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Effect of optical sensor based N management on yield, quality and energetics of irrigated wheat (*Triticum aestivum*)

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Wheat (*Triticum aestivum* L.) is the most important cereal crop for the majority of world's populations. It is the most important staple food of about two billion people (36% of the world population). In India, it is grown on 30.21 m ha mainly confined to north-western plain zone with production and productivity of 94.88 mt and 3.1 tonnes/ha, respectively (Anonymous 2014). Globally, India occupies second place in production and area under wheat cultivation but its productivity is much lower as compared to developed countries. Nitrogen is one of the most important nutrient element limiting crop's growth and development particularly in intensive cereal-based cropping systems. Excess nitrogen is applied by the farmers without giving due consideration to actual crop demand to avoid risk of N deficiency (Singh *et al.* 2012). Blanket N recommendations for a vast area, have served the purpose very well but could not help in increasing the nutrient use efficiency beyond a limit (Bijay-Singh 2008). Precision N management including real time corrective N management using leaf and canopy characteristics is a new approach. Use of remotely sensed indices like NDVI (Normalized Difference Vegetative Index) is emerging as a potential tool for efficient N management using the geo-optical sensors by measuring canopy reflectance in red and near-infrared (NIR) bands of wavelength (Raun *et al.* 2005). In the present investigation GreenSeeker® hand held optical sensor was used to determine fertiliser N requirement at 2nd and/or 3rd irrigation in combination with fixed doses of N at fixed time, i.e. at planting and 1st irrigation when crop is too young to use canopy reflectance for assessing crop N requirement.

The field experiment was carried out at the Agronomy Research Farm of CCS Haryana Agricultural University, Hisar located at latitude of 29°10' N and longitude of 75º46' E during the winter (*rabi*) season of 2013-14. The soil was sandy loam soil of inceptisol order with pH 8.3, low in available nitrogen (135 kg/ha), medium in available phosphorus (16 kg/ha) and high in available potash (351 kg/ha). The experiment was laid out in randomized block design with three replications. There were 12 treatments comprising N application with and without using GreenSeeker taking one treatment as absolute unfertilized control (Table 1). Need based GreenSeeker guided N application was done in addition to differential rate of N application at 75, 100 and 125 kg N/ha at 2nd (50 DAS) and/or 3rd irrigation (65 DAS) as described in T_3-T_{11} treatments. GreenSeeker® optical sensor was used with each fixed level of N application at 2nd (50 DAS) and/or 3rd irrigation (65 DAS). Nitrogen fertilizer optimization algorithm, i.e. procedure for calculating fertilizer N requirement by crop using NDVI described by Bijay-Singh *et al.* (2011) was used. Relationship between grain yield and In-season estimation of yield (INSEY) based on NDVI values were taken from Bijay-Singh *et al*. (2011). Phosphorous and potash were drilled uniformly @ 60 and 40 kg/ha, respectively. Wheat variety WH 711 was sown on 19 November 2013 using 125 kg seed/ha with a row-to-row spacing of 20 cm and was harvested on 24 April, 2014. To fulfil the crop water requirement, a total of four irrigations were applied at 18, 42, 58 and 91 DAS. All other cultural practices were followed as per the crop requirement following state recommendations. The data on growth (plant height, above ground dry matter accumulation) and yield attributes (effective tillers/mrl, spike length, grains/ear and 1000 grain weight) were recorded at harvest. Plot-wise data on grain and straw yield were recorded manually by harvesting and threshing the produce of net plot which later on converted into tonnes/ha. The data on quality parameters, viz. N content, hecto liter weight, sedimentation value and grain appearance score were recorded following statndard procedure. N use efficiency was calculated as given below:

$$\text{NUE (kg grain/kg N applied)} = \frac{\text{Grain yield in N fertilized plot} - \text{Grain yield in zero –N plot}}{\text{Quantity of N fertilizer applied}}$$

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Table 1 Effect of time and rate of GreenSeeker based N application on growth, yield attributes and yield of wheat

