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Development Of Sensor Reflection Indices To Predict Yield And Protein Content Based On In-Season N Status

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Abstract. *Environmental and economic demands make it necessary for farmers to adopt management systems that improve Nitrogen Use Efficiency. The premium paid to producers has made farmers striving for maximum grain protein levels because protein is a very important quality component of grains and an important attribute in the market place. The protein content of wheat grains approximately ranges from 8 to 20%. The optimization of nitrogen (N) fertilization is the object of intense research efforts around the world. Soil tests are capable of estimating the intensity of N release at any point in time, but rarely the capacity factor over a longer period. Fluorescence sensing methods have been used to monitor crop physiology for years, and they may offer solutions for N status diagnosis over reflectance-based methods. Developed precision management of nitrogen through precision agriculture allows growers to use fertilizer input on more productive areas as well as saving nitrogen costs across the field. On the other hand, grain protein in cereal crops as well as yield is receiving increased attention because of premiums being paid to producers. Research has shown that grain protein levels are mainly affected by N availability. This paper presents a model which was develop to determine the optimum rate of nitrogen for yield and protein content through using different indices from nitrogen sensor in winter wheat. This model will allow for mid season variable rate application of N fertilizer. For this purpose, an experiment was established to determine the effect of nitrogen on yield and protein content using a randomized block design by applying five different rates of nitrogen (0, 80, 120, 160, 200 kgN/ha) and the two different varieties of wheat. A quadratic polynomial model was best describe the relationship between nitrogen, yield and protein content for optimum nitrogen rate.*

Keywords. *Winter wheat yield and protein content, vegetation index, nitrogen use efficiency,*

precision agriculture, variable rate fertilizing.

Introduction

Nowadays, developed nitrogen (N) management practices, increase wheat yield and quality, due to fertilizing more productive area across the field. This approach also decrease nitrogen fertilizer cost.

Right prediction of nitrogen status during fertilizing application is extremely important to manage nitrogen application for yield and protein. The aim of this study was to use optical sensor to establish a model to determine actual in-season nitrogen requirements according to the relationship between NDVI index and N status in mid season with yield and protein content of wheat.

Variable rate applications create principle stage of precision agriculture and is seen as agriculture's future. In accordance with different areas across the field, the fertilizing costs can be noticeably reduced by adjusting the fertilizing application with actual requirements of this area. (Talebpour et al., 2014). On the other hand, the negative environmental effect of using chemical inputs can be reduced by avoiding overuse of these inputs. Site specific management of inputs can be applied not only by using soil analyzing but also by employing various remote sensing techniques to monitor plant status in different growing stages, for the optimal rate of nitrogen (Talebpour et al., 2014).

Genetic increases in cereal grain yield are, for the most part, coincides by decreases in grain protein concentration. The grain protein concentration reflects the ratio of grain protein yield to grain yield. If the grain protein concentration is to remain constant, then genetic increments in grain protein yield must keep pace with those in grain yield (Feil, 1997).

The magnitude of grain protein response was proportional to the degree of flag leaf nitrogen deficiency below this threshold value. For example, grain protein was increased by nearly 0.7% at 4.3% flag leaf nitrogen, and 1.8% at 4% flag leaf nitrogen. This response was consistent across locations and with a high degree of correlation. Irrigated spring wheat grain protein will be increased by N applications at heading where flag leaf N is below 4.2 to 4.3% (Westcott et al.,1997).

One method of evaluating the protein response likelihood of topdress N is to measure total plant nitrogen in flag leaves at heading. Fairly strong relationships were found between flag leaf total plant nitrogen and grain protein increase due to topdress N (Judith, $R^2 = 0.55$; McGuire, $R^2 = 0.67$). Variety selection and optimum management practices must be integrated for good production enterprises and McGuire winter wheat is more responsive to early season and late season applied N compared to a standard variety, Judith also Flag leaf total plant nitrogen provides a good diagnostic tool for determining the likelihood of a grain protein response (Lorbeer et al. 2000).

Based on analysis of 23 winter wheat experiments conducted from 1998 to 2001 under different growing RI_{NDVI} was found to provide good prediction of $RI_{Harvest}$ at Feekes growth stages 5, 9, and 10.5. This ability to determine the responsiveness of the crop to additional N at early stages of growth additional N at early stages of growth (i.e., Feekes 5) allows altering N management schemes to potentially increase yield and nitrogen use efficiency (Mullen et al., 2003).

Material And Methods

Field experiments were carried out in a randomized block design with five replications at Central Anatolia, Haymana, Ankara, Turkey in two consecutive years. Also field experiments were carried out with the two commercial varieties of bread wheat (T_1 = bezostaja, T_2 = Ahmetaga) and five nitrogen rates as ammonium nitrate (0, 80, 120, 160, 200 kgN/ha). Field experiments design and area was shown in figure 1 and in figure 2 respectively.

