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A framework for refining nitrogen management in dry direct-seeded rice using GreenSeeker™ optical sensor

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ABSTRACT

To reduce the amount of wasted reactive nitrogen (N) reaching the environment and to achieve high N fertilizer use efficiency, a site-specific N management strategy using GreenSeeker™ optical sensor (GS) was evaluated in dry direct-seeded rice (DDSR) in the north-western India. Four field experiments were conducted during 2011–2013 to develop an optical sensor algorithm for fine tuning in-season N fertilizer applications. It was demonstrated that panicle initiation of rice is the appropriate stage for applying GS guided N fertilizer dose. Application of a prescriptive dose of 60 kg N ha^{-1} in two or 90 kg N ha^{-1} in two or three equal split doses, followed by a corrective N dose guided by GS at panicle initiation stage resulted in rice yield levels comparable to that obtained by following general recommendation, but with lower total N fertilizer application. On an average, N use efficiency was improved by more than 12% when N fertilizer management was guided by GS as compared to when general N fertilizer recommendation was followed. The results prove the inadequacy of general recommendations for N fertilizer management in DDSR and possibility of increasing N use efficiency along with high rice yield levels through site-specific N fertilizer management using GS.

1. Introduction

In the Indo-Gangetic plain of South Asia, nitrogen (N) fertilizer in rice is generally managed following a general recommendation over large areas. To ensure high crop yields, farmers often apply doses of N fertilizer higher than the general recommendation. As recovery efficiency of applied N fertilizer in rice at on-farm locations rarely exceeds 30% (Bijay-Singh et al., 2001; Ladha et al., 2005), a large amount of N is lost from the soil–plant system. One of the major factors contributing to low N use efficiency is the uniform application rates of N fertilizer to spatially variable landscapes. Uniform applications within fields discount the fact that N supplies from the soil, crop N uptake, and responses to N are different spatially (Inman et al., 2005). Efficient use of N fertilizer is restricted due to large temporal and field-to-field variability when broad-based general recommendations are used (Adhikari et al., 1999; Dobermann et al., 2003; Varinderpal-Singh et al., 2010).

In recent years, a shift from transplanted rice to direct-seeded rice (DSR) has initiated in several countries of South and Southeast Asia (Kumar and Ladha, 2011). Besides higher economic returns, DSR is easy to plant, less labour intensive, consumes less water (Bhushan et al., 2007), conducive to mechanization (Khade et al., 1993) and emits less methane (Ko and Kang, 2000; Bhatia et al., 2012). Dry seeding of rice and subsequent dry soil conditions avoid water application of water for puddling and maintenance of submerged soil conditions, and thus reduces the overall water demand (Sharma et al., 2002; Sudhir-Yadav et al., 2011). However, loss of N due to denitrification, volatilization and leaching is likely to be higher in dry DSR (DDSR) than in the transplanted rice (Singh and Singh, 1988; Davidson, 1991). Generally, low rice yields have been demonstrated to be mainly due to insufficient N uptake (Kropff et al., 1993).

GreenSeeker™ optical sensor (GS) is emerging as tool for site-specific need based N fertilizer management in cereals. It uses normalized difference vegetation index (NDVI) based on reflectance of radiation in the red and near infrared bands. Raun et al. (2001) found that the relationship between NDVI and grain yield of winter wheat was the highest between growth stages Feekes 4 and 6. Raun et al. (2002) developed an algorithm that can estimate midseason N requirement of winter wheat. Their work has shown that the N use efficiency of winter wheat was improved by more

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than 15% when this approach was employed compared with conventional N rate recommendations. Raun et al. (2005) further refined the N application algorithm using the coefficient of variation from NDVI readings. Bijay-Singh et al. (2011) observed that high N use efficiency in irrigated wheat grown in Northwest India can be achieved by replacing general fertilizer recommendation by an optical sensor based N management strategy.

A considerable amount of research is required before producers in South Asia, and elsewhere, will be able to use optical sensors in different crops. Algorithms for applying N fertilizer to DDSR need to be developed under local environmental conditions. The objective of this study was to develop an optical sensor algorithm that can be used to translate GS optical sensor readings into appropriate in-season N applications to ensure high DDSR yields as well as N fertilizer use efficiency as compared to general recommendations.

2. Materials and methods

2.1. Experimental sites

Field experiments with DDSR were conducted during three consecutive years (2011, 2012 and 2013) on a Typic Ustipsamment (Fatehpur loamy sand) soil at the research farm of the Punjab Agricultural University, Ludhiana (30° 56′ N, 75° 52′ E), located in the northwestern India. The climate of Ludhiana is subtropical with annual rainfall of 730 mm $year^{-1}$, about 80% of which occurs from June to September. The mean monthly temperatures during the rice seasons range between 23.4 and 37.4 °C. Initial soil samples collected from each experiment were mixed, air dried, sieved, and analyzed for physical and chemical characteristics (Table 1).

