CROP CIRCLE SENSOR-BASED PRECISION NITROGEN MANAGEMENT STRATEGY FOR RICE IN NORTHEAST CHINA

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ABSTRACT

GreenSeeker (GS) sensor-based precision N management strategy for rice has been developed, significantly improved N fertilizer use efficiency. Crop Circle ACS-470 (CC) active sensor is a new user configurable sensor, with a choice of 6 possible bands. The objectives of this study were to identify important vegetation indices obtained from CC sensor for estimating rice yield potential and rice responsiveness to topdressing N application and evaluate their potential improvements over GS normalized difference vegetation index (NDVI) and ration vegetation index (RVI). Two site-years of field N rate experiments were conducted from 2012 to 2013 to evaluate the in-season N requirement prediction developed by Oklahoma State University in Jiansanjiang Experiment Station of China Agricultural University. The GS and CC active canopy sensor with green, red edge and near infrared bands was used to collect rice canopy reflectance data at stem elongation stages. The results indicated that the CC active multispectral canopy sensor had a better performance than GS for estimating rice yield potential and responsiveness to topdressing N application at stem elongation stage. More studies are needed to further evaluate CC sensor-based precision N management strategy as compared with GS active sensor-based precision N management strategy under diverse on-farm conditions.

Keywords: Precision agriculture, Crop Circle sensor, In-season nitrogen management, Site-specific nitrogen management, Active crop canopy sensor

INTRODUCTION

Unsuitable rates as well as wrong timing of N application were major reasons for very low N use efficiency for rice (Dobermann et al., 2002; Peng et al., 2010). Technologies and methods for effective N management strategies are urgently needed in rice production area.

To advance rice N management, Dobermann et al. (2002) developed site-specific N management (SSNM) strategy that estimated total N rate based on indigenous N supply capacity and target yield. This strategy has been evaluated in farmer's fields in eight major irrigated rice domains in Asia, average of grain yield increased by 11% and average recovery efficiency increased from 31% to 40% (Dobermann et al., 2002). In China during the past decade, this strategy produced 5% higher grain yield, saved 32% of N fertilizer over farmers' N practice, and almost doubled farmer's N practice in agronomic N use efficiency (Peng et al., 2010). However, several limitations and problems are associated with implementing the SSNM strategy. These problems may be overcome by developing remote sensing technology for determining the timing and rate of fertilizer N topdressing during the rice growing season (Peng et al., 2010; Xue and Yang, 2008).

Unlike chlorophyll meter and leaf color chart as point measurements at leaf level, crop canopy sensors are efficient and suitable for large area applications due to their collection of data at population or community level (Cao et al., 2012; Miao et al., 2009). Many researchers have used crop canopy sensors to estimate rice growth and N status (Bajwa et al., 2010; Cao et al., 2013; Stroppiana et al., 2009). There are limited studies performed for practical applications of N fertilizer based on crop canopy sensor recommendation for rice. In a recent study conducted in Northeast China, Yao et al. (2012) developed a canopy sensor-based precision N management strategy for rice according to the NFOA developed by Raun et al. (2002) to make in-season N recommendation for winter wheat (*Triticum aestivum* L.). However, the relationships between RI at harvest ($RI_{Harvest}$) and RI_{NDVI} or RI_{RVI} were poor whether at stem elongation stage, booting stage or across growth stages, with R^2s being less than 0.3 (Yao et al., 2012), which may result in inaccurate estimation of rice responsiveness to additional N application.

Due to the limitation of traditional two band sensors, active canopy sensors with more than two spectral bands may have better potential to improve in-season prediction of rice responsiveness to additional N application under high-yielding conditions. Recently, an advance in active canopy sensing is the development of CC sensor (Holland Scientific Inc., Lincoln, Nebraska, USA), which is user configurable with a choice of up to 6 spectral bands (450±20, 550±20, 650±20, 670±11, 730±10 and >760 nm) and 3 of these spectral bands can be used at a time. As a result, many potential spectral vegetation indices can be derived by data collected using CC. Some of these indices may perform better than the traditional NDVI and RVI indices for estimating crop N status. In a recent study conducted in Northeast China, Cao et al. (2013) systematically evaluated 43 vegetation indices derived from three CC bands (550±20, 730±10 and >760 nm) for estimating rice N status. The results indicated that the modified chlorophyll absorption reflectance index 1 (MCARI1) had consistent correlations with rice biomass and plant N uptake (R^2=0.79-0.83) across site-years, varieties and growth stages. Four red edge-based indices performed equally well for estimating rice NNI (R^2=0.76) under high-yielding conditions.