1	T1G4	T2G3	T2G4	T1G5	T1G3	T2G5	T2G1	T2G2	T1G2	T1G1
2	T1G5	T1G3	T2G4	T2G2	T2G1	T1G2	T1G1	T1G4	T2G3	T2G5
3	T1G5	T1G1	T1G4	T2G3	T1G2	T2G1	T2G2	T1G3	T2G5	T2G4
4	T1G3	T2G2	T1G4	T1G1	T2G3	T1G2	T2G4	T2G5	T1G5	T2G1

Figure 1. Field experiment design. Randomized block design with five replications.

Where T1 and T2 are seed variety. T1 is Bezostaja and T2 is Ahmetaga. And G1, G2, G3, G4, G5 are fertilizing levels.

Figure 2. Field experiment area (Central Anatolia, Haymana, Ankara, Turkey).

All other culture practices, including preplant fertilizing were carried out as recommended common practices at experiment region.

NDVI values were collected in different stage of plant growth using the Green Seeker handheld sensor. Also flavonol values were collected using the Force-A Dualex Scientific sensor for protein content prediction.

All the data were analyzed using analysis of variance and Tukey's multiple comparison method that was applied to determine differences between treatments.

Statistical Analysis System (SAS) programs were used for analyses of variance and determination of variance components. The results of analysis were evaluated in terms of different nitrogen rates and seed variety. The acquired models for estimating yield content were used to determine the economic optimum rate of nitrogen fertilizer. The average values from two different experiments were used to determine this optimum rate.

In order to determine the best appropriate time of fertilizing, the concept of RI (Response Index) was exploited. This index was calculated for NDVI and Yield separately. Response index for yield is known as $RI_{harvest}$ and indicates the actual crop response to applied nitrogen (Johnson and Raun, 2003) and in-season sensor measurements of NDVI that indicates N uptake between plots receiving nitrogen and those not receiving nitrogen was used for calculating NDVI response index (Mullen et al., 2003) by using following equitions:

$$RI_{NDVI} = NDVI_{(max)} / NDVI_{(control)} \quad (1)$$

$$RI_{harvest} = Yield_{(max)} / Yield_{(control)} \quad (2)$$

The calculated value related to response index in terms of yield and NDVI was compared with each other. As a result of the correlation analysis, the measurement period with the highest R-square obtained from comparing two series of data was identified as appropriate period for applying fertilizer. After determining the appropriate time for applying nitrogen fertilizer, the relationship between corresponding NDVI values and nitrogen rates was determined using linear regression method in order to estimate the nitrogen requirement in wheat.

The concept of INSEY (in-season estimated yield) was used to estimate potential yield using GreenSeeker readings (Franzen et al., 2013). In-season estimated yield (INSEY) values were computed using NDVI readings in any period of growth divided by the cumulative growing degree day (CGDD) over the same time period from planting to sensing (Lukina et al., 2001, Teal et al., 2006).

Results

The influence of different nitrogen rate on yield and some quality index (protein content) are shown in Table 1. The result of variance analysis showed that all quantities and quality parameters were affected significantly by N rates.

Table 1. Effect of nitrogen fertilizer rate on yield and protein content in Haymana experiment location[n.]

N Rate KgN/ha	Yield	Protein
0	2.153±0.380 B	15.280±1.273 B
80	2.623±0.485 AB	15.747±1.381 AB
120	3.082±0.383 A	16.717±1.086 B
160	3.285±0.559 A	17.712±1.132 B
200	3.225±0.528 A	18.018±1.805 B

[*] Means with the same letters are not significantly different at the 5% probability level.

The data collected at each experimental location was analyzed as a five-replication in randomized complete design. As a result, the relationship between nitrogen fertilizer rate, yield and protein content values were statistically significant.

Determination of Economically Optimum Nitrogen Fertilizer Rate

Determination of optimum nitrogen rate in nitrogen fertilizer consumption is important because of its impact on the wheat quantity and quality.

Determination of the economical optimum rate of nitrogen is required. In order to determine optimum nitrogen rate, the average of yield and protein content values were used to estimate response functions to nitrogen (Figure 3). Estimated regression parameters and R^2 for the averaged winter wheat yield and protein response functions to nitrogen was shown in table 2.