2.2. Treatment details in different experiments

Two categories of experiments were established. The experiments in 2011 and 2012 were designed to understand the relation between N uptake, grain yield and NDVI in rice cultivar PR114. In the experiment conducted in 2011 season, along with a no-N control, urea N levels of 120, 150 and 180 kg N ha^{-1} were applied either at 0, 35 and 63 days after sowing (DAS) or 14, 35 and 63 DAS in three equal split doses and at 0, 28, 49 and 70 or 14, 28, 49 and 70 DAS in four equal split doses in PR114 cultivar. In the 2012 experiment, 0, 60, 90, 120, 150, 180, 210 and 240 kg N ha^{-1} were applied as urea in four (14, 28, 49, 70 DAS) equal split doses. The purpose of applying a range N fertilizer rate was to establish plots with different yield potentials. In the second category, the experiments were conducted in 2013 season with two rice cultivars PR114 and PR115. These experiments aimed at validating the established sensor algorithms. Sensor-based N management treatments were tested to determine N fertilizer application at 60 DAS for PR115 (shorter duration cultivar) and at 70 DAS for PR114 (medium duration cultivar) when different doses of N were applied as prescriptive N management (Tables 2 and 3). These timings coincided with panicle initiation growth stage, which was selected as the appropriate stage to apply N fertilizer doses guided by optical sensor. In all the four experiments, the treatment plots were arranged in a randomized complete block design with three replications. Also, in each experiment, an N-rich strip was established by applying 200 kg N ha^{-1} in split doses to ensure that N was not limiting.

2.3. Soil and crop management

Prior to sowing rice, the land was plowed twice to about 20 cm depth and leveled. A basal dose of 13 kg P ha^{-1} as single superphosphate and 25 kg K ha^{-1} as muriate of potash was applied at the time of sowing. Rice was sown in the first fortnight of June in all the experiments by drilling the seed (40 kg ha^{-1}) with a seed-cum-fertilizer drill at a row to row spacing of 20 cm (plot size 19.8 m^2). The field was surface-irrigated immediately after sowing. Weeds were controlled by applying a pre-emergence herbicide (pendimethalin) at 1 DAS, and a post-emergence herbicide (bispyribac) at 21 DAS. Weeds that escaped these treatments were removed manually at 45 DAS. The irrigation was applied at 3–4 day interval but it was stopped during rainfall events.

2.4. NDVI measurements

Spectral reflectance expressed as NDVI was measured using a handheld GreenSeeker™ optical sensor unit (NTech Industries Incorporation, Ukiah, CA, USA). The readings were collected by holding the unit at a height of about 1 m above the plant canopy. The sensor unit has self-contained illumination in both the red (656 nm with about 25 nm full width half magnitude (FWHM)) and near infrared (NIR) (774 with about 25 nm FWHM) bands. The GS calculates NDVI as:

$$NDVI = (F_{NIR} - F_{RED})/(F_{NIR} + F_{RED})$$

where F_{NIR} and F_{RED} are, respectively, the fractions of NIR and red radiation reflected back from the sensed area. The sensor samples at a very high rate (approximately 1000 measurements per second) and averages measurements between outputs. The sensor outputs NDVI at a rate of 10 readings per second with travel velocities at a slow walking speed of about 0.5 m s^{-1}.

2.5. Plant sampling measurements and analysis

At maturity, rice crop was harvested manually. Grain and straw yields were recorded from a net area of 8 m^2 from the center of different treatment plots. Grains were separated from straw. Grain and straw samples of rice collected from each plot were air dried at 70 °C in a hot air oven. Grain yields were adjusted to 14% moisture content. Straw yields were expressed on an oven-dry basis. The dried samples were ground and N content in grain and straw

Table 1
Soil (0–15 cm) properties of experimental sites at Ludhiana, India.

Experiment	Sand (%)	Clay (%)	pH[a]	EC (dS m^{-1})[b]	Organic carbon (g kg^{-1})[c]	Available P (kg ha^{-1})[d]	Available K (kg ha^{-1})[e]
Experiment 1, 2011	67	13.7	7.2	0.16	3.3	11	108
Experiment 2, 2012	68	14.3	7.6	0.24	3.5	18	140
Experiment 3, 2013 (PR114 cultivar)	77	6.2	7.4	0.15	3.1	10	99
Experiment 4, 2013 (PR115 cultivar)	65	14.7	7.6	0.25	3.7	14	155

EC Electrical conductivity.
[a] 1:2 soil/water suspension.
[b] 1:2 soil/water supernatant.
[c] Walkley and Black (1934).
[d] Olsen et al. (1954).
[e] Pratt (1965).