DEVELOPING AN ACTIVE CROP SENSOR-BASED IN-SEASON NITROGEN MANAGEMENT STRATEGY FOR RICE IN NORTHEAST CHINA

Yinkun Yao, Yuxin Miao*, Shanyu Huang, Lei Gao, Kang Yu, Rongfeng Jiang, Xinping Chen

College of Resources & Environmental Sciences
China Agricultural University
Beijing, China
**Email: ymiao2007@gmail.com*

Martin L. Gnyp, Georg Bareth

Institute of Geography, University of Cologne, 50923, Köln, Germany

Liqin Zhao

Qixing Research and Development Center, Qixing Farm, Jiansanjiang, Heilongjiang, China

Chuanqin Liu

Jiansanjiang Institute for Scientific Research, Jiansanjiang, Heilongjiang, China

ABSTRACT

Chlorophyll meter has been commonly used for instantaneous diagnosis of rice nitrogen (N) status and in-season site-specific N management. However, in large scale rice farming like Heilongjiang farms in Northeast China, chlorophyll meter is still time consuming for practical applications and a better approach needs to be developed. Recent development in crop canopy sensors has presented a promising alternative. Crop sensor-based in-season site specific N management strategies have been successfully developed and evaluated for winter wheat around the world, but little has been reported for rice. The objective of this study was to develop an "active sensor"-based strategy for potential real time N management of rice in Northeast China. Two field experiments were conducted in 2008 and 2009, respectively, in Jiansanjiang, Heilongjiang Province, Northeast China. Both experiments used randomized block design with four or three replications and five N rate treatments: 0, 35, 70, 105 and 140 kg N/ha. The N fertilizers were split into three applications: 45% before transplanting, 20% at tillering stage, and 35% at panicle elongation. In order to estimate rice yield potential without N application at panicle elongation, each plot was split into two parts: 10m x

10m as the main plot, and 5m x 10m as the split plot without receiving the third N application. All the remaining management practices were the same for entire experiment. An active crop canopy sensor, GreenSeeker, was used to collect rice canopy reflectance data across the growing season. At harvest, rice grain yield, biomass, N concentration and uptake were determined. Preliminary analysis indicated that In-Season Estimated Yield (INSEY) was highly correlated with measured yield in plots without N application at panicle elongation at site 1, but the relationship was quite weak at panicle elongation stage at site 2. Response index (RI) calculated with normalized difference vegetation index (NDVI) at panicle elongation was significantly correlated with RI calculated with yield at site 1 as well. A preliminary N recommendation algorithm was developed and the potential application and future research needs are discussed.

Keywords: Rice, GreenSeeker, In-Season Estimate Yield, Remote Sensing, Nitrogen Management

INTRODUCTION

Conventional wet-chemistry techniques for rice foliar nitrogen (N) analysis are time-consuming and not practical for in-season management of N supply. Several methods have been proposed for non-destructive estimation of plant N nutrition, including leaf color charts, chlorophyll meter, reflectance spectra, and chlorophyll fluorescence (Shukla et al., 2004; Nguyen and Lee, 2006; Huang et al., 2008). Crop or leaf N was often diagnosed by using chlorophyll meters. It records point data from a single leaf on a single plant. However, in large scale rice farming like Heilongjiang farms of Northeast China, chlorophyll meter is still time consuming for practical applications. In contrast, remote sensing of canopy reflectance measures the crop growth in a population or a community rather than individual plants.

GreenSeeker (N tech Industries, Ukaih, CA) is an active crop canopy sensor that has been used successfully for in-season N management of wheat in both US and China (Lukina et al., 2001; Ruan et al., 2002; Li et al., 2009), however, little has been reported for rice N management. Xue and Yang (2008) used CropScan sensor and modified the N fertilizer optimization algorithm (NFOA) as developed by Lukina et al. (2001) and Ruan et al. (2005) for wheat. They increased agronomic N efficiency by 20% compared with standard N management practice. The objective of study is to evaluate the potential of using GreenSeeker for in-season N management of rice in Northeast China.

