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Article

Sensor based calibration study for in-season nitrogen management of winter wheat in Turkey

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Abstract: The aims of this study were to compare the responses of four winter wheat cultivars to nitrogen fertilization with vegetation indices calculated using spectral reflection (GreenSeeker hand-held sensor) and to estimate in-season yield (INSEY) using the vegetation indices. The field experiment was conducted at Transitional Zone Agricultural Research Institute of Eskisehir province, Turkey in 2007-2008, 2008-2009 and 2009-2010 growing seasons. The experimental layout was a 2factor factorial in the randomized complete block design. Nitrogen rates were 0, 40, 80, 120, 160 and 200 kg N ha^{-1}. Vegetation Index (NDVI) was obtained at growth stages of Zadoks 24 (tillering stage), Zadoks stage 30 (stem elongation), Zadoks stage 31 (the first node is visible) and Zadoks stage 32 (the second node is visible). The results revealed that Zadoks stage 30 was the most realistic reading time. NDVI had the advantage of providing information on biomass, in addition to nitrogen nutrition status of crops, enabling in-season yield estimation possible. Therefore, NDVI based calibration equations were preferred for testing in the fields of actual farmers for the last year of study. A comparison of the system with traditional farmer applications indicated that yield estimation obtained by the new system was quite similar yields with 13.2 kg ha^{-1} less N in the spring (ZD 3.0), showing its economically promising value.

Keywords: wheat; vegetation index; NDVI; Greenseeker; INSEY

1. Introduction

Nitrogen (N) is one of the essential nutrients for plant growth (Baral *et al*., 2015). The use of optical sensors to detect N deficiencies and determine in-season fertilizer recommendations have recently increased (Bushong *et al*., 2018). The N recommendations for the irrigated wheat area lead to low N-use efficiency due to field-to-field variability in soil N supply and seasonal variability in yield (Bijay-Singh *et al*., 2011). Expected yields could be inconsistent from field-to-field and year-to-year depending on factors that are difficult to predict prior for fertilizer applications. A positive correlation was observed between grain yield and NDVI (Aparicio *et al*., 2000) and between NDVI and N use efficiency (NUE) (Naser, 2012). Sensor-guided fertilizer N applications resulted in high yield levels and high N use efficiency (NUE) values (Bijay-Singh *et al*., 2010). In this study, the investigated the performance of optical sensors in large field trials, to predict yield and biomass characteristics (Christoph *et al*., 2018). Farmers use sensors to estimate crop biomass production and yield potential, and make fertilizer recommendations (Olga, 2015).

Raun *et al*. (2002) have been reported recent developments in the adjustment of N fertilizer recommendations using in-season yield estimates (INSEY). The INSEY index is calculated by dividing the NDVI value by the number of days between sowing and sensing. Then the response index (RI) can be calculated (Mullen *et al*., 2003). Flowers *et al*. (2003) reported a strong relationship between NDVI and N uptake and plant N concentration in wheat.

The method basically composed of three stages: i.) Establishing calibration equations between INSEY values and actual yields attained ii.) Setting validation trials on farmer fields in the target region to refine these equations considering the deviations from experimental results and iii.) establishing N-rich strips on each individual farmer field to compare INSEY values and calculate RI values from the differences between N-rich strips and application of farmer to provide the recommendation for that individual field and the season (Raun *et al.*, 2005).

The experiment presented in this paper is the first application of the calibration stage of this new method in Turkey. The objective of this study was to determine the wheat yield potential estimated using an in-season estimation of NDVI.

2. Materials and Methods

Calibration experiments were conducted for 3 years (2007-2008, 2008-2009 and 2009-2010) on experimental fields of Transitional Zone Agricultural Research Institute in Turkey. Four registered bread wheat cultivars (Alpu2001, Katea 1, 1 Bezostaya1 and Konya2002) adapted to the irrigated conditions of the region were used in the experiments. The responses of these cultivars to N fertilization were compared with vegetation indices based on spectral reflection and calculated In-Season Estimated Yield values. However, the results were presented as the average of the cultivars since limited data for individual cultivars cause deviations. Nitrogen rates of 0, 40, 80, 120, 160 and 200 kg ha^{-1} were used. Whole nitrogen was applied just before planting as urea or ammonium nitrate form. Sowing time applied Nitrogen treatments to create a variation for NDVI read. The experimental layout was factorial in randomized complete block design, the seeding rate of the experimental treatments was 450 kernel m^{-2}.