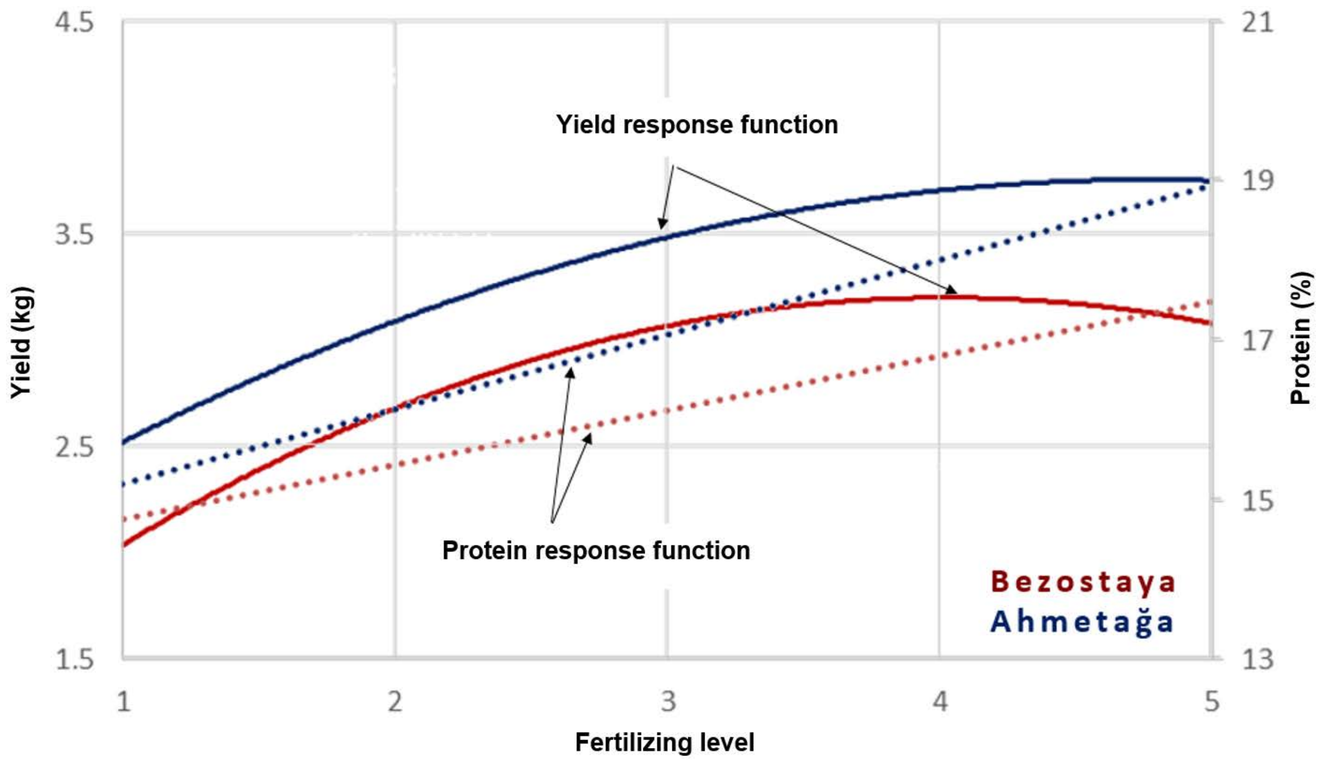

Fig 3. Estimated yield and ptotein content response function to nitrogen rate.

Table 2. Estimated regression parameters and R² for the averaged winter wheat yield and protein response functions to nitrogen.

Seed	Yield response functions				Protein response functions		
	a	b	c	R^2	α	β	R^2
Bezostaya	-0.127	1.0216	1.1493	0.7272	0.6765	14.105	0.6746
Ahmetağa	-0.0869	0.8288	1.769	0.7303	0.935	14.427	0.5684
Average	-0.107	0.925	1.4592	0.5917	0.8057	14.176	0.535

Quadratic polynomial curves, as the most appropriate statistical model, were used to estimated yield and protein content values. Economically optimum nitrogen rate corresponding to yield and protein content, wheat price and net return derived from net return equation using mean values of 167.6 kgN/ha for bezostaja and 206 kgN/ha for ahmetaga. According to the result of statistical analysis related to yield and protein content, the high protein content was obtained when the amount of 160 kgN/ha for bezostaja and 200 kgN/ha for ahmetaga nitrogen was applied.

Evaluation of NDVI Results

Green seeker sensor reading were used to determine optimum timing of nitrogen fertilizing. For achieving this purpose, response index calculated from different NDVI readings and yield at different measurement periods were utilized. The results of regression analysis to determine the relationship between RI_{NDVI} and corresponding $RI_{harvest}$ are reported in Table 3.

Table 3. Relationship between RI_{NDVI} and RI_{Hasat} (R^2).