Treatment	N application (kg/ha)		Height (cm)	Dry matter (g)	Effective tillers/mrl (No.)	Grains/ spike (No.)	1000-grain weight (g)	Grain yield (tonnes/ ha)	Straw yield (tonnes/ ha)
	Split doses	Total							
T_1	75-75-0-0	150	85.3	339.2	106.3	46.2	43.1	6.32	8.27
T_2	50-50-50-0	150	91.4	342.7	110.4	46.3	43.5	6.57	8.45
T_3	25-50-34*-0	109	87.2	324.8	99.8	44.7	41.0	5.53	7.29
T_4	25-50-0-36**	111	84.2	307.1	96.5	44.1	40.9	5.24	6.71
T_5	25-50-33*-31**	139	90.1	330.9	112.5	46.5	43.9	6.60	7.82
T_6	25-75-29*-0	129	89.1	334.9	100.4	45.2	42.1	5.66	7.31
T_7	25-75-0-33**	133	87.3	318.1	98.1	44.8	41.3	5.42	6.79
T_8	25-75-28*-23**	151	91.0	342.5	101.2	45.1	42.8	5.80	7.72
T_9	50-75-20*-0	145	89.1	352.8	102.3	46.2	42.5	5.74	7.52
T_{10}	50-75-0-28**	153	88.7	336.0	101.0	45.0	42.5	5.68	7.06
T_{11}	50-75-19*-18**	162	90.8	360.2	108.0	46.4	43.2	6.46	8.00
T_{12}	Control	0	67.2	235.2	74.1	39.7	39.3	2.25	3.29
CD (P=0.05)			7.0	22.8	7.0	2.0	1.8	0.31	0.75

* Indicates GreenSeeker guided N application at 2nd irrigation. ** Indicates GreenSeeker guided N application at 3rd irrigation.

Energy input was calculated as the summation of energy requirement for human, diesel, seed, herbicide, and chemical fertilizers used for crop production. For calculating energy output main product and by-product were converted into energy equivalents (MJ/ha) by using conversion factors (Devsenapathy *et al*. 2009). The formulae for calculating energy use efficiency are given below:

Energy use efficiency = $\sum_{i=1}^{n}$ (EU ÷ EI); (Datta *et al*. 2014)

Energy – output efficiency (MJ/ha/day)= $\frac{EU}{\text{Duration of system}}$; (Singh and Kumar 2014)

Specific energy (MJ/kg) = $\sum_{i=1}^{n}$ (EU ÷ EI); (Datta *et al*. 2014)

Energy productivity (kg/MJ) = $\sum_{i=1}^{n}$ (GY ÷ EI); (Datta *et al*. 2014)

Net energy (MJ/ha) = $\sum_{i=1}^{n}$ (EU ÷ EI); (Datta *et al*. 2014)

where, EU is energy output (MJ/ha); EI is energy input (MJ/ha); GY is grain yield (kg/ha) and duration of system is time taken to days from sowing to harvesting.

In general, yield components, viz. no. of effective tillers/ mrl, grains/spike, 1000-grain weight increased by 0.6 to 6.7%, 0.7 to 2.9% and 1.0 to 2.9%, respectively, with each successive increase in N dose by 25 kg/ha while comparing 75/100/125 kg N/ha, irrespective of number and doses of GS guided N application (Table 1). Increased N application at sowing and 25 DAS fulfilled the nutritional requirement at early stage of crop growth reflecting in taller plants and more dry matter accumulation, higher translocation of photosynthates which ultimately resulted in increase in yield. Positive association of fertilizer N application with photosynthetic efficiency, source-sink ratio and yield parameters have been reported by Patra (1990).

Application of 75 kg N/ha coupled with GS guided N application at 2nd and 3rd irrigation (T_5) produced highest wheat yield (6.60 tonnes/ha) though it was at par with treatments receiving recommended N (150 kg N/ha) in two (T_1) or three (T_2) splits and treatment having 125 kg N/ha as fixed rate coupled with GS guided N application at two stages, i.e. 2nd and 3rd irrigation (Table 1). This may be due to the fact that GS guided N doses applied at later stages, i.e. 2nd and 3rd irrigation were higher in this treatment which led to enhanced yield attributing characters and eventually the higher yield. Relatively higher doses of need based N application at both of the later stages, i.e. 2nd and 3rd irrigation and moderate doses at earlier stages ensured the N availability more uniformly as compared to corresponding treatments where higher doses of differential N and lower doses of need based N caused imbalance in N availability throughout the crop duration. Kaur *et al*. (2010) also reported that application of moderate N doses at early growth stages and replacing the same at later stages proved superior in yield attributing characters and yield, respectively as compared to other treatments.

