Optical Sensor-based Nitrogen Management for Irrigated Wheat in the Indo-Gangetic Plains

By Bijay-Singh, R.K. Sharma, Jaspreet-Kaur, M.L. Jat, K.L. Martin, Yadvinder-Singh, Varinderpal-Singh, H.S. Thind, H.S. Khurana, M. Vashistha, W.R. Raun, and R. Gupta

Robust relationships were observed between in-season GreenSeeker™ optical sensor-based estimates of yield at Feekes 5-6 and 7-8 growth stages and actual wheat yields. Sensor-guided fertilizer N applications resulted in high yield levels and high N use efficiency. Application of 90 kg N/ha at planting, or in two equal doses at planting and crown root initiation stage, were appropriate prescriptive fertilizer N management options before applying a corrective GreenSeeker™ guided fertilizer N dose for the Indo-Gangetic Plains (IGP) in northwest India.

In the IGP in northwestern India, wheat is generally grown under assured irrigation conditions and with a standard fertilizer recommendation (120 kg N/ha in the state of Punjab and 150 kg N/ha in Haryana and Uttar Pradesh) applied in two equal split rates at planting and at crown root initiation stages. The second application coincides with a first irrigation event around 21 days after planting. To achieve high fertilizer use efficiency, prescriptive N applications at planting and crown root initiation stage (or first irrigation) can be moderately reduced provided the N needs of the crop are considered for the entire season. This can be done by considering field-to-field and temporal variability using a suitable criterion to apply a corrective fertilizer dose. These subsequent applications usually coincide with a second or third irrigation event. Therefore, the major objective of the present study was to evaluate optical sensor-based N management in irrigated wheat compared to the standard fertilizer N recommendations in the IGP. Different combinations of prescriptive and corrective N management scenarios were evaluated to compare a more objective basis for N management in wheat.

Demonstration of GreenSeeker™ optical sensor technology on-farm with lead author on the left.

Materials and Methods

Field experiments were conducted in three wheat seasons (2004 to 2005 and 2006 to 2007) at Ludhiana (30°56'N, 75°52'E), Karnal (29°42'N, 77°02'E), and Modipurm (29°40'N, 77°46'E). The three sites have subtropical climates. Soils were mildly alkaline loamy sands (Typic Ustipsamment) at the Punjab Agricultural University farm, Ludhiana; mildly alkaline sandy loam (Typic Ustochrept) at the Directorate of Wheat Research farm, Karnal; and alkaline sandy loams (Typic Ustochrept) at the farms of Project Directorate for Cropping Systems Research, Modipuram.

The treatments consisted either of application of fertilizer N as urea at 60, 120, 180, and 240 kg N/ha during planting, or 60, 120, and 180 kg N/ha applied in two equal split doses, one at planting and one at crown root initiation stage, which occured around 21 days after planting and coincided with the first irrigation. A zero N control plot was also included. During the 2004 to 2005 wheat season, two on-going field experiments at Ludhiana and one on-going experiment at Karnal were used to generate data to develop relationships for in-season estimation of wheat yields. In these experiments, two equal doses of urea, varying from 0 to 90 kg N/ha, were applied at planting and crown root initiation. During 2006 to 2007 at Ludhiana, two experiments were conducted under zero-till; one with rice straw mulch and the other without mulch. All field experiments were laid out in a randomized complete block design with three or four replications.

Spectral reflectance, expressed as NDVI, was measured using a handheld GreenSeeker™ optical sensor unit (NTech Industries Incorporation, Ukiah, CA, USA). In-season estimated yield proposed by Raun et al. (2002) was calculated by dividing NDVI data by the number of growing degree days (GDD) > 0. The yield potential with no additional fertilization (YP_0) was calculated using an empirically-derived function relating in-season estimated yield to yield potential. In all experiments, an N-rich strip was established by applying 200 kg N/ha in split applications to ensure that N was not limiting. The NDVI measurements from the N-rich strip ($NDVI_{NRICH}$) and the test plots ($NDVI_{TEST}$) were used to calculate the response index (RI) to fertilizer N (Johnson and Raun, 2003) and then the appropriate fertilizer N application.

Grain and straw subsamples were collected for analysis of total N. The data generated from the calibration experiments

Common abbreviations and notes: N = nitrogen; GDD = growing degree days; YP_0 = yield potential with no added fertilization; YP_N = yield potential with additional fertilizer N; NDVI = normalized difference vegetation index; RI = response index.

were used to fit relationships between in-season estimated yield and YP_0.

Predicting Yield Potential of Wheat from In-season Optical Sensor Measurements

The relationship between grain yield and in-season estimated yield was plotted from data generated from Karnal, Ludhiana, and Modipurum for both the Feekes 5 to 6 and Feekes 7 to 8 growth stages (**Figure 1**). With wheat planting dates ranging from the 2nd to 23rd of November, and sensing dates ranging from the 2nd to 23rd of January, a value of R^2 as high as 0.61 suggest that wheat yields can be predicted fairly accurately as early as the Feekes 5 to 6 growth stagewhen the first node appears on the wheat plant and the second irrigation becomes due. This relationship was even more robust (R^2 = 0.76) at Feekes 7 to 8 when more data became available from the field trials. At Feekes 7 to 8, the wheat crop requires irrigation once again and an application of fertilizer can also be applied along with this water.