Monthly precipitations for the experimental years of the research institute were provided in Table 1.

The experimental soils formed over deep alluvial sediments. The soils were high clay content (50.2%), low organic matter (1.13%), medium in lime content and slightly alkaline character (pH=7.83). The NO_3 and NH_4+NO_3 N analyses were performed with two different methods recommended by Bremner (1965) (Table 2).

The GreenSeeker^{TM} (NTech Industries, Inc., Ukiah, CA Model 505) hand-held sensor was used to compute the Normalized Difference Vegetation Index (NDVI). The reading dates were determined according to Zadoks scale (Zadoks *et al.*, 1974) as Zadoks stage 24 (tillering stage with 4 tillers), Zadoks stage 30 (pseudo stem elongation), Zadoks stage 31 (onset of stem elongation when the first node is visible) and Zadoks stage 32 (onset of stem elongation when the second node is visible). In-Season Estimated of Yield (INSEY) was calculated as described by Raun *et al*. (2002). The INSEY was calculated by dividing the NDVI data by the number of growing degree days (GDD)>0 (GDD=(Tmin+Tmax)/2–4.4 °C, where Tmin and Tmax represent daily ambient low and high temperatures) from planting to sensing as proposed by Raun *et al*. (2002). Response Index (RI) values for NDVI and grain yields were calculated according to Raun *et al*. (2005).

The N Rich Strip should be applied at before planting for winter wheat. All the N in the N rate experiment was applied just before planting time as urea or ammonium nitrate and incorporated to the planting operation. The N rich strip in wheat field was established by applying 200 kg N ha^{-1} to a strip of 4 m wide and about 50 m long (200 m^2). Spring season N was applied based on NDVI value depending on N rate calculated in calibration experiments. The NDVI was calculated as follow-

NDVI= (P – NIR) / (P + NIR).

Where NDVI is the reflectance of red (660 nm) and NIR (770 nm) and NDVI values ranged from 0.00 to 0.99.

2.1. Statistical analysis

Fisher's protected LSD post-hoc analyses were performed on significant (alpha D 0.10) main and interactive treatment effects. Calibration equations were developed using JMP 13.0.0 (SAS Institute Inc. Cary, NC, USA) statistics package program.

3. Results and Discussion

3.1. Grain yield and NDVI

Grain yields obtained in the experiments were given in Table 3. As can be seen in Table 3, applications of different rates of nitrogen increased grain yield in every 3 years. There were statistically significant differences between genotypes for the grain yield all the years.

Different Nitrogen rate applications were significant increases in wheat grain yields in all of the experiments. The effect of nitrogen rates on the grain yield is given in Table 3. As it is seen in Table 3, that four Genotype

