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Precision Nitrogen Management Based on NDVI and in-Season Estimates of Response Index in Wheat

Rekha Ratanoo[1*], Satish Kumar[2], A.K. Dhaka[2] and Lalit Rolaniya[1]

[1]*Department of Agronomy, Punjab Agricultural University, Ludhiana, Punjab-141004, India*
[2]*Department of Agronomy, CCS Haryana Agricultural University, Hisar, Haryana-125001, India*

**Corresponding author*

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A B S T R A C T

Fertilizer N management using optical sensor (GreenSeeker®) was evaluated at CCSHAU, Hisar. The experiment was laid out in randomized block design with three replications. There were 12 treatments comprising N application with and without using GreenSeeker. N application without using GreenSeeker consisted of two treatments having recommended dose (150 kg/ha) in two (75 kg/ha each) and three (50 kg/ha each) equal splits. GreenSeeker guided N application was combined with fixed rate (75, 100 and 125 kg/ha) and fixed time N application (nine treatments) as basal and at 25 DAS. GreenSeeker was used with each fixed level of N application at 2nd (50 DAS) and/or 3rd irrigation (65 DAS). One treatment was control where no fertilizer N was applied. During the procedure of finding out fertilizer N requirement using GreenSeeker, NDVI values and related parameters were calculated and analyzed. In general, NDVI values were higher in treatment having higher dose of fixed rate N at planting and CRI stage. At 65 DAS (3rd irrigation) the increase in NDVI values was more in treatment having N application at 50 DAS (2nd irrigation) with or without using GreenSeeker and it ranged from 11.7 to 22.2% as compared to treatment having no N application at 2nd irrigation where it was only 2.6 to 9.1%. Responsiveness of a particular treatment to further addition of applied fertilizer i.e. Response index (RI_{NDVI}) values were inversely proportional to amount of fixed rate N application. RI_{NDVI} values remained low throughout the crop growth stages where frequency of N application was higher. Total N uptake and NDVI values were highly correlated and values of coefficient of determination were higher at middle crop growth stages as compared to early and late stages.

Introduction

Nitrogen is most limiting nutrient in crop production particularly in irrigated cereal-based cropping systems and is applied by farmers with priority to get profitable yields. During 2015-16, total fertilizer N consumption of India was 17.6 million tonnes. Nitrogen consumption by cereals is 60% and 72% of total N consumption in world and India, respectively (Raun and Johnson, 1999; FAI, 2010). Among various N management strategies site-specific N management is one of the most advanced ones. This can be prescriptive, corrective management (real time N management) or a combination of both (Dobermann and Cassman, 2004). Prescriptive are based on supplying capacity of soil, expected crop demand, targeted yield, efficiency of fertilizer and risk from weather and pest infestation. Real-time corrective nitrogen management is based on rapid assessment of leaf N content- a sensitive indicator of changes in crop N demand during the growing season. This approach revolves around quick and reliable diagnostic tools which are based on measurement of spectral characteristics of the radiation reflected, transmitted or absorbed by the leaves to estimate the chlorophyll content. Since most of the plant N is found in chloroplasts and chlorophyll protein, the N status of the plant could be assessed. In the present study, GreenSeeker® optical sensor was used to find out the in-season N requirement.

Materials and Methods

Experimental site and location

A field experiment was conducted at Agronomy Research Farm of Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana to study the optical sensor based N management in wheat.

Details of experimental design and treatments

The experiment was laid out in randomized block design with three replications. There were 12 treatments comprising N application with and without using GreenSeeker®. N application without using GreenSeeker consisted of two treatments having recommended dose (150 kg/ha) in two (75 kg/ha each) and three (50 kg/ha each) equal splits. GreenSeeker (GS) guided N application was combined with fixed rate (75, 100 and 125 kg/ha) and fixed time N application (nine treatments) as basal and at 25 DAS. GreenSeeker was used with each fixed level of N application at 2^{nd} (50 DAS) and/or 3^{rd} irrigation (65 DAS) when crop canopy is developed sufficient in order to give estimation of crop N requirement based on current status of crop N. Earlier than that GreenSeeker cannot be used because crop canopy cover is not full and combined reflectance of crop and soil cannot give précised N requirement. One treatment was control where no fertilizer N was applied.