MATERIAL AND METHODS

Site Descriptions

The study area Qixing farm is located in the Sanjiang Plain (47.2 N°, 132.8° E), at the lower stretch of Songhua River (Songhua Jiang), approx. 60 km south of the Amur River (Heilong Jiang) and 450 km west of the Pacific ocean in the Northeast of Heilongjiang Province, being bordered by Siberia in the North and East. This study region belongs to the temperate zone and is characterized by a sub-humid continental monsoon climate.

The mean annual air temperature is about 1-2°C and the mean yearly precipitation ranges from 500 mm to 600 mm (Wang and Yang, 2001). Average temperatures reach -18°C in January and 21-22°C in July. The frost-free period is only about 120-140 days long (Zhang et al., 2009). The maximum values of temperature and precipitation are both observed in July and August. The rainfall from June to September covers about 72% of the annual amount, with 59% of the yearly precipitation occurring from June to August (Yan et al., 2002).

The Sanjiang Plain is an alluvial plain of the three rivers, Heilongjiang, Songhua and Wusuli River and covers about 108900 km². The main part (60%) is plain (50-70m above sea level) whereas the remaining part is hilly and mountainous (Wang and Yang, 2001), with elevations reaching up to 1000m. Originally the Sanjiang Plain was dominated by marshes. The most abundant soils are wet black clays with a general thickness of more than 20 cm. The soils offer high concentrations of organic matter and nutrients, being most favorable for agricultural productivity (Zhou and Liu, 2005).

Experiment design

Two field experiments were conducted at two sites in 2008 and 2009, respectively, in Jiansanjiang, Heilongjiang Province, China. Each plot was 15m x 10 m. In order to estimate rice yield potential without N application at panicle elongation stage, each plot was splited into two parts: 10m x 10m as the main plot, and 5m x 10m as the split plot without receiving the third N application. Both experiments used randomized block design with four replications and five N rate treatments: 0, 35, 70, 105 and 140 kg N ha^{-1} at site1 and site2 in 2008. In 2009, the experiment at site2 had three replications. In addition to the five N rate treatments as in 2008, we added one treatment of N recommendation based on the GreenSeeker-based N management strategy developed using 2008's result. For all treatments, 135 kg [P_2O_5] ha^{-1} ([$Ca(H_2PO_4)_2$]) and 210 kg ha^{-1} (as K_2O) were incorporated into the soil before transplanting. The N source for all experiments was urea.

The experiments cultivation dates were shown in Table 1. As shown below (Tab.2), the days from planting (DFP) and cumulative growing degree days (GDD) are categorized by leaf stage, 2008 through 2009.

Table 1. Field trial information for all experiments, 2008 though 2009.

Location	Year	maturity	Plant date	Tansplant date	Harvest date
Site 1	2008	116	20 Apr.	29 May.	21 Sep.

Site 2	2008	135	10 Apr.	13 May.	23 Sep.
Site 1	2009	131	15 Apr.	20 May.	27 Sep.
Site 2	2009	131	15 Apr.	20 May.	27 Sep.

Note: Rice cultivar is Kongyu 131

Table 2. Days from transplanting (DFP) and cumulative growing degree days (GDD) are categorized by leaf stage.

Location	Year	1		2		3		4		5	
		DFP	GDD	DFP	GDD	DFP	GDD	DFP	GDD	DFP	GDD
Site 1	2008	33	32	41	40	57	56	68	67	80	79
Site 2	2008	47	45	54	54	70	70	83	83	97	95
Site 1	2009	38	38	50	46	60	59	74	73	92	91
Site 2	2009	38	38	50	46	60	59	74	73	92	91

Note: DFP, days from transplanting; GDD, growing degree days; GDD calculated= [(maximum daily temperature + minimum daily temperature)/2] - 12.5 ℃.

The N fertilizer was applied at three growing stages: 45% as base N before transplanting, 20% at tillering stage, and 35% at panicle initiation. Treatment 1 to 5 is the main plots with topdressing at panicle stage. Treatment 2s to 5s is the split plots, which did not have N application at panicle elongation stage (Table 3).