have increased the grain yield on three locations. But the yields were a bit lower in the third year as compared to first two years. Increasing nitrogen rates have increased the grain yields according to control treatment.
Walsh *et al*. (2018) has also found out increased grain yields of wheat when N fertilizers are applied at sowing time. The difference in yields of three locations might be due to the fact of different amount of precipitation, precrop and of different physical and chemical properties of the locations. NDVI Sensor system is a promising approach for predicting Wheat yield. Yield prediction is important in the development of algorithms for sensor-based Nitrogen management (Tagarakis and Ketterings, 2017).
The NDVI and Response Index (RI) values were shown in Figure 1 The NDVI values obtained at growth stages of Zadoks stage 24 (tillering stage with 4 tillers), Zadoks stage 30 (pseudo stem elongation stage) and Zadoks stage 31 (stem elongation stage with 1 node) and Zadoks stage 32 (stem elongation stage with 2 nodes) (Zadoks *et al.,* 1974) were presented in Table 4.
The differences in crop establishment among three years were also reflected in NDVI readings (Figure 1). Olga *et al*. (2018) have also reported **a** significant positive correlation between NDVI values and preplant N application rates. The lowest NDVI values obtained at Zadoks stage 24 in the third year were resulted not only from weaker early crop growth but also from the insufficient ground cover (Figure 1). Soil background has a significant effect on canopy reflectance, especially at low biomass rate (Huete *et al.,* 1985). Heilman and Kress (1987) showed that the effect of soil background on irradiance is significant when total aboveground biomass is less than 50% (Heilman and Kress, 1987). In contrast, Lukina *et al*. (2000) stated that soil reflectance was not an important factor when total aboveground biomass was more than 40%.
The RINDVI values at Zadoks 30 stage were higher, however, RINDVI values reduced Zadoks 31 and 32 stages became closer to those obtained at Zadoks 24 stage. The main objective of the study was to determine the growth stage where RINDVI is the most representative of RIYIELD rather than the highest value of RINDVI per se. Therefore, mean RIYIELD values of 3 experiments and correlation coefficients between RINDVI and RIYIELD were given in Table 5.
The RI_{YIELD} values of Alpu2001 and Konya, recent breed cultivars with high yield potentials were higher than the other two varieties (Table 5). The results confirmed that higher RI_{YIELD} values are related to higher yields. High correlation coefficients obtained for all growth stages indicate the greater importance of ground cover than the stage itself. The early growth stages such as Zadoks 24 can also be used for recommendations, provided that there is enough ground cover (giving at least 0.30-0.40 NDVI values).
Calibration equations: Calibration equations for irrigated winter wheat in 3 different years as averaged over 4 cultivars. The algorithms were generally based on in-season estimated yield (INSEY). The INSEY was determined by dividing the sensor NDVI readings by the growing degree days.
ZADOKS 24: YIELD (kg ha^{-1}) = -1489.5 + 808017.9 (INSEY) (R^2 = 0.98**, n = 6) *(1)*
ZADOKS 30: YIELD (kg ha^{-1}) = 192.2 + 659592.3 (INSEY) (R^2 = 0.99**, n = 6) *(2)*
ZADOKS 31: YIELD (kg ha^{-1}) = -1055.9 + 876962.7(INSEY) (R^2 = 0.99**, n = 6) *(3)*
ZADOKS 32: YIELD (kg ha^{-1}) = -1324.9 + 100745.0 (INSEY) (R^2 = 0.99**, n = 6) *(4)*
In contrast to the others who used exponential equations, the linear relations were obtained for all seasons and cultivars (Figure 2). Exponential transformations (Central Anatolia of Turkey) did not make any significant contribution to the determination coefficients. The differences between ecologies of Central Anatolia and Oklahoma and Mexico might cause to the differences. The results revealed that calibration equations are site specific and the equations obtained in this study can be used for the farmer recommendations in Central Anatolia of Turkey. The readings for all growth stages resulted in significantly high determination coefficients ($p<0.01$), when averaged over years and cultivars. The differences in determination coefficients among growth stages were not significant, thus Zadoks 30 was accepted as the most suitable growth stage for applications in farmer fields. The N applied at Zadoks stage 30 was reported to have the highest effect on the growth of winter wheat (Baethgen and Alley, 1989). Melaj *et al*. (2003) reached the same conclusion, explaining that wheat reaches to maximum growth rate at this stage. However, Weisz *et al*. (2001) reported that some of the N should be used earlier than Zadoks stage 30 when early growth and tillering of wheat is not sufficient. Considering the difficulties and risks of using a tractor in the field after this stage, Zadoks 30 was considered as the most suitable time to apply N for irrigated winter wheat. Olga *et al.* (2018) stated that N fertilizer rates recommended by the USA/Canada/Mexico Algorithm were not appropriate for grain yield optimization. The recommendation brought by Olga *et al*. (2018) puts forward a question of whether there is a need for two separate algorithms, one developed for dryland spring wheat and the other for irrigated spring wheat production system.
In the six experiments carried out at in Eskisehir during 2011-2012 growing seasons, 200 kg N ha^{-1} was applied to the rich strips. The response indices RINDVI and RIHarvest were calculated (Mullen *et al*., 2003; Johnson and Raun, 2003). NDVI was obtained from the sensor measurements.