Calculation of Nitrogen requirement

Nitrogen doses using GreenSeekr® were calculated as per the procedure developed by Raun *et al.,* (2002); Raun *et al.,* (2005) and Singh *et al.,* (2011) which can be separated into several discrete components:

Normalized difference vegetation index (NDVI) measurements made by Green Seeker are based on following formula:

$$NDVI = [(NIR_{ref}/NIR_{inc})-(Red_{ref}/Red_{inc})]/[(NIR_{ref}/NIR_{inc})+ (Red_{ref}/Red_{inc})]$$

Where, NIR_{ref} and Red_{ref} = magnitude of reflected near infrared and red lights, and NIR_{inc} and Red_{inc} = magnitude of the incident near infrared and red lights.

In-season Estimation of yield (INSEY) was made by using following formula:

$$INSEY = \frac{NDVI}{\text{Days from planting to sensing,}}$$

Yield potential (YP_0) with no added fertilizer was calculated from following equation:

$$YP_0 = a(INSEY)^b \text{ or exponential function}$$

Where the values of constants a and b were used as depicted from graphs showing relationship between grain yield and INSEY developed by Singh *et al.*, (2011) using data from several regions of Indo-Gangetic Plains over several years.

One N rich strip (NRS) was laid out along with experiment as a prerequisite for precisely work out the N requirement based on possible response of that crop to applied N.

The Response Index (RI) or the potential responsiveness to added fertilizer N indicates the likelihood of obtaining a response and how much of a response can be expected.

$$\text{Response Index } (RI_{NDVI}) = \frac{NDVI_{NRS}}{NDVI_{\text{Test plot}}}$$

The predicted attainable yield (YP_N) with added nitrogen was calculated as:

$YP_N = YP_0 \times RI$

N requirement (based on projected N removed in the grain with and without N fertilizer) should theoretically be the difference between the two divided by an efficiency factor. Therefore, it was calculated as given below:

$[(GNUP\_YP_N) – (GNUP\_YP_0)] / 0.5$

Where, $GNUP\_YP_0$ (Grain N uptake, YP_0) = Grain Yield (YP_0)× average % N in the grain

$GNUP\_YP_N$ (Grain N uptake, YP_N) = Grain Yield (YP_N) × average % N in the grain

Average percentage (%) N in grain used in these calculations were 1.8%.The divisor 0.5 represents the fertilizer N use efficiency factor of 50% for wheat. Average percentage (%) N in grain used in these calculations was 1.8%. Therefore, fertilizer N doses were calculated as given below:

$$\text{Fertilizer N dose} = \frac{1.8 \times (YP_N - YP_0)}{100 \times 0.5}$$

In the present article in-season response index (RI_{NDVI}), relationship of RI_{NDVI} and actual response index ($RI_{Harvest}$) and relationship of total N uptake with NDVI values has been discussed.

Results and Discussion

Normalized Difference Vegetation Index (NDVI)

The data pertaining to NDVI values at 50 DAS and 65 DAS are presented in figure 1. NDVI values at 50 DAS were affected by initial fixed N doses i.e. at planting and at CRI stage (25 DAS). At 50 DAS the treatment having recommended schedule of N (@150 kg/ha) recorded highest NDVI values, followed by treatment where initially 125 kg N/ha had been applied i.e. T_9, T_{10} and T_{11}.

At 65 DAS, NDVI values increased in all the treatments except control, however, increase was more in treatment when GS guided N was applied at 2nd irrigation i.e. at 50 DAS, as compared to when GS guided N was not applied at that stage. Extent of increase in NDVI values till 65 DAS was 11.7 to 22.2% in treatments where GS guided N was applied at 2nd irrigation (T_3, T_5, T_6, T_8, T_9 and T_{11}) whereas NDVI values increased only by 2.6 to 9.1% when GS guided N was not applied at 2nd irrigation (T_1, T_4, T_7 and T_{10}). Pradhan *et al.*, (2013) also observed that ensuring the higher and rapid availability of N during the crop growth period resulted into significant increase in NDVI values.

Estimating the response to applied N

Average RI_{NDVI} values computed for different treatments at different growth stages are presented in Table 1. In-season estimate of response index (RI_{NDVI}) helps to predict the extent of response of present crop to added fertilizer N in that season and for that field.