GreenSeeker Measurements

The GreenSeeker Hand-Held optical reflectance sensor (Ntech Industries, Ukiah, CA) was used in this research. It uses active radiation from red (650 ± 10 nm) and near infrared (770 ± 15 nm) band independent of solar conditions. The device uses the software to calculate normalized difference vegetation index (NDVI) directly and it generates NDVI at a rate of 10 readings per second. NDVI value was collected from tillering to heading growth stage. Measurements were made at three sites over each plot, 5-10 m^2 facing vertically downwards from 0.5 m above the rice canopy on five different dates: tillering, panicle initiation, booting, before heading, heading stage. The data from treatments 1 to 4 were used to calibrate the N topdressing algorithm, and the data from treatment 5 at panicle initiation stage were used to calculate the N topdressing rate based on the calibrated site-specific N recommendation algorithms.

Plant Sampling Measurements

Aboveground biomass was collected by randomly clipping 3 to 5 hills vegetation from scanned plants following GreenSeeker optical sensor data collection in each plot. Clip 5 hills at tillering stage and panicle elongation stage, clip 3 hills rice at booting, before heading, heading stage. All plant samples were oven dried at 70℃ to constant weight and then weighed, ground, and analyzed for N concentration using the Kjeldahl-N method. Sampling dates were at tillering, panicle elongation, booting, before heading and heading stage. The plant N uptake (N uptake) was determined by multiplying whole-plant N concentration and dry biomass.

Table 3. Treatment structure and nitrogen fertilizer of the trials, 2008 through 2009.

Treatment	N Input (kg/ha)			Total N Rate
	Base N	Tillering N	Heading N	
1	0	0	0	0
2	15.75	7	12.25	35
3	31.5	14	24.5	70
4	47.25	21	36.75	105
5	63	28	49	140
6	63	28	*	*
2s	15.75	7	0	22.75
3s	31.5	14	0	45.5
4s	47.25	21	0	68.25
5s	63	8	0	91

Note: In 2009, we add treatment 6 at site1 and site2 which had the some base N and tillering N, but the heading N is definited by predicting the in-season poteintal yield.

Yield samplings

Rice was harvested at the end of September. Yield was determined by harvesting the central three 1 by 1 m area of each plot and adjusted to a moisture content of 14 %.

NFOA approach

NFOA means nitrogen fertiliser optimisation algrithm, with this approach,

$$NDVI = (NIR_{760}-R_{670})/(NIR_{760}+R_{670}) \quad [1]$$

The in-season estimate of grain yield (GDD INSEY) is calculated as:

$$INSEY = NDVI/GDD \quad [2]$$

GDD is cumulative growing degree days from transplanting days to sensing and calculated using the “optimum day method” (Barger, 1969). Once the INSEY by Eq 2 is known, the predicted potential grain yield can calculated based on:

$$\text{Yield potential (YP0)} = A\exp^{bINSEY} \quad [3]$$

This estimated yield is the yield potential without additional N fertilizer at panicle initiation stage.

Response index ($RI_{Harvest}$) was proposed that indicates the actual crop response to applied N (Johnson et al., 2000). It is calculated using the following equation:

$$RI_{Harvest} = \text{(Mean yield of N rich strip)/(Mean yield of check 0-N)} \quad [4]$$

In-seanson sensor measurements of NDVI was an indicator of crop N uptake between plots receiving N and those not receiving N can be used in the same way using the following equation:

$$RI_{NDVI}=\text{(Mean NDVI of N rich strip)/(Mean NDVI of check)} \quad [5]$$

$$RI_{harvest}=A*RI_{NDVI}+B \quad [6]$$

The yield potential with additional nitrogen (YPN) is calculated using the following equation:

$$YPN=YP0\times RI_{harvest} \quad [7]$$

Nitrogen recommendation (Nr) can be determined using equation [8]:.

$$Nr=(YPN-YP0)\times N\%/NUE \quad [8]$$

We use REN to make NUE: apparent recovery efficiency of applied N (kg N taken up per kg N applied), it was calibrated with only the data from the panicle initiation stage.

RESULTS AND DISCUSSION

Calibration of site-specific N algorithms

The relationships between INSEY and rice yield without the third N application at site 1 improved with time (Fig. 1.), however, the relationship was not well establsihed at site 1 at any stage (Fig. 2).