Can we use the CC sensor to improve in-season prediction of rice responsiveness to additional N application compared with GS sensor? Up to now, review of literature indicates that no study has been reported to use CC to develop precision N management strategy for rice. Therefore, the objectives of this study were to: (1) identify important vegetation indices obtained from CC sensor for estimating rice yield potential and rice responsiveness to topdressing N application, and (2) evaluate their potential improvements over GS NDVI and RVI.

MATERIALS AND METHODS

Study Site Description

A field experiment was conducted at Jiansanjiang Experiment Station of China Agricultural University (47.2°N, 132.6°E). This field has been under rice production since 1992. The soil type is Meadow Albic bleached soil. The chemical parameters of the 0-30 cm soil layer before transplanting in 2011 were as follows: organic matter content 35 g kg^{-1}, pH 6, total N 145 mg kg^{-1}, Olsen-phosphorus 36 mg kg^{-1}, and exchangeable potassium 111 mg kg^{-1}.

Nitrogen Rate Experiments

Field experiments were conducted in two rice seasons (2012 and 2013) to develop relationships for predicting yield potential of rice from in-season optical sensor measurements, as well as RI calculated with CC sensor data and harvested yield data (response index at harvest ($RI_{Harvest}$)). All field experiments were replicated three times in a randomized split block design. Each plot was divided into two parts: 6 m×9 m as the main plot and 3 m×9 m as the subplot. The main plot consisted of application of fertilizer N as urea at 0, 70, 100, 130, and 160 kg N ha^{-1}, which were applied as three splits: 40% as basal N before transplanting, 30% of N at tillering stage, and the remaining 30% of N at stem elongation stage. In order to evaluate the potential of using CC sensor to estimate rice yield potential, the subplot was not receiving the third N application at stem elongation stage.

Active Canopy Sensor Data Collection

The first sensor was GS handheld sensor, which is an active optical crop canopy sensor detecting reflection in red and NIR spectral regions. Sensor readings were collected by holding GS approximately 0.7-0.9 m above the canopy at different stages and walking at a constant speed in all experimental plots. The sensor path was parallel to the seed rows or the beam of light was perpendicular to the seed row. The GS handheld sensor uses built-in software to calculate NDVI and RVI directly and generates 10 NDVI and RVI determinations per second.

The second sensor was the CC active sensor, which incorporates three optical measurement channels and is user configurable (440 nm to 800 nm) using 12.5 mm interference filters. In this study, we selected three bands based on literature reviews and previous research with winter wheat (Gao, 2011): green (550±20 nm), red edge (730±10 nm) and NIR (>760 nm). Spectral reflectance data can be easily and quickly recorded to a text file on a SD flash card using the Holland Scientific GeoSCOUT GLS-400 data logger. Sensor readings were collected approximately 0.7-0.9 m above rice canopy at a rate of 10 readings per second and walking at a constant speed in each plot. The average reflectance values were computed to represent each plot. Although this sensor offer calculated vegetation indices as output, we used single wavelength reflection values calculated vegetation indices. The calculated spectral vegetation indices selected for this study are listed in Table 1.

Grain Yield Determined

Rice was harvested in mid-September. Yield was determined by harvesting by hand from three 1 m^2 areas of each plot where spectral reflectance data were collected. Grains were separated from straw using a small grain thresher and weighed. Grain moisture was determined immediately after weighing. Grain weight for rice was adjusted to a moisture content of 14%.

Table 1. Vegetation index selected for Crop Circle Multispectral Active Canopy Sensor.