Table.1 Average RI_{NDVI} and $RI_{HARVEST}$ computed at different crop growth stages in wheat

Treatments	Nitrogen application (kg/ha)*					RI_{NDVI}						$RI_{HARVEST}$	Grain yield (t/ha)
	Days after sowing				Total	Days after sowing							
	Basal	25	50	65		50	58	65	73	90	120		
T_1	75	75	0	0	150	1.07	1.08	1.08	1.10	1.18	1.13	2.81	6.32
T_2	50	50	50	0	150	1.12	1.09	1.07	1.08	1.15	1.09	2.93	6.57
T_3	25	50	34	0	109	1.25	1.26	1.17	1.19	1.19	1.16	2.46	5.53
T_4	25	50	0	36	111	1.22	1.26	1.26	1.26	1.22	1.16	2.33	5.24
T_5	25	50	33	31	139	1.24	1.21	1.21	1.13	1.18	1.12	2.94	6.60
T_6	25	75	29	0	129	1.20	1.18	1.16	1.14	1.18	1.12	2.52	5.66
T_7	25	75	0	33	133	1.15	1.20	1.23	1.21	1.21	1.13	2.41	5.42
T_8	25	75	28	23	151	1.19	1.17	1.15	1.12	1.16	1.11	2.58	5.80
T_9	50	75	20	0	145	1.13	1.11	1.10	1.10	1.15	1.16	2.55	5.74
T_{10}	50	75	0	28	153	1.12	1.16	1.19	1.17	1.16	1.09	2.53	5.68
T_{11}	50	75	19	18	162	1.12	1.11	1.11	1.09	1.11	1.14	2.88	6.46
T_{12}	Control (no nitrogen)					1.56	1.64	1.72	1.81	2.07	1.97	1.00	2.25
SEm±													0.10
$CD_{0.05}$													0.30

In treatments three to nine, N application at 50 DAS (2nd irrigation) and 65 DAS (3rd irrigation) was done using GreenSeeker (GS)

Fig.1 Effect of time and rate of GreenSeeker based N application on NDVI values of wheat

