at 5 (beginning of emergence), 9 (end of emergence), and 10.5 (flowering) were similarly effective (Mullen et al. 2003). Still, in large farmer field applications, recommendations are guided by readings taken at Feekes 5, the beginning of emergence, which is equally effective as the others. The INSEY value is calculated by dividing the NDVI value by the number of days from planting to the day of the reading when the average temperature was above 4.4 °C (Raun et al. 2002). Then, the equations obtained as a result of regression analysis, where the INSEY values calculated from the NDVI readings of the plots are taken as the independent variable (x) and the grain yields obtained from the same plots as the dependent variable (y), are used as calibration equations that guide the practices in farmers' fields.

The method used in this study increases wheat yield and protein content. This method allows more productive areas in the field to be fertilized at the optimum rate and reduces the nitrogen cost. This study found the effects of different nitrogen rates on yield and quality parameters statistically significant.

As a result of the analysis, the relationship between seed variety and yield, the relationship between fertilizer dose and yield, and the relationship between seed variety and fertilizer interactions were found to be statistically significant. Similarly, the relationship between seed variety and protein ratio and between seed variety and fertilizer interaction in terms of protein ratio were statistically insignificant. However, the relationship between fertilizer dose and protein, essential for this study, was statistically significant.

Determination of economic optimum fertilizer rates has been done using yield and protein values for wheat. This method has been used for in-season nitrogen estimation in wheat (Raun et al. 1999, Solie et al. 1996).

The aim of this study, in summary, is to investigate what should be done to improve grain protein coverage, which is one of the most critical problems in wheat production and marketing in Turkey, and to determine the most appropriate nitrogen fertilization management system and nitrogen fertilizer application method that will minimize nitrogen losses and maximize nitrogen utilization efficiency of the plant in terms of nitrogen nutrition, which is one of the most critical factors determining wheat yield and quality, especially protein coverage, this study aims to contribute to both input and production economy by developing and disseminating a system that will regulate nitrogen fertilizer applications, which are generally made based on average recommendation values, according to the course of the year, so that wheat grain yield and quality will be at the highest level.

By determining the most appropriate nitrogen fertilizer application method in which nitrogen losses will be at the lowest level and the efficiency of nitrogen use of the plant will be at the highest level and reflecting it to practice, both the national economy and the input economy for the farmer will be contributed. At the same time, significant contributions will be made to environmental cleanliness by reducing nitrogen losses from agricultural areas.

The study determined the relationships between the readings obtained from the established plots and fertilizer rates. Therefore, the 4th reading period after fertilization (CGDD=928.9) was the most suitable for variable rate fertilizer application regarding NDVI variability. The experiment obtained $p<0.05$ statistically significant results between fertilization levels and yield and protein values. p values were determined as 0.001, 0.006, and 0.003, 0.025 for yield and protein for the 1st and 2nd years, respectively. According to the results, the seed varieties used in the experiment had statistically significant effects on yield and protein. Based on the results obtained at the trial location, the 4th fertilizer rate (16 kgN da^{-1}) in the 1st and 2nd years of the trials in terms of yield and the 5th fertilizer rate (20 kgN da^{-1}) in the 1st year and the 4th fertilizer rate (16 kgN da^{-1}) in the second year were determined as the appropriate fertilizer rate in terms of the highest protein content.

Conclusions

It was determined as 16.76 and 20.6 kg ha^{-1} for the Bezostaya and Ahmetağa varieties, respectively. When an economic analysis is made for the Haymana region where the study was carried out, the ton price of AN fertilizer is 815 TL, the size of the wheat cultivated land in Haymana Research and Application Farm is 570 da, and 20 kg of pure nitrogen is applied to 1 decare. However, the amount that should be used is 16.76 kg. The difference is 3.24 kg of pure nitrogen, and since AN contains 33% nitrogen, 9.72 kg of AN is over-applied to 1 decare. For 570 decades, approximately 5540.4 kg more AN fertilizer is applied. Therefore, there is a loss of at least 45150.42 TL every year. As a result of this study, this loss can be prevented.

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