Index	Formula	Reference
Normalized NIR Index (NNIR)	NIR/(NIR+RE+G)	Sripada et al., 2006
Normalized Difference Red Edge (NDRE)	(NIR-RE)/(NIR+RE)	Barnes et al., 2000
Green Normalized Difference Vegetation Index (GNDVI)	(NIR-G)/(NIR+G)	Gitelson et al., 1996
Red Edge Chlorophyll Index (CI_{RE})	NIR/RE-1	Gitelson et al., 2005
Green Chlorophyll Index (CI_{G})	NIR/G-1	Gitelson et al., 2005
Green Soil Adjusted Vegetation Index (GSAVI)	1.5*[(NIR-G)/(NIR+G+0.5)]	Sripada et al., 2006
Modified GSAVI (MGSAVI)	0.5*[2*NIR+1-SQRT ((2*NIR+1)2-8*(NIR-G)]	Cao et al., 2013

Statistical Analysis

In-season estimated yield (INSEY) proposed by Raun et al. (2002) as the measure of the daily accumulated biomass from the time of planting to the day of sensing was calculated as NDVI divided by the number of growing degree days (GDD). In this study, however, the number of days from transplanting to sensing was used to replace GDD to calculate INSEY in order to calculate easily for users. The selected vegetation indices derived from CC were used to take the place of NDVI. The yield potential with no additional fertilization (YP_0) was calculated from the equation for grain yield and INSEY.

A response index at harvest, $RI_{Harvest}$, indicates the actual crop response to additional N within a given year (Johnson and Raun, 2003; Mullen et al., 2003) and was calculated as follows:

$$RI_{Harvest}=\frac{Yield\_N_{rich}}{Yield\_CK}$$

where Yield_Nrich is the average yield of plots receiving sufficient N application, and Yield_CK is the average yield of a check plot or plot without receiving the third N application at stem elongation stage.

In-season predict the magnitude of response to N fertilization (RI_{VI}) were calculated in the same way as $RI_{Harvest}$, with the exception that vegetation indices derived from GS and CC sensor were used instead of yield. The yield potential with additional N (YP_N) was calculated by multiplying YP_0 and $RI_{Harvest}$ estimated by RI_{VI}. In the above analyses, the 160 kg N ha^{-1} treatment was used as N rich treatment.

The coefficient of determination (R^2) relating YP_0 with INSEY and RI_{VI} with $RI_{Harvest}$ were subjected to regression analysis to identify the best fit model from the linear, quadratic, exponential, power, and logarithmic models using SPSS 18.0 (SPSS Inc., Chicago, Illinois, USA). The corrected R^2-values were used for model selection in addition to visual inspection of each curve.

RESULTS AND DISCUSSION

Rice Grain Yield

Rice grain yield was increased significantly by N fertilizer application (Fig. 1). The Kongyu131 had higher or same grain yield compared to Longjing21, indicating that variety selection plays a critical role in increasing grain yield. The main plots also had higher grain yield at any N rate or for any of two varieties, compared with the subplots without receiving third N application (Fig. 1), indicating that the third topdressing N application is important to the rice yield.

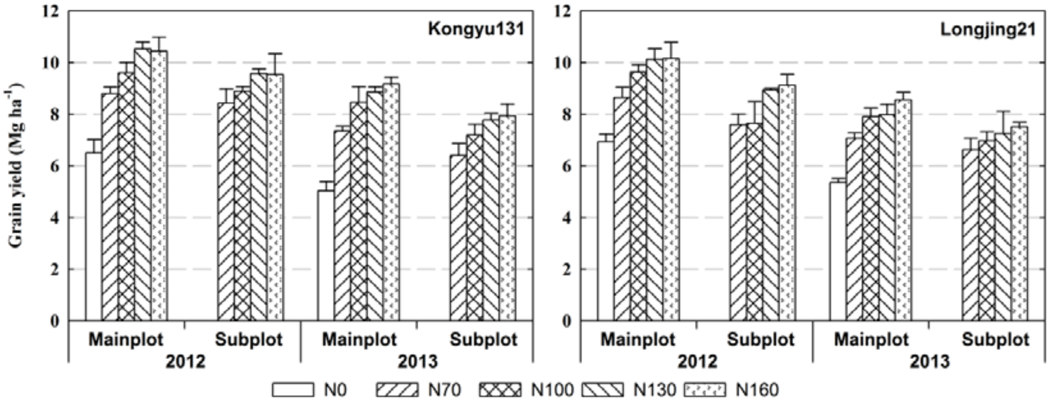

Fig. 1. Rice grain yield as affected by different N rates at different years for different varieties (left: Kongyu131; right: Longjing 21).

In-season Estimate of Rice Yield Potential

The regression models between INSEY calculated with vegetation indices derived from both GS and CC sensor and YP_0 were showed in Fig. 2. Two of the top CC vegetation indices were selected for estimating rice yield potential at stem elongation stage. The INSEY calculated with normalized NIR index (NNIR) was linearly related with YP_0 (R^2=0.71), followed by INSEY calculated with green soil adjusted vegetation index (GSAVI) with R^2 being of 0.68 (Fig. 2c-d).

