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Prediction of dry direct-seeded rice yields using chlorophyll meter, leaf color chart and GreenSeeker optical sensor in northwestern India

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ABSTRACT

Prediction of potential yields during crop growth season is important for successful agricultural decision-making. The objective of this study was to predict grain yield of dry direct-seeded rice (DDSR) using leaf greenness as measured by chlorophyll meter (SPAD) and leaf color chart (LCC) and using normalized difference vegetation index (NDVI) worked from GreenSeeker optical sensor measurements. Regression analysis was performed to predict rice grain yield at maturity from the LCC, SPAD and NDVI readings recorded from two multi-rate nitrogen level experiments conducted in two consecutive rice seasons. The measurements made at early growth stage could not explain satisfactorily the variations in rice grain yield. Predictions made by the LCC were not reliable. The SPAD meter was superior to the LCC at booting growth stage. The NDVI readings at panicle initiation growth stage exhibited the highest coefficient of determination and explained 63% of the variation in rice grain yield. Yield predictability with SPAD measurements at 70 and 84 DAS, and NDVI readings at 70, 84 and 98 DAS did not improve by introducing the element of cumulative growing degree days (CGDD). However, CGDD based SPAD meter readings at 98 DAS, and LCC readings at 70, 84 and 98 DAS improved the crop yield predictability. The regression models were validated on an independent data set obtained from experiment conducted in the same area. The root mean square error (RMSE) for NDVI and SPAD readings was lower than the LCC readings. On the contrary, adjusting the LCC score with CGDD reduced the RMSE. The study reveals that yield of DDSR can be satisfactorily predicted with in-season measurements of NDVI, SPAD meter and the LCC scores adjusted with CGDD.

1. Introduction

Globally, rice (*Oryza sativa* L.) is grown on 156 million hectares, out of which 85% of the area is in Asia (IRRI, 2006). It is estimated that 2.3 billion farmers and their households, in the world, depend on rice as their main source of livelihood (Mohanty, 2010). The sustainability of rice-based systems is threatened because of inefficient use of inputs, particularly water and mineral fertilizers. Rice consumes 34–43% of the world's irrigation water (Bouman et al., 2007) and 14.6% of the world's fertilizer (Heffer, 2009). Dry direct-seeded rice (DDSR) has been proposed as an alternative to transplanted lowland/wetland rice as it does not require puddling of the soil and maintenance of submerged soil conditions during crop growth season. Direct-seeded rice can also reduce labor requirements compared with transplanted system (Rashid et al., 2009) and is conducive to mechanization (Khade et al., 1993). A shift from transplanted to direct-seeded rice (DSR) has already started occurring in the South Asia (Kumar and Ladha, 2011). However, there are reports that yields of DSR are lower than the transplanted rice. For example, Bhushan et al. (2007) observed that DSR can save 13–23% of irrigation water, but with a yield loss of 14–25%. Inadequate nitrogen (N) management can possibly be one of the reasons for low yields of DDSR. As fertilizer N and irrigation exhibit a strong interaction, it is possible that yield loss due to savings in irrigation water is compensated with fertilizer N. Recently, tools such as leaf color chart (LCC), chlorophyll meter (SPAD) and GreenSeeker optical sensor have become available for site-specific and need-based N management in rice (Varinderpal-Singh et al., 2010; Bijay-Singh et al., 2011). These site-specific N management strategies, however, include an element of prediction of yield potential during crop growth season.

Leaf color chart has been used successfully to guide fertilizer N application in rice, wheat and maize (Bijay-Singh et al., 2002; Yadvinder-Singh et al., 2007; Varinderpal-Singh et al., 2010, 2011).

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Ramesh et al. (2002) found that the SPAD meter values at 79 days after sowing (DAS) of wet DSR correlated well with the grain yield. Using LCC and SPAD meter for applying N to wet DSR resulted in reduced application of fertilizer N and increased the N-use efficiency vis-à-vis blanket fixed-time N management schedules in northwestern India (Bijay-Singh et al., 2006). The normalized difference vegetation index (NDVI) as measured by an optical sensor is based on the reflectance at red and near infrared (NIR) regions and has the ability to predict yield potential of rice (Harrell et al., 2011) and maize (Baez-Gonzalez et al., 2002; Teal et al., 2006). The yield prediction is reported to be improved when NDVI values were adjusted using cumulative growing degree days (CGDD) in wheat and sorghum (Raun et al., 2001; Moges et al., 2007).

Crop growth stage is important for measuring a plant attribute to predict grain yield at maturity. Raun et al. (2001) reported that relationship between NDVI and grain yield of winter wheat was the highest between Feekes 4 and 6. Bijay-Singh et al. (2011) observed robust relationships between in-season sensor-based estimates of yield at Feekes 5–6 and Feekes 7–8 stages of spring wheat. Teal et al. (2006) could achieve a strong relationship between NDVI measured at the V8 growth stage and grain yield of maize. No such information is, however, available for DDSR, possibly because DDSR has been introduced only recently. The objectives of the present investigation were to: (i) study the ability of in-season measurement of leaf color with LCC and SPAD meter and that of NDVI with GreenSeeker optical sensor to predict yield of DDSR, (ii) assess improvement in yield prediction by including CGDD in regression models and (iii) identify the optimum growth stage for making reliable yield predictions.