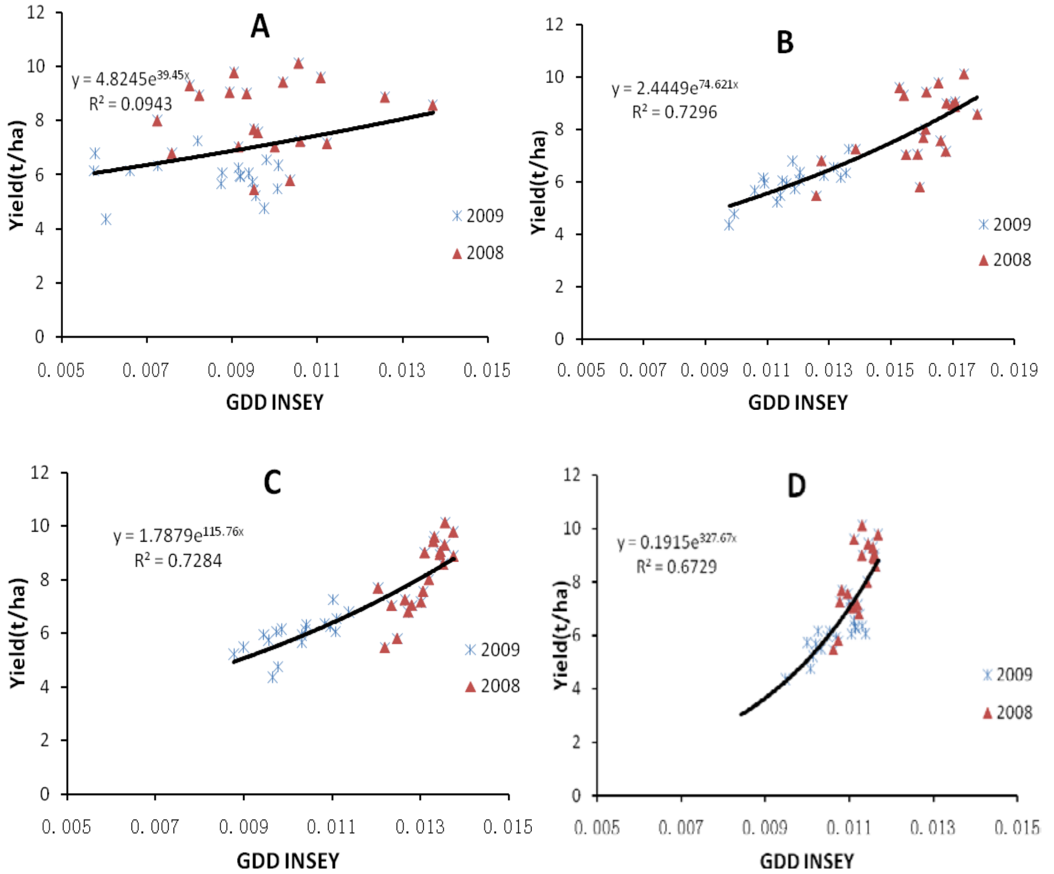
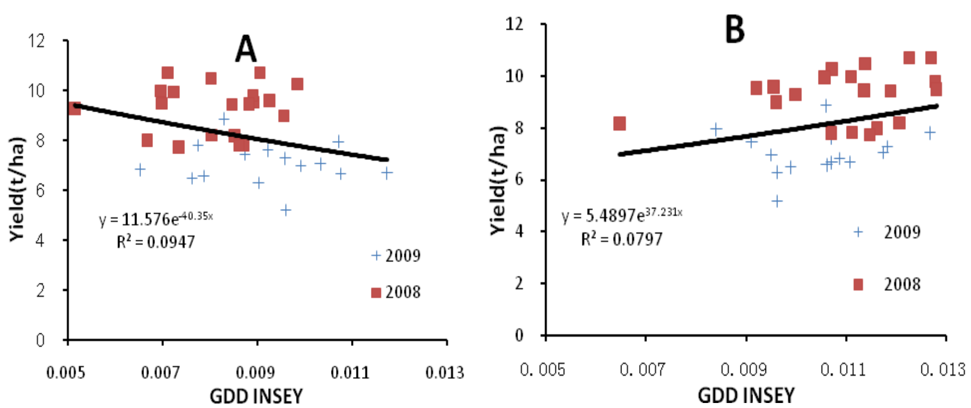