RI_{NDVI}	$RI_{HARVEST}$
RI_{NDVI} - first reading	8.81
RI_{NDVI} - second reading	11.21
RI_{NDVI} - third reading	69.37
RI_{NDVI} - fourth reading	77.51
RI_{NDVI} – fifth reading	76.57
RI_{NDVI} - sixth reading	65.30

Table 4. The effects of different nitrogen fertilizer rate on NDVI values at second Green Seeker readings after fertilizing.

N Rate KgN/ha	NDVI-1	NDVI-2	NDVI-3	NDVI-4	NDVI-5	NDVI-6
0	0.404±0.075 A	0.608±0.090 A	0.679±0.066 B	0.622±0.039 B	0.646±0.102 AB	0.567±0.106 A
80	0.460±0.149 A	0.637±0.093 A	0.679±0.035 B	0.696±0.066 AB	0.614±0.043 B	0.549±0.089 A
120	0.495±0.102 A	0.646±0.059 A	0.734±0.067 AB	0.716±0.067 A	0.701±0.063 AB	0.485±0.109 A
160	0.467±0.117 A	0.714±0.060 A	0.784±0.032 A	0.747±0.019 A	0.709±0.093 AB	0.468±0.063 A
200	0.425±0.118 A	0.685±0.044 A	0.747±0.053 AB	0.767±0.022 A	0.740±0.045 A	0.581±0.102 A

* Means with the same letters are not significantly different at the 5% probability level.

In order to create this equation, INSEY index calculated from fourth NDVI readings after fertilizing was used. The following equation estimated the potential yield at trial site (where NDVI values response to nitrogen fertilizer were significant) without additional nitrogen fertilizer:

Potential Yield = 6952 INSEY – 2.302 (R^2=0.7674)

Considering that CGDD were 928.9 °C with reference to INSEY=NDVI/CGDD, the relationship between Potential yield and NDVI values can be calculated as follows:

Potential Yield = 7.484 NDVI – 2.302 (R^2=0.7674)

So, using INSEY index can be used to determine potential yield without additional nitrogen fertilizer.

Determination of Variable Nitrogen Rate Using Green Seeker Readings

In order to drive nitrogen rate using a NDVI-based calibration equation, the data from Haymana trial site with meaningful data were used. Using obtained equation resulted in maximized economic return by avoiding unnecessary use of nitrogen and balancing between yield and protein content and harmful nitrogen. Because of statistical significance of the effect of two seed variety on NDVI values ($p<0.05$), the relationship between NDVI and additional nitrogen rate were determined for both seed varieties. The results were expressed by the following equations:

NDVI = 0.0341 Fertilizer Rate + 0.6073 (R^2=0.92)

Nitrogen fertilizer rate obtained from above equations was determined as nitrogen level in winter wheat. Therefore, calculated NDVI values using Green Seeker and Force-A can be used to estimate the nitrogen status in wheat. So, the recommendation of nitrogen rate that should be used in the variable rate nitrogen application can be done by subtracting estimated nitrogen level in plants from predetermined optimum nitrogen rate 167.6 kgN/ha for bezostaja and 206 kgN/ha for ahmetaga.

Conclusion

This study demonstrates that crop reflectance measurements using optical sensors can be used to set more efficient and profitable fertilization levels. The techniques that have been developed are appropriately applied at spatial scales of 1 m^2 and will require variable rate applicators equipped with optical sensors. The techniques rely on non-N-limiting test strips in fields that allow an in-season estimate of fertilizer response (Raun et al., 2002).

A quadratic model was used to determine the relationship between applied nitrogen rate and yield and protein content. The results show that the estimated economically optimal nitrogen rate for mean values were 167.6 kgN/ha for bezostaja and 206 kgN/ha for ahmetaga when the relationship between the protein content and the price are considered. Few studies related to winter wheat investigated economic consequences with regard to quality factors response to nitrogen fertilizer and the relationship between protein content and yield (Baker et al., 2004, Gandorfer and Rajsic, 2008).

Wheat quality is greatly affected by nitrogen fertilizer. Production of high quality wheat is especially important to growers. In this study, it was found that applying different nitrogen fertilizer rates has significant impact on the yield and quality parameters. According to the result, maximum yield and protein content were achieved obtained when 160 and 200 kgN/ha was applied, respectively.

Based on the results of NDVI readings from experimental pilots, the relationship between in-season estimate yield (INSEY) computed from NDVI readings collected from second sensor reading after fertilizing divided by the number of days from planting to the reading date and measured wheat yield were used to determine potential wheat yield. With regard to response index of NDVI readings and yield at harvest, the application of nitrogen fertilizer at 928.9 °C CGDD was suggested when the highest correlation were obtained between NDVI indecies. It can be concluded that nitrogen fertilizer requirement can be calculated using response function of NDVI to different fertilizer rate.

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