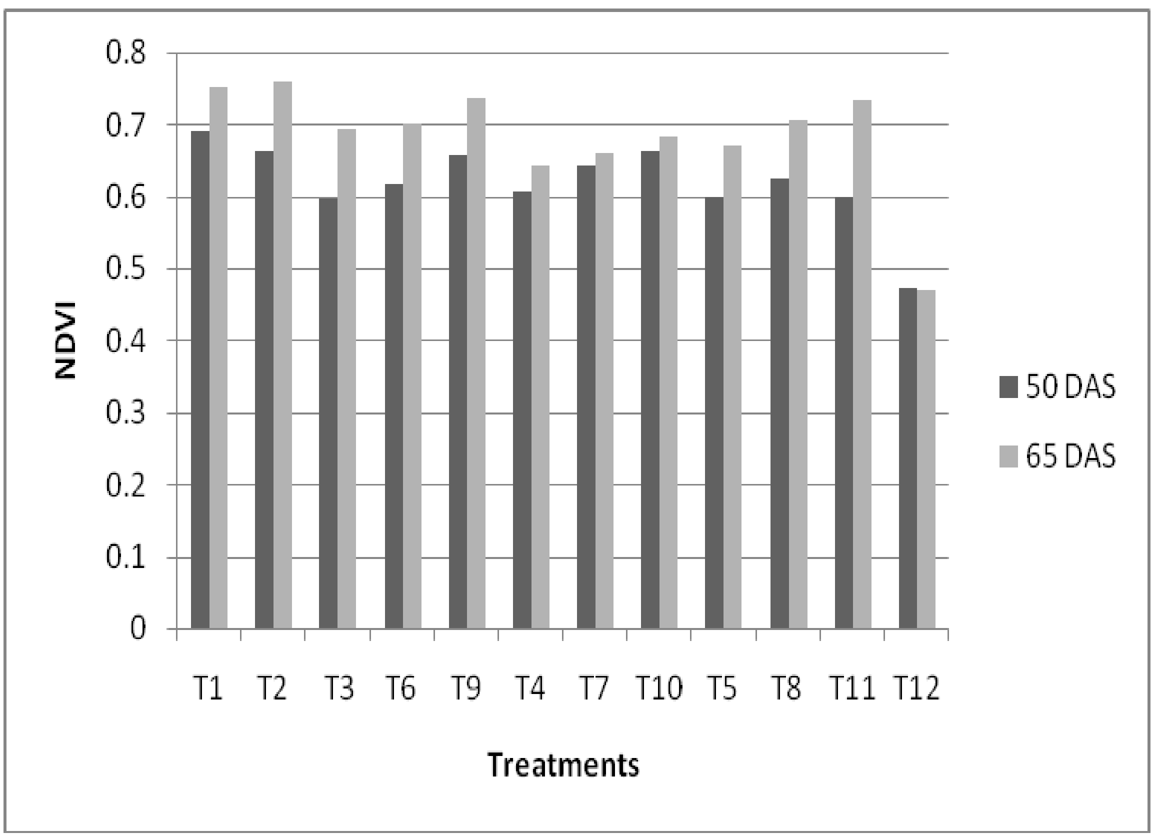


Fig.2 Relationship between RI_{NDVI} and $RI_{HARVEST}$ of wheat

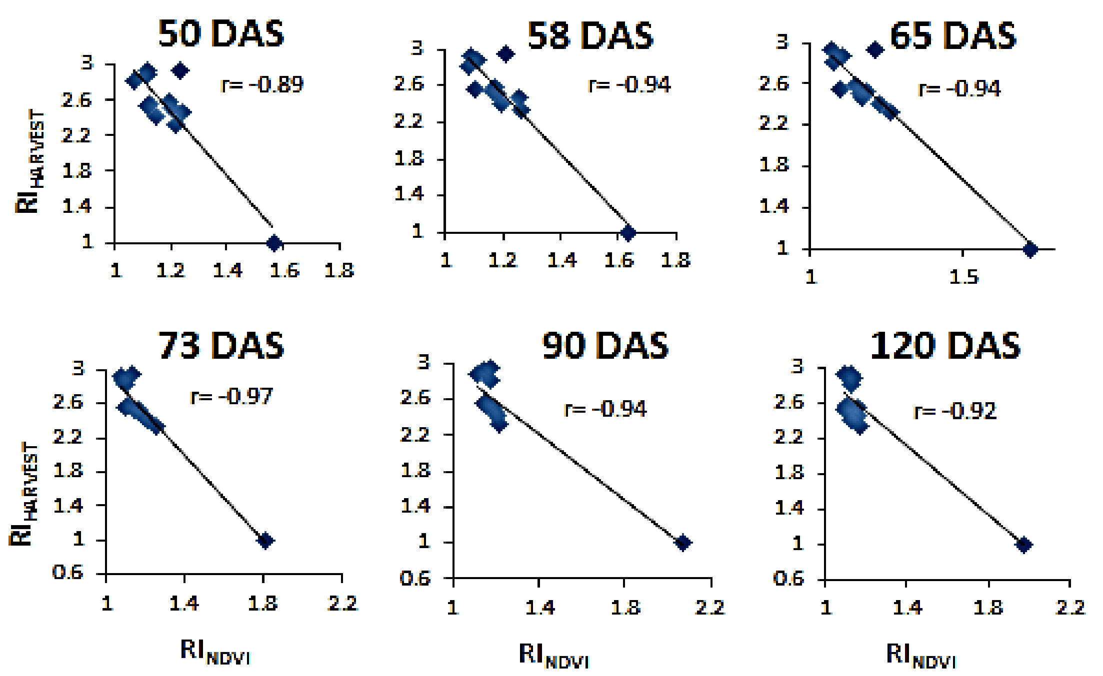
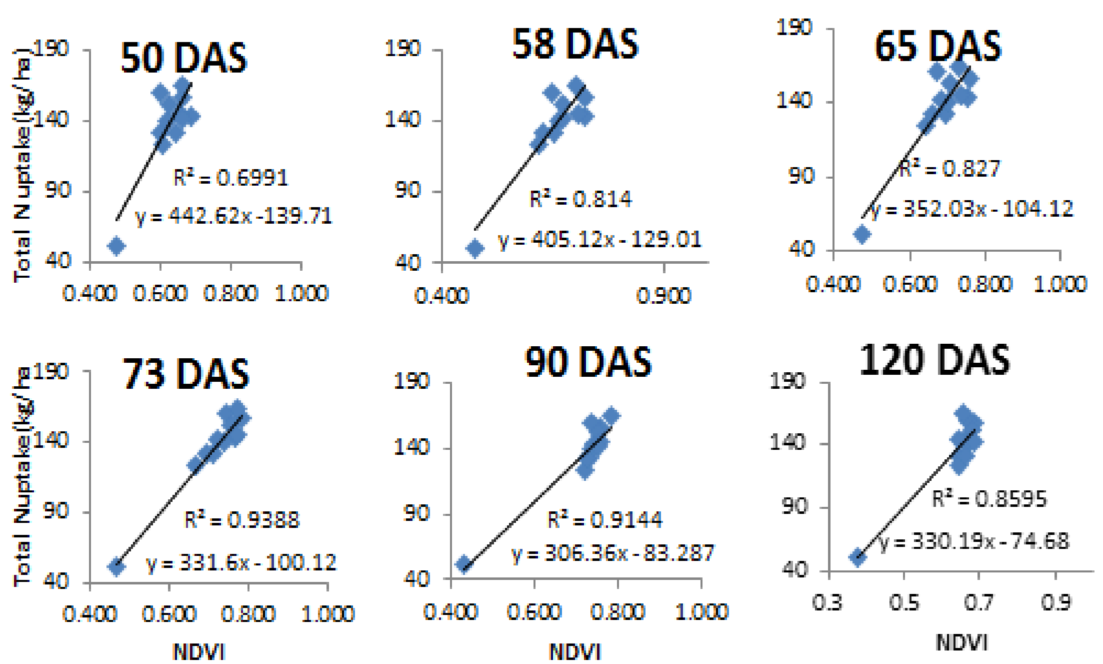