Yield increase ranged from 0.4 to 1.4 tonnes/ha and 0.2 to 1.1 tonnes/ha respectively when treatments having single stage GS guided N at 3rd and 2nd irrigation were compared with two stage GS guided N treatment. Wagan *et al*. (2002) also reported better yield advantage with three split N application as compared to two applications. It was interesting to note that corresponding decrease in wheat yields was 0.83% to 4.3% more when N application was skipped at 2nd irrigation as compared to N application skipped at 3rd irrigation.

Highest sedimentation value (36.7) was recorded

Table 2 Effect of time and rate of GreenSeeker based N application on quality parameters and protein yield of wheat

Treatment	N application (kg/ha)		Sedimentation value (ml)	Hectolitre weight (kg/hl)	Grain appearance score (0-10)	Protein content (%)	Protein yield (kg/ha)	NUE (kg grain/kg N applied)
	Split doses	Total						
T_1	75-75-0-0	150	35	81	6	11	683	27
T_2	50-50-50-0	150	36	80	6	11	731	29
T_3	25-50-34*-0	109	34	79	6	11	613	30
T_4	25-50-0-36**	111	33	78	6	11	593	27
T_5	25-50-33*-31**	139	36	80	6	12	767	31
T_6	25-75-29*-0	129	35	80	6	11	648	26
T_7	25-75-0-33**	133	34	79	6	12	633	24
T_8	25-75-28*-23**	151	37	80	7	12	707	24
T_9	50-75-20*-0	145	36	80	6	12	680	24
T_{10}	50-75-0-28**	153	35	79	6	12	677	22
T_{11}	50-75-19*-18**	162	37	81	7	12	780	26
T_{12}	Control	0	32	76	6	11	239	27
CD (P=0.05)			2	NS	0.2	NS	72	2

* Indicates GreenSeeker guided N application at 2nd irrigation. ** Indicates GreenSeeker guided N application at 3rd irrigation.

when 100 (T_8) and 125 kg N/ha (T_{11}) in 2 splits was supplemented with GS guided N application at 2nd and 3rd irrigation , whereas, application of 150 kg N/ha in two or three equal splits proved statistically at par with these treatments (Table 2). In general, N application at later stages (2nd and/or 3rd irrigation) proved better in grain appearance than recommended schedule. The minimum sedimentation value (31.7) and grain appearance score (6.0) was observed in unfertilized control (T_{12}) and when 75 kg N/ha as fixed dose was combined with GS guided N application at 2nd irrigation. So it is obvious that there was combined effect of total N dose and time of N application. Uppal *et al.* (2002) found that the increasing level and delayed application of nitrogen improved different grain quality parameters including sedimentation value. Highest value of NUE (31 kg grain/kg N applied) was recorded in T_5 treatment and it was significantly superior to rest of the treatments. NUE values were higher with 2nd irrigation applied N (24 to 30 kg grain/kg N) using GS than 3rd irrigation applied N (22-27 kg grain/kg N) using GS at all the fixed rates of N. These results corroborated with Bijay-Singh *et al.* (2011).