2. Materials and methods

2.1. Site description

Field experiments were conducted during 2011 and 2012 rice seasons (June–October) on a Typic Ustipsamment (Fatehpur loamy sand) at the experimental farm of the Punjab Agricultural University, Ludhiana, India (30° 56′ N, 75° 52′ E). The climate of Ludhiana is subtropical, semi-arid with an annual rainfall of 774 mm. About 80% of the annual rainfall is received during June to September when rice is grown. The mean monthly temperatures during the rice season (June-September) varied from 23.4° to 37.4 °C. Surface (0–15 cm) soil samples were collected prior to sowing rice each year. Some physico-chemical characteristics of soil samples were air dried and sieved (2 mm) were: pH (1:2 soil/water suspension) 7.2, electrical conductivity (1:2 soil/water supernatant) 0.16 dS m^{-1}, organic C (Walkley and Black, 1934) 3.3 g kg^{-1}, 0.5 M $NaHCO_3$ extractable P (Olsen et al., 1954) 4.8 mg kg^{-1} and NH_4OAc-extractable K (Pratt, 1965) 48 mg kg^{-1} in 2011 and 7.6, 0.24 dS m^{-1}, 3.5 g kg^{-1}, 8 mg kg^{-1} and 62.2 mg kg^{-1} in 2012, respectively.

2.2. Treatments, experimental design and crop management

To establish relationships between yield potential of DDSR and leaf/canopy measurements with LCC, SPAD and optical sensor, field experiments were conducted in 2011 and 2012 rice seasons with a medium duration rice genotype – PR114. The experiment in 2011 consisted of 13 treatments laid out in a randomized complete block design in which 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 DAS or at 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 the experiment conducted in 2012, 0, 60, 90, 120, 150, 180, 210 and 240 kg N ha^{-1} were applied as urea in four equal split doses at 14, 28, 49 and 70 DAS. The gadgets readings were collected from an independent experiment of DDSR conducted in 2012. The experiment was designed to test real-time and fixed-time N management using LCC. A basal dose of 13 kg P ha^{-1} as single superphosphate and 25 kg K ha^{-1} as muriate of potash was applied to rice at the time of sowing during both the years. Rice was sown on 7th June, 2011 and 8th June, 2012 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 pre-emergence herbicide (at 1 DAS), and a post-emergence herbicide (at 21 DAS). Weeds that escaped these treatments were removed manually at 45 DAS. The irrigation was applied at 3–4-day intervals except during rainfall events. 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 using a plot thresher. Grain yields were adjusted to 14% moisture content.

2.3. Plant measurements

Leaf color chart with six green shades (manufactured by N Parameters, Chennai, India) was used in this study. The topmost fully expanded leaf was placed on the LCC and the color of the middle part of the leaf was matched with greenness of the panels on the LCC. The chlorophyll meter used was the hand-held Minolta SPAD-502. The SPAD values were recorded by inserting the middle portion of the index leaf in the slit of SPAD meter. From each plot, readings from ten randomly selected plants were averaged. Optical sensor readings were taken with a hand held GreenSeeker™ (NTech Industries Inc., Ukiah, CA, USA). The sensor measured canopy reflectance at red region (656 nm) and near infrared (NIR) region (774 nm) and NDVI was determined as:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}}$$

where NIR and Red represent the fraction of emitted NIR and red radiation reflected back from the sensed area, respectively. The sensor was passed over the crop at a height of about one meter. Sensor height above ground increased as the crop growth progressed. The readings with all the three gadgets were recorded every two weeks between vegetative and reproductive growth stages (between 42 and 98 DAS).

2.4. Statistical analyses

Statistical analyses were performed on the pooled data of both seasons using Statistical Product and Service Solutions (SPSS 18.0). Exponential regression equations were fitted between crop grain yield and the readings recorded with different gadgets at different growth stages. Additionally, an index was computed by dividing NDVI, SPAD meter and LCC readings by CGDD from planting to sensing date as:

$$\mathrm{GDD} = \frac{T_{\max} + T_{\min}}{2} - 10\,^{\circ}\mathrm{C}$$

where GDD is growing degree days, $T_{\max}$ and $T_{\min}$ represent daily maximum and minimum temperature, respectively. 10 °C is the base temperature for rice production (Barger, 1969).

For validation of the prediction model, root mean square error (RMSE, %) (Wallach and Goffinet, 1989) was used to test the goodness of fit between the predicted and observed yields from an independent data acquired from another DDSR nitrogen