In-season Estimating the Responsiveness to Topdressing N Application

The regression models between RI calculated with vegetation indices derived from both GS and CC sensor and $RI_{Harvest}$ were showed in Fig. 3. Two of the top CC vegetation indices were selected for estimating responsiveness to additional topdressing N application at stem elongation stage. The RI calculated with modified GSAVI (MGSAVI) was closely related with $RI_{Harvest}$ (R^2=0.77), followed by RI calculated with GSAVI with R^2 being of 0.76 (Fig. 2c-d).

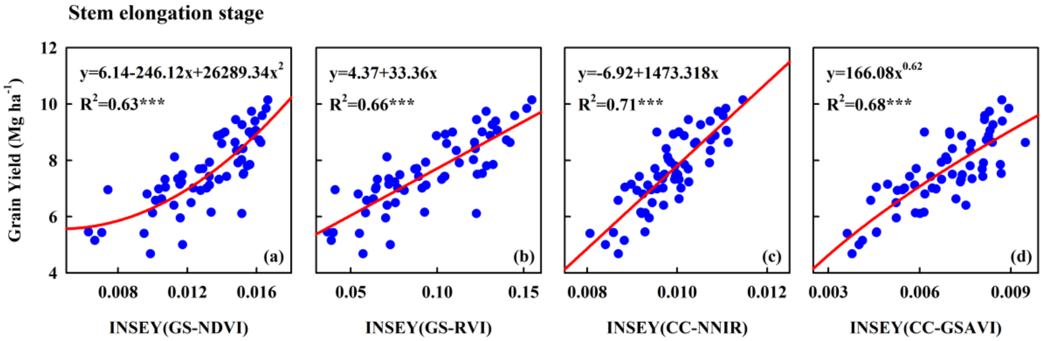

Fig. 2. The relationships between yield without additional topdressing N application (YP_0) and in-season estimated of yield estimated with vegetation indices derived from GreenSeeker (NDVI, RVI) and Crop Circle ACS-470 (Top two indices) at stem elongation across varieties during 2012 and 2013.

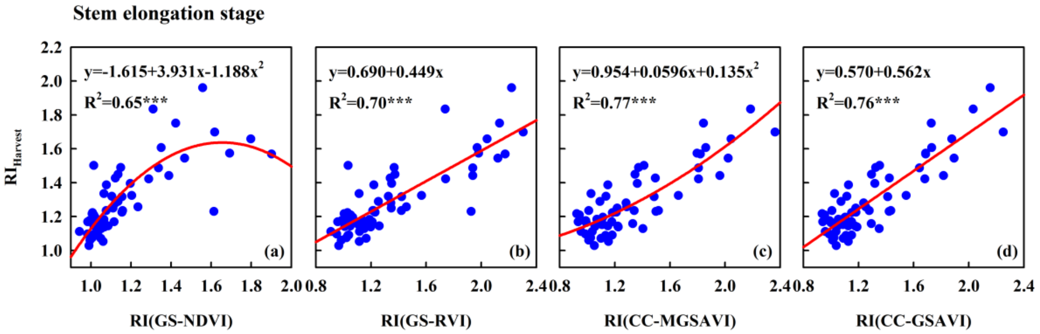

Fig. 3. The relationships between response index calculated with yield ($RI_{Harvest}$) and response index calculated with vegetation indices derived from GreenSeeker (NDVI, RVI) and Crop Circle ACS-470 (Top two indices) at stem elongation across varieties during 2012 and 2013.

CONSLUSIONS

The results of this study indicated that the CC sensor cloud be used to estimate rice yield potential and responsiveness to additional topdressing N application at stem elongation stage. Under high-yield conditions, CC could overcome the limitation of GS sensor and provided more accurate estimation. Future studies are needed to improve the strategy with more site-years and different varieties, conduct more on-farm experiments to evaluate this strategy against other N management strategies, like GS sensor-based precision N management, the chlorophyll meter-based site-specific N management, and regional optimum N management under different on-farm conditions and integrate this strategy into high yield crop management systems to achieve both high yield and high N use efficiency simultaneously for food security and sustainable development.

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