Protein yield was 7.05% higher with N application (150 kg/ha) in three equal splits (T_2) than that in two equal splits. Irrespective of the level of fixed rate N application, GS guided N application at two stages was significantly

Table 3 Effect of GreenSeeker based N management on energetics and economics of wheat

Treatment	N application (kg/ha)	Energy input (×10³ MJ/ha)	Energy output (×10³ MJ/ha)	Net energy (×10³ MJ/ha)	Energy-use efficiency	Energy-output efficiency (MJ/ha/day)	Energy productivity (kg/J)	Specific energy (MJ/kg)	Net returns (₹/ha)	B:C ratio
T_1	75-75-0-0	15.3	196.3	181.0	12.8	1.25	0.41	2.42	62486	2.37
T_2	50-50-50-0	15.3	202.2	186.9	13.2	1.29	0.43	2.33	65702	2.43
T_3	25-50-34*-0	12.8	172.5	159.6	13.4	1.10	0.43	2.32	51584	2.14
T_4	25-50-0-36**	13.0	161.0	148.0	12.4	1.03	0.40	2.48	47565	2.05
T_5	25-50-33*-31**	14.7	194.8	180.1	13.2	1.24	0.45	2.23	65977	2.44
T_6	25-75-29*-0	14.1	174.6	160.5	12.4	1.11	0.40	2.49	53119	2.17
T_7	25-75-0-33**	14.3	164.6	150.3	11.5	1.05	0.38	2.64	49760	2.09
T_8	25-75-28*-23**	15.4	181.9	166.4	11.8	1.16	0.38	2.66	54639	2.19
T_9	50-75-20*-0	15.0	178.3	163.3	11.9	1.14	0.38	2.62	54055	2.18
T_{10}	50-75-0-28**	15.5	171.8	156.2	11.1	1.09	0.37	2.73	53203	2.16
T_{11}	50-75-19*-18**	16.1	195.0	178.9	12.1	1.24	0.40	2.49	63766	2.38
T_{12}	Control	6.2	74.2	68.0	12.0	0.47	0.36	2.75	7711	1.18

* Indicates GreenSeeker guided N application at 2nd irrigation. ** Indicates GreenSeeker guided N application at 3rd irrigation.

superior in protein yield over other treatments having single stage GS guided N application either at 2nd or 3rd irrigation. Supplemental N application at later stages in treatments receiving GS applied N resulted into higher grain protein content as well as higher grain yield. Krishnakumari *et al*. (2000) and Uppal *et al*. (2002) also reported importance of later application of N in improving the grain quality parameters.

The data presented in Table 3 revealed that there is added advantage in terms of energy input, output and net energy when supplemental N application through GS was done at 3rd irrigation in comparison to its application at 2nd irrigation (Table 3). Energy input was same but energy output, net energy; energy use efficiency, energy output efficiency and energy productivity were slightly higher in three split application of recommended dose as compared to two split application. Energy use efficiency decreased with increase N application (fixed rate + GS guided N) while reverse trend was observed for energy output efficiency. At the same level of fixed N the values of energy output efficiency was higher when fixed rate N application was coupled with GS guided N at 2nd and 3rd irrigation. Energy productivity was highest in T_5 (0.45 kg/MJ) followed by T_2 and T_3 treatments. In contrast to other energy parameters, energy productivity generally decreased as the dose of fixed N application was increased.

Highest net returns (₹ 65 977/ha) and B:C ratio (2.44) was recorded with application of total N @ 139 kg/ha into four splits (25-75-33-31 kg/ha). Net returns were lowest when GS guided N application was skipped at 2nd irrigation, There was decrease in B:C ratio by 4.2, 3.6 and 0.6% due to N application using GS at 3rd irrigation as compared to that at 2nd irrigation in treatments having 75, 100 and 125 kg N/ha as fixed initial doses, respectively. Net returns and B:C ratio also showed increasing trend with increasing the fixed doses of N at early stages. Jat *et al*. (2014) reported increase in net returns and B: C ratio with increased N application.

SUMMARY

Growth parameters increased with increase in level of fixed rate N application, whereas, within the same level of N application growth parameters significantly improved in two stage GS guided N application. Yield attributes as well as yield, improved significantly with increase in level of fixed rate N application. The highest yield as well as N use efficiency was recorded in treatment having fixed dose of 75 kg N/ha (25 kg/ha as basal + 50 kg/ha at 25 DAS) combined with GS guided N application both at 2nd and 3rd irrigation stages, i.e. 33 kg/ha and 31 kg/ha, respectively. This treatment also led to highest B:C ratio and energy use efficiency closely followed by three split application of recommended dose.

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