Differences from yield prediction equations formulated using the data collected for the three wheat-growing seasons were not substantial.

Estimating Fertilizer N Application Using an Optical Sensor for Correcting In-season N Deficiency

Using YP_N and YP_0, the amount of additional N fertilizer required was determined by taking the difference in estimated N uptake between YP_N and YP_0 and an efficiency factor (Raun et al., 2002). Prescriptive N management in the form of applying different amounts of fertilizer N at planting and the crown root initiation stage of wheat, and whether optical sensor-based N management was practiced at either Feekes 5 to 6 or Feekes 7 to 8 greatly influenced the amount of fertilizer N to be applied following the N fertilizer optimization algorithm (**Table 1**).

In general, the amount of sensor-guided N to be applied at Feekes 5 to 6 was less than that determined for Feekes 7 to 8. For similar prescriptive applications of fertilizer N at planting and the crown root initiation stage, higher optical sensor-guided fertilizer N rates at Feekes 7 to 8 were due to higher RI values recorded at this stage. Also, when only 60 or 80 kg N/ha was applied at planting, and no N was applied at crown root initiation stage, optical sensor-guided recommendations were underestimated. Thus total fertilizer N applications in these treatments were less than in treatments with 100 kg N/ha or more, applied either all at planting or in two split amounts. This was possibly because at low prescriptive N levels, YP_0 is low and the associated RI value is not proportionately high. Since the fertilizer N rate is calculated from the difference of YP_N and YP_0, the total fertilizer recommendation (prescriptive + optical sensor-based) remained low relative to a treatment receiving an adequate prescriptive rate of fertilizer N.

Evaluation of GreenSeeker™ Guided N Management Versus Blanket Recommendations

Increased fertilizer N use efficiency at optimum yield levels was observed due to lower rates of total N application compared with blanket recommendations when appropriate prescriptive fertilizer N applications strategies were combined with a GreenSeeker™ optical sensor-guided fertilizer N application (**Table 1**). However, this reduction in total N application cannot be used as a clue for formulating another blanket recommendation consisting of moderate amounts of N at planting, the first irrigation stages, and a small dose of N during the Feekes 5 to 8 growth stages.