Fig.3 Relationship between wheat total N uptake and NDVI values



For example if the RI is 1.23, then 23% increase in yield is possible through N fertilisation. A thorough understanding of data on RI_{NDVI} reveals that it was affected by fixed rate N application at planting and 25 DAS (Table 1). Higher the fixed rate N application, lower was the RI_{NDVI} value. Raun *et al.,* (2002) also reported that no preplant N application resulted into higher RI values than that obtained with preplant N application.

However, from the detail of N application time and doses (Table 1) it can be comprehended that applying comparatively lower doses at early stages and thereafter applying N doses using response index is a powerful tool to decrease the total amount of N required without significantly sacrificing the grain yield. Among treatments having N application without using GS, RI_{NDVI} was lower in two split application initially i.e. at 50 DAS, as compared to three split application.

Thereafter, this pattern reversed as RI_{NDVI} values in two split applications continued to increase while in three split application RI_{NDVI} values decreased and reached at values < 1.1. This indicated that doses of 75 kg N/ha at planting and 25 DAS were in excess of crop needs and it was not efficiently utilized and subjected to leaching losses whereas small amount of N applied in more splits makes the crop sufficient in N status and crop doesn't need any additional fertilizer N. Pattern of change in RI_{NDVI} values with advancement of crop age varied as the time of N application varied.

Using NDVI values and RI_{NDVI} values, In-season estimation of yield (INSEY), yield potential without additional fertilizer (YP_0) and yield potential with fertilizer N (YP_N) were calculated to find out the fertilizer N requirement at 50 DAS and 65 DAS as per the procedure.

Relationship between RI_{NDVI} and $RI_{HARVEST}$

RI_{NDVI} values were plotted against actual response of crop to total N applied i.e. response index at harvest ($RI_{HARVEST}$) which was computed by dividing the mean grain yield of N applied test plot with mean grain yield of control plots (Fig. 2).

The values were significantly negatively correlated with $RI_{HARVEST}$. Lower correlation coefficient at 50 DAS means lower predictability of RI_{NDVI} about $RI_{HARVEST}$ at that stage. It also indicates N application at later stages i.e. at 2nd and 3rd irrigation also affected actual response of crop to N fertilizer i.e. $RI_{HARVEST}$.

Correlation coefficient increased, the maximum being at 73 DAS and thereafter, decreased. Lower values of correlation coefficient at later stages may be due to overestimation of RI_{NDVI} because crop in test plot tended to attain maturity faster than crop in N-rich strip and due to this NDVI in test plot lowered down. The results were found in confirmation with Mullen *et al.,* (2003).

Relationship between total N uptake and NDVI

Total N uptake (straw and grain) by wheat was plotted against NDVI at different crop growth stages using linear function (Fig. 3). The amount of N taken up in wheat was highly correlated with NDVI. The early and later stages showed less correlation than middle stages. Coefficient of determination increased from 50 DAS to 73 DAS and then decreased upto 120 DAS. Kaur (2007) also reported increased values of R^2 from 49 to 80 DAS. Hence potential yield levels with GreenSeeker optical sensor can be estimated during the crop growth stage from 65 to 90 DAS.

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