Fig.1. Relationships between INSEY and rice yield without the third N application at different growth stages in 2008 and 2009 at site 1. A: At tillering stage, 32 and 38 days after transplanting in 2008 and 2009, respectively; B: At panicle initiation stage, 40 and 46 days after transplanting; C: At booting stage, 56 and 59 days after transplanting in 2008 and 2009 days, respectively; and D: Before heading stage, 67 and 73 days after transplanting in 2008 and 2009, respectively.



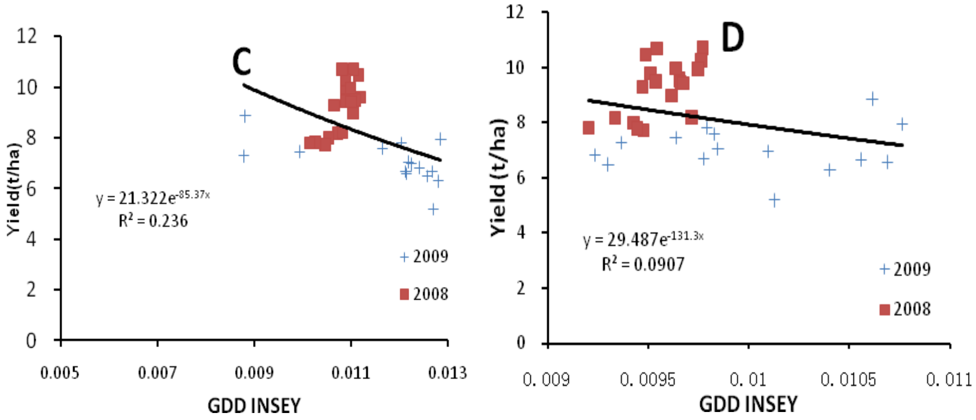


Fig.2. Fig.1. Relationships between INSEY and rice yield without the third N application at different growth stages in 2008 and 2009 at site 2. A: At tillering stage, 45 and 38 days after transplanting in 2008 and 2009, respectively; B: At panicle initiation stage, 55 and 46 days after transplanting; C: At booting stage, 71 and 59 days after transplanting in 2008 and 2009 days, respectively; and D: Before heading stage, 67 and 73 days after transplanting in 2008 and 2009, respectively.

Relationship between RI_{NDVI} and RI $_{Harvest}$

RI_{NDVI} measured in-season was highly correlated to $RI_{Harvest}$ at site 1 (Fig. 3), but the relationship was not satisfactory at site 2 (Fig. 4).