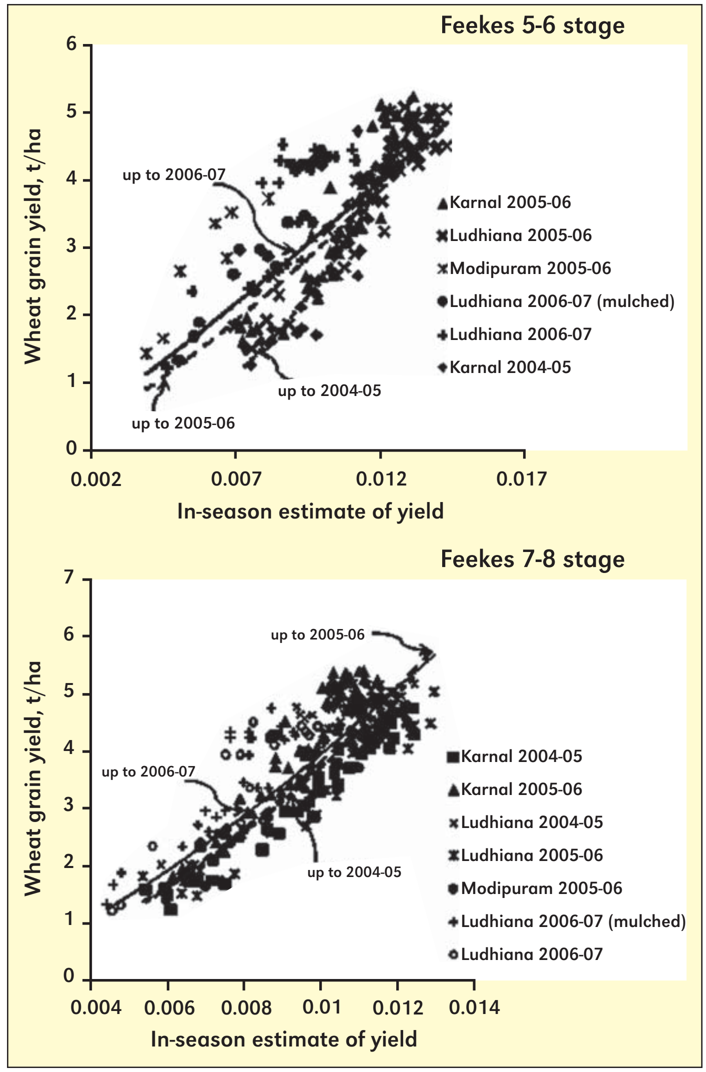

Figure 1. Relationship between in-season estimate of yield and potential grain yield of irrigated wheat at Feekes 5 to 6 and 7 to 8 stages. For Feekes 5 to 6 stage, R^2=0.90 (up to 2004 to 2005), 0.66 (up to 2005 to 2006), and 0.61 (up to 2006 to 2007). Relationship between in-season estimated yield (x) and potential yield (y) up to 2006 to 2007: $y=602.47x^{1.1348}$. For Feekes 7 to 8 stage, R^2=0.84 (up to 2004 to 2005), 0.83 (up to 2005 to 2006), and 0.76 (up to 2006 to 2007). Relationship between in-season estimated yield (x) and potential yield (y) up to 2006 to 2007: $y=2581x^{1.4072}$

Corrective N application determined by use of the GreenSeeker™ optical sensor and grain yield revealed that for different variants of moderate prescriptive N application, the corrective N application to obtain high yield levels was influenced by the timing of the prescriptive N amounts as well as the timing of the corrective N amounts. Thus, a combination of moderate prescriptive fertilizer N consisting of either 90 kg N/ha at planting, or 45 to 50 kg N/ha both at planting and at the crown root initiation stages, and a corrective GreenSeeker™-guided fertilizer N application at the 2nd or 3rd irrigation events can lead to improved fertilizer N use efficiency with no reduction

Table 1. Evaluation of GreenSeeker™-based N management in wheat (cultivar PBW 343) at Ludhiana, India during 2005-06.

Treatment	Fertilizer N application, kg N/ha: Basal sowing	CRI[¥] 1st irrigation	Feekes 5 to 6 2nd irrigation	Feekes 7 to 8 3rd irrigation	Total	YP_0[‡], t/ha	RI[§]	Grain yield, t/ha	Total N uptake, kg/ha	AE[†]	RE[¶]	PE[#]
1	0	0	-	-	0			1.52	31.9	-	-	-
2	60	60	-	-	120			4.35	103.2	23.6	59.2	39.9
3	75	75	-	-	150			4.41	110.3	19.3	52.3	37.1
4	60	0	17 *	-	77	3.25	1.16	3.66	73.1	27.8	53.2	52.2
5	80	0	12 *	-	92	3.52	1.11	3.80	87.8	24.8	60.9	40.7
6	100	0	10 *	-	110	3.61	1.09	4.20	95.2	24.4	57.3	42.5
7	40	40	3 *	-	83	4.02	1.02	3.81	88.5	27.6	68.1	40.6
8	50	50	0 *	-	100	4.30	0.98	4.32	98.8	28.0	67.0	41.8
9	60	60	0 *	-	120	4.20	0.99	4.39	105.4	23.9	61.3	39.3
10	60	0	-	29 *	89	2.98	1.30	3.99	94.2	27.8	69.7	39.4
11	80	0	-	24 *	104	3.24	1.24	4.13	97.6	25.1	63.5	40.5
12	100	0	-	21 *	121	3.43	1.19	4.29	102.4	22.9	58.3	39.2
13	40	40	-	18 *	98	3.62	1.15	4.27	100.5	28.1	70.0	39.9
14	50	50	-	12 *	112	3.84	1.10	4.35	108.5	25.3	68.4	36.8
15	60	60	-	15 *	135	3.77	1.12	4.40	115.2	21.3	61.5	34.7
LSD ($p = 0.05$)								0.37	11.04	3.03	9.52	4.41

*GreenSeeker™ guided N application; [¥]Crown root initiation stage; [†]AE: Agronomic efficiency of applied N (kg grain/kg N applied); [¶]RE: Recovery efficiency of applied N (%); [#]PE: Physiological efficiency (kg grain/kg N uptake); [‡]YP_0: Yield potential with no additional fertilizer N applied; [§]RI: Response index, RI_{NDVI}.

in yield. This strategy saved total fertilizer N application if compared with the prevalent blanket recommendations. BC

Dr. Bijay-Singh, Dr. Jaspreet-Kaur, Dr. Yadvinder-Singh, Dr. Varinderpal-Singh, Dr. H.S. Thind, and Dr. M. Vashistha are with the Department of Soil Science, Punjab Agricultural University, Ludhiana, India. e-mail: bijaysingh20@hotmail.com, Dr. R.K. Sharma is with the Directorate of Wheat Research, Karnal, India, Dr. Raj Gupta and Dr. M.L. Jat are with CIMMYT-India, New Delhi, India, Dr. K.L. Martin is with Southwest Area Extension, Kansas State University, Garden City, KS, USA, Dr. H.S. Khurana is International Agronomic and Technical Support Specialist, Saskatoon, SK, Dr. W.R. Raun is with the Department of Plant and Soil Sciences, Oklahoma State University, Stillwater, OK, USA.

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