Active Canopy Sensor-based Precision Rice Management Strategy for Improving Grain Yield, Nitrogen and Water Use

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Abstract. *The objective of this research was to develop an active crop sensor-based precision rice (Oryza sativa L.) management (PRM) strategy to improve rice yield, N and water use efficiencies and evaluate it against farmer's rice management in Northeast China. Two field experiments were conducted from 2011 to 2013 in Jiansanjiang, Heilongjiang Province, China, involving four treatments and two varieties (Kongyu 131 and Longjing 21). The results indicated that PRM system significantly increased rice grain yield, N recovery efficiency (RE), agronomic efficiency (AE) and partial factor productivity (PFP) by an average of 12%, 63%, 89% and 53% over FP system across two varieties and the three years, respectively. Water use efficiency was increased by 59-60%. It is concluded that the PRM system can significantly increase rice yield, N and water use efficiencies than farmer's practices and has the potential to contribute to both food security and sustainable development.*

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Keywords. *Precision rice management, food security, sustainable development*

Introduction

Previous precision agriculture research has mainly focused on nutrient (Miao et al., 2007; Peng et al., 2010; Yao et al., 2012b), water (King and Stark, 2006; Hedley and Yule, 2009), pesticide (Mahlein et al., 2012), and tillage (Agüera et al., 2013) management to improve resource use efficiencies, without significantly affecting crop yield in many cases. Precision agriculture must move from precision management of single input or practice to integrated precision crop management strategies to spatially and temporally optimize all the key factors influencing crop yield, quality and/or profitability to contribute to both food security and sustainable development in the 21st century (Miao et al., 2011; Zhao et al., 2013).

China produces about 19% of the world's rice (Oryza sativa L.) by area and 28% of its yield. However, rice in China consumes about 36% of the total nitrogen (N) fertilizer used for rice production in the world (Heffer, 2013). To improve rice N use efficiency, several canopy sensor-based precision N management strategies have been developed for rice. The GreenSeeker active crop canopy sensor (Trimble Navigation Limited, Sunnyvale, California, USA) is more commonly used for precision N management. Yao et al. (2012b) developed a GreenSeeker sensor-based precision N management strategy for rice in Northeast China, with a regional optimum N rate as an initial rough estimate of total N rate, and applied 45% as basal N fertilizer, and 20% at tillering stage. Then the GreenSeeker sensor was used to estimate topdressing N rate at stem elongation stage based on the N Fertilizer Optimization Algorithm (NFOA) originally developed by Raun et al. (2002 and 2005) for wheat. This strategy increased N PFP by 48%, but did not have any significant impact on grain yield when compared with farmer's practice.

To increase both rice yield, N and water use efficiencies and reduce environmental risks, integrated crop management practices need to be developed (Miao et al., 2011; Zhang et al., 2013a; Chen et al., 2014). So far, little has been reported on the development and evaluation of active canopy sensor-based precision rice management (PRM) systems. Therefore, the objectives of this study were to develop an active crop canopy sensor-based precision rice management system to improve grain yield, N and water use efficiencies simultaneously in Northeast China, and evaluate this system as compared with farmer's practice (FP).

Materials and methods

Study sites

The study site was located in Jiansanjiang on the Sanjiang Plain (47.2º N, 132.8º E) in northeast part of Heilongjiang Province, Northeast China. Two field experiment was conducted from 2011 to 2013 at Jiansanjiang Experiment Station of China Agricultural University (47º13′58.46″ N, 132º38′47.91″ E). This field has been under rice production for more than 10 years.

Experiment design

Two field experiments used two varieties in 2011-2013: one used 11 leaf variety Kongyu 131 (with maturity days of 127) and the other used 12 leaf variety Longjing 21 (with maturity days of 133), respectively. Each field experiment was replicated 3 times in a randomized complete block design. Each experiment had the same three treatments: (i) Check (CK), with no N application. The transplanting density for Kongyu 131 was 30 × 10 cm, with 30 hills m^{-2}, and 4 plants $hill^{-1}$. The transplanting density for Longjing 21 was 30 × 12 cm, with 27 hills m^{-2}, and 6 plants $hill^{-1}$. A water saving irrigation system called alternate wetting and drying irrigation (AWD) was adopted, as described by Zhao et al. 2013. (ii) Farmer's practice (FP), with 150 kg N ha^{-1} as total N rates, which was all applied during the early stages as basal and tillering N. Transplanting density of two varieties was 30 × 14 cm, with 24 hills m^{-2}, and 4 plants $hill^{-1}$. Traditional flood irrigation was used, that is, rice was under flooded conditions during the rice growing season. (iii) Active canopy sensor-based precision rice management (ACS-PRM), using the regional optimum N rate of 110 kg N ha^{-1} as the rough estimate of total N rate, which was applied as 3 splits (basal, tillering stage and stem elongation stage), the topdressing N rates at stem elongation were adjusted based on the ACS-PNM strategy developed by Yao et al. (2012b).

Seedlings of two varieties were transplanted at 3.1–3.5 leaf stage. The transplanting dates were May 15-16 in 2011-2013. Each plot was 7 m × 8 m = 48 m^2. Phosphorus (P) fertilizer in the form of $Ca(H_2PO_4)_2$ was incorporated into the soil before transplanting. The rates were 30 and 60 kg P_2O_5 ha^{-1} for CK and FP, respectively, and 50 kg P_2O_5 ha^{-1} for the precision rice management strategy. Potassium (K) fertilizer in the form of K_2SO_4 was split into 2 doses: 50% as basal application and 50% was applied at stem elongation stage. The total K_2O rates were 60 and 50 kg ha^{-1} for CK and FP, respectively, and 105 kg ha^{-1} for the precision management strategies.

Statistical analysis

Rice was harvested in the end of September. At maturity, three 1 m^2 areas were randomly identified in each plot and cut for grain yield determination. Harvest index (HI) was calculated as dry grain yield/aboveground dry biomass. N recovery efficiency (RE), agronomic efficiency (AE) and partial factor productivity (PFP) were calculated using the following equations:

$$\text{RE (\%)} = (\text{N uptake} - \text{N uptake at CK})/\text{N rate} * 100 \quad (1)$$

$$\text{AE (kg kg-1)} = (\text{Grain yield} - \text{Grain yield at CK})/\text{N rate} \quad (2)$$

$$\text{PFP (kg kg-1)} = \text{grain yield}/\text{N rate} \quad (3)$$

The data were analyzed with two way analysis of variance (ANOVA) using the SAS software package (Version 9.0) to test whether significant differences