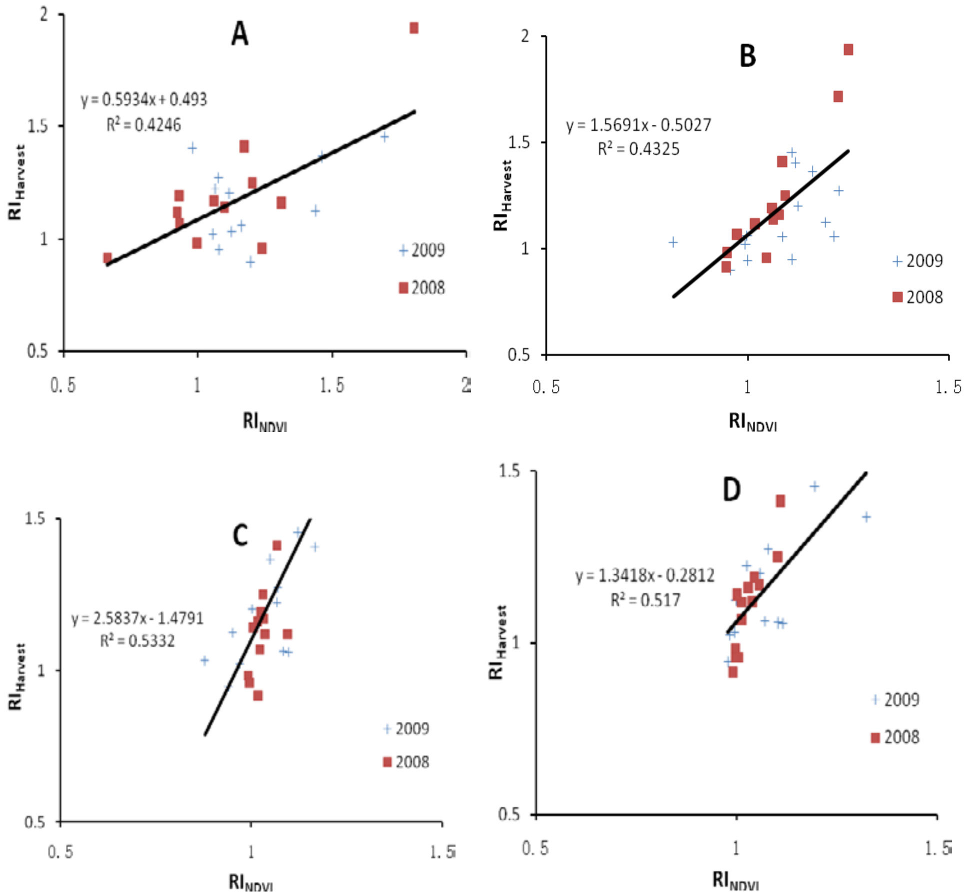


Fig.3. Relationships between RI_{NDVI} and $RI_{Harvest}$ at different growth stages in 2008 and 2009 at site 1. A: At tillering stage, 32 and 38 days after transplanting in 2008 and 2009, respectively; B: At panicle initiation stage, 40 and 46 days after transplanting; C: At booting stage, 56 and 59 days after transplanting in 2008 and 2009 days, respectively; and D: Before heading stage, 67 and 73 days after transplanting in 2008 and 2009, respectively.

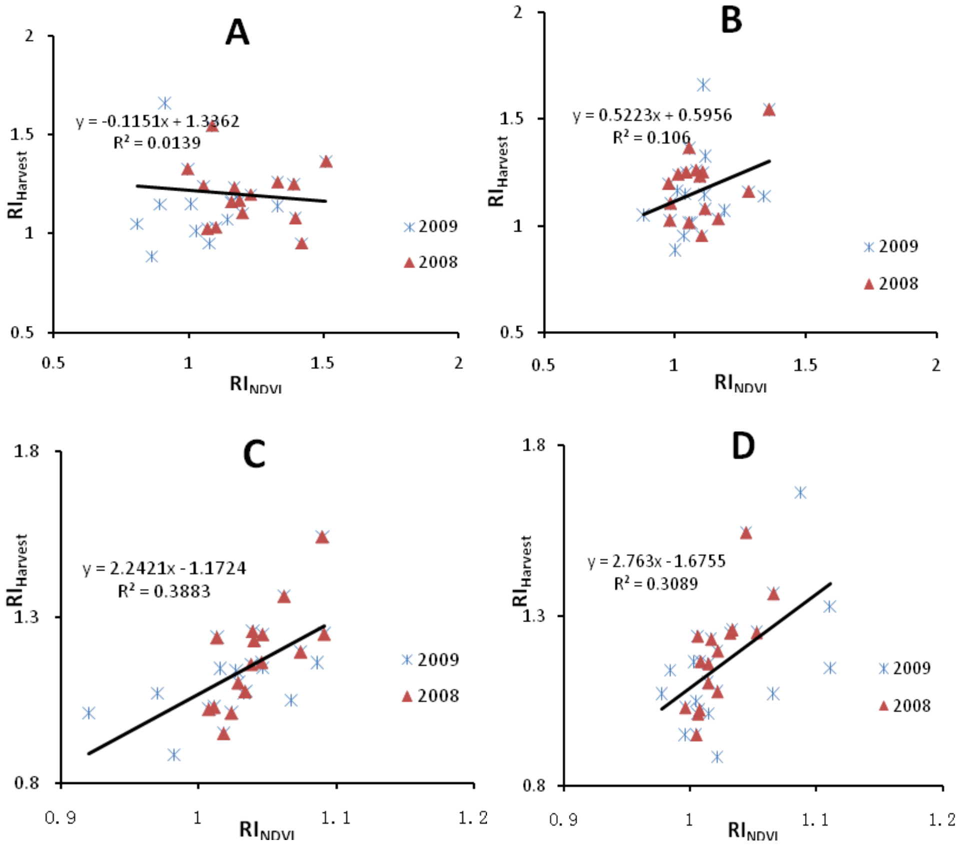


Fig. 4. Relationships between RI_{NDVI} and $RI_{Harvest}$ at different growth stages in 2008 and 2009 at site 2. A: At tillering stage, 45 and 38 days after transplanting in 2008 and 2009, respectively; B: At panicle initiation stage, 55 and 46 days after transplanting; C: At booting stage, 71 and 59 days after transplanting in 2008 and 2009 days, respectively; and D: Before heading stage, 67 and 73 days after transplanting in 2008 and 2009, respectively.

Fertilizer N Recommendation

At site1, we chose the relationship between $RI_{harvest}$ and RI_{NDVI} in panicle initiation stage.

For example, YP0=6.0 t/ha, $RI_{harvest}$ is 1.4, then YPN=6.0×1.4 t/ha=8.4 t/ha,

The diference in nitrogen uptake would be:

N diference (kg/ha)=(8.4-6.0 t/ha) ×1000kg/t×0.013 (kg/ha)=31.2 (kg/ha)

We assume N% = 1.3%.

Then we give the N fertiliser recommendation in panicle initiation stage:

We use REN to make NUE: apparent recovery efficiency of applied N (kg N taken up per kg N applied), it was calibrated with only the data from the panicle initiation stage, NUE=0.5.

Nr=(YPN-YP×N%/NUE=(8.4-6.0)×1000×0.013/0.5(kg/ha)=62.4 (kg/ha).

Evaluation of the Algorithm

In 2009 summer, we only had the data of 2008. Since the relationship at Site 2 was not good, we only discuss the result of Site 1.

$$Y=2.7385e^{71.709x},\ R^2=0.3209 \qquad [9]$$

where x is INSEY value at panicle initaiton, y is YP0 at site 1.

Then we get the potential yield at site1:

$$Y=2.7385e^{71.709x}=2.2385\ e^{71.709\times 0.01106}=6\ t/ha$$

$RI_{harvest}$ is calculated by Eq [4], RI_{NDVI} is calculated by Eq [5].

In 2009, we collected NDVI data at panicle initiation stage, and used the RI_{NDVI} in-season. Because the real $RI_{harvest}$ can only be obtianed at harvest time, so $RI_{harvest}$ is the experiental value of 2008 at panicle initiation stage.

$$Y=1.2266x—0.047,\ R^2=0.3605 \qquad [10]$$

Where RI_{NDVI} is x, $RI_{harvest}$ is y. So $RI_{harvest}$=1.2266×1.02—0.047= 1.20 at site1 in 2009.

Depending on the relationship between the $RI_{harvest}$ and $RI_{NDVI,}$ we can calculate the potential yield with additional nitrogen (YPN).

$$YPN= 6\ (t/ha)\times 1.20=7.2\ (t/ha) \qquad [11]$$

Using 1.3% for N% and 0.5 for NUE, we can calculate N recommendation rate for the third application as below:

$$\begin{aligned} Nr &= (YPN—YP0)\times N\%/NUE \\ &= (7.2—6.0)\times 0.013\times 1000/0.5 \\ &=31.5\ (kg/ha) \qquad [12] \end{aligned}$$

CONCLUSION

This study evaluated the potential of developing GreenSeeker sensor-based in-season N management strategy for rice in Northeast China. The tentative conclusion is that the GreenSeeker sensor can be used for in-season N management at medium yield levels like site 1 (around 6-7t ha^{-1}), but may not be suitable for high yield levels like site 2 (7-10 t ha^{-1}). More research is needed to confirm the results.

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