3.2. Farmer applications

The system works in the farmers field by establishing an N-rich strip (to guarantee that there will be no N deficiency in that area). The new system was compared with traditional farmer applications, based on the average of 6 farmer fields. The new system provided similar yields with 13.2 kg ha^{-1} less N in the spring (ZD 3.0), showing its economically promising value (Table 6).

The results of validation trials showed that farmers were able to save 69 kg N ha^{-1}, without any yield reduction (Ortiz-Monasterio and Raun, 2007). The use of crop sensors has been shown to produce savings of \$10 to \$20 per acre (Andrews, 2011). GreenSeeker sensors can improve N use efficiency with significant increase in net profits (Li *et al*., 2009; Tubaña *et al*., 2008). The N use efficiency could be increased at a rate of 15% with sensor-based variable rate N fertilization (Raun *et al*., 2002).

Table 1. Monthly precipitation of the experimental site at the Institute during 2007-2010 growing seasons (mm).

Years	Sep.	Oct	Nov	Dec	Jan	Feb	Marc	April	May	June	July	Aug.	Annual Total (mm)
Long-Term	14.7	25.2	30.6	45.6	38.4	32.6	33.3	35.0	42.1	29.3	13.8	6.5	347
2007-08	0.0	19.2	92.4	49.9	15.7	1.0	42.4	38.5	11.7	9.3	0.0	5.5	286
2008-09	30.7	6.4	49.6	34.5	66.3	82.0	40.9	28.0	15.4	10.2	19.4	2.0	385
2009-10	7.1	9.0	29.5	65.1	36.0	42.8	32.6	23.9	20.7	79.0	7.4	0.9	354

Table 2. Soil characteristics of experimental sites (0 to 30 cm soil layer).

Characteristics	Unit	2008 INST.	2009 INST.	2010 INST.
Texture		Clay	Clay	Clay
pH (1:2.5 Soil:Water)		7.83	7.52	7.54
EC (Salt) (1:5 Soil:Water)	(µS cm^{-1})	156	140	230
$CaCO_3$ (Lime)	(%)	10.9	9.6	8.0
Organic Matter	(%)	1.13	1.1	1.77
Phosphorus	(mg kg^{-1})	33.3	32.1	27.8
Potassium	(mg kg^{-1})	671	666	493
Phenoldisulphonic Acid Method (NO_3)	(mg kg^{-1})	2.1	3.30	0.84
KCl Extraction Method (NH_4^+ , NO_3)	(mg kg^{-1})	10.3	15.90	9.33

Table 3. Effects of Nitrogen fertilization on grain yields of irrigated winter wheat in 3 different years as averaged over 4 cultivars.

N RATE	Grain Yield (kg ha^{-1}) 2007-2008				
(kg N ha^{-1})	ALPU2001	BEZOSTAYA1	KATE-A1	KONYA	Mean
0	5196	4053	4713	4438	4600 c
40	6830	4750	5070	5150	5450 b
80	7770	4830	5320	4759	5670 b
120	8068	4869	5969	5933	6210 a
160	8338	4859	5840	6085	6280 a
200	7981	4710	5544	6526	6190 a
Mean	7364 a	4678 c	5409 b	5482 b	
CV (%):11.5 Lsd (0.05) Genotype: 389** Lsd (0.05) Nitrogen :475** Lsd (0.05) Genotype*Nitrogen: 950*					
N RATE	Grain Yield (kg ha^{-1}) 2008-2009				
(kg N ha^{-1})	ALPU2001	BEZOSTAYA1	KATE-A1	KONYA	Mean
0	6600	5138	6359	5264	5840 b
40	6810	5060	6930	6680	6370 ab
80	7749	5482	6639	6729	6650 a
120	8310	5610	6800	6920	6910 a
160	7150	5320	7118	7090	6670 a
200	7370	4300	5463	5507	5660 b
MEAN	7332a	5152 c	6552 b	6365 b	
CV (%):13.1 Lsd (0.05) Genotype: 511* Lsd (0.05) Nitrogen :610* Lsd (0.05) Genotype*Nitrogen: 1025*					
N RATE	Grain Yield (kg ha^{-1}) 2009-2010				
(kg N ha^{-1})	ALPU2001	BEZOSTAYA1	KATE-A1	KONYA	Mean
0	1610	1750	2410	1750	1880 e

40	3205	2889	3820	2965	3220 d
80	4830	4340	4230	4599	4500 c
120	5793	5526	5100	5339	5440 b
160	6643	5419	5472	6025	5890 a
200	7309	5374	5403	6675	6190 a
Mean	4898a	4216c	4406bc	4559b	
CV (%):12.1 Lsd (0.05)Genotype: 316 * Lsd (0.05) Nitrogen :387** Lsd (0.05) Genotype*Nitrogen: 710*					

Means with the same the letters are statistically non-significant, ** Significant at p<0.01 level, * Significant at p<0.05 level by Fisher's Lsd, NS: Non-significant

Table 4. The Effects of Nitrogen fertilization on NDVI values obtained at 4 different growth stages in 3 different years as averaged over 4 cultivars.

N RATE (kg N ha^{-1})	NDVI			
	Zadoks 24	**Zadoks 30**	**Zadoks 31**	**Zadoks 32**
0	0.538	0.524	0.570	0.587
40	0.656	0.664	0.678	0.673
80	0.745	0.765	0.760	0.754
120	0.772	0.813	0.805	0.803
160	0.788	0.836	0.828	0.824
200	0.795	0.849	0.843	0.844
Mean	0.716	0.742	0.747	0.747
Lsd (0.05)	0.026**	0.020**	0.018**	0.016**
CV (%)	9.3	6.7	5.9	5.5

N RATE (kg N ha^{-1})	RI_{NDVI}				
	Zadoks 24	**Zadoks 30**	**Zadoks 31**	**Zadoks 32**	**Mean**
0	1.00	1.00	1.00	1.00	1.00
40	1.39	1.59	1.37	1.31	1.42
80	1.68	2.04	1.67	1.61	1.75
120	1.79	2.29	1.85	1.80	1.93
160	1.82	2.38	1.94	1.89	2.00
200	1.87	2.42	1.99	1.95	2.06
Mean	**1.59**	**1.95**	**1.64**	**1.59**	**1.69**

Means with the same the letters are statistically non-significant, ** Significant at p<0.01 level, * Significant at p<0.05 level by Fisher's Lsd, NS: Non-significant

Table 5. Correlation coefficients between RI_{YIELD} and RI_{NDVI} values obtained at different growth stages at the irrigated calibration study (n=18).

N RATE (kg N ha^{-1})	RI_{YIELD}				
	ALPU2001	**BEZOSTAYA1**	**KATE-A1**	**KONYA**	**Mean**
0	**1.00**	**1.00**	**1.00**	**1.00**	1.00
40	1.32	1.21	1.22	1.29	1.26
80	1.56	1.38	1.19	1.45	1.40
120	1.70	1.51	1.36	1.64	1.55
160	1.76	1.48	1.35	1.72	1.58
200	1.76	1.45	1.40	1.78	1.60
Mean	**1.52**	**1.34**	**1.25**	**1.48**	1.40
GROWTH STAGE	**CORRELATION COEFFICIENTS**				
	ALPU2001	**BEZOSTAYA1**	**KATE-A1**	**KONYA**	**Mean**
Zadoks 24	0.98**	0.99**	0.97**	0.98**	0.98
Zadoks 30	0.98**	0.99**	0.98**	0.99**	0.99
Zadoks 31	0.99**	0.99**	0.98**	0.99**	0.99
Zadoks 32	0.99**	0.99**	0.97**	0.99**	0.99
Mean	**0.99**	**0.99**	**0.98**	**0.99****	0.99

** Significant at p<0.01 level, * Significant at p<0.05, NS: Non-significant

Table 6. Effect of Nitrogen fertilization on grain yield of irrigated winter wheat in 6 farmer fields.

Genotype	Previous Plant	Field	Applied Nitrogen		Grain Yield	
			Farmer	**Sensor**	**Farmer**	**Sensor**
Sönmez2001	Beans	1	120	77	7780	6950
Katea1	Corn	2	120	133	7240	8050
Konya	Sugar Beet	3	120	98	6570	7310
Bezostaya1	Corn	4	120	130	3220	4270
Konya	Corn	5	120	123	4610	4360
Harmankaya99	Potato	6	120	80	7770	8470
		Mean	120.0	106.8	6198	6568
		Difference	13.2		370	

Note: 6 farmer fields demonstrations aren't replicates.

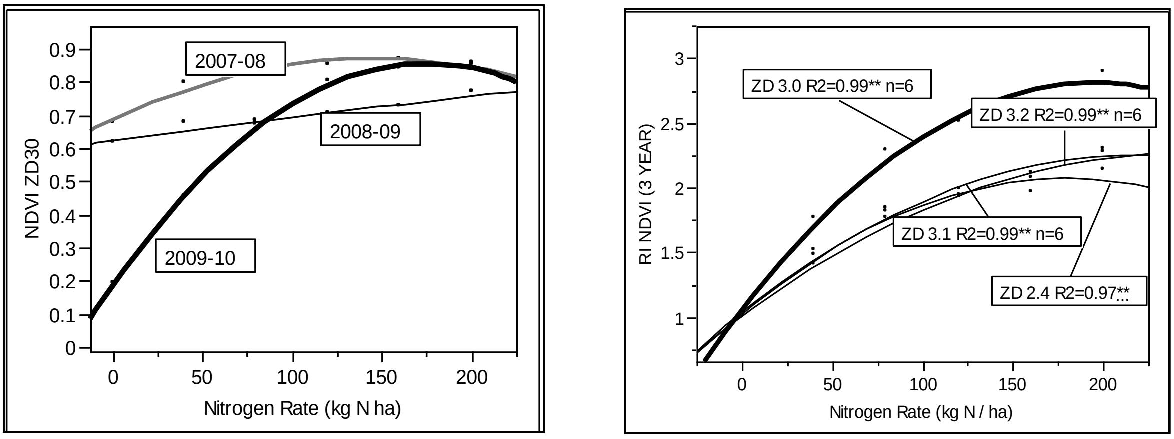

Figure 1. Effect of N fertilization on NDVI and RI NDVI of irrigated winter wheat in 3 different years as averaged over 4 cultivars.

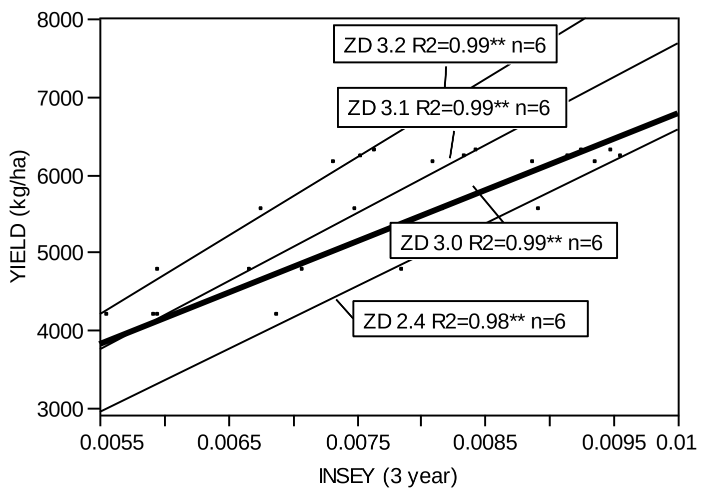

Figure 2. Regression lines of grain yield over INSEY in 3 different years.

4. Conclusions

Calibration equations required for the optic-sensor-based in-season nitrogen management system for irrigated wheat farming in Central Anatolia were investigated. Promising results were obtained on its applicability in preliminary tests conducted at farmer fields. Sufficient data were obtained to initiate an improved nitrogen fertilizer recommendation system compared to those reported by presently used methods. The results indicated that yield potential in wheat could be predicted in season with INSEY measured with the optic sensor.

Optic sensor readings were performed at four different growth stages. The Zadoks 30 stage (pseudo stem elongation) was considered to be the most suitable time for readings and recommendations. Similar yield levels were obtained in the preliminary tests conducted on 6 farmer fields by 13.2 kg Nitrogen ha^{-1} less nitrogen than farmer applications. The lower rate of N shows the economic benefits of the new system proposed.

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Conflict of interest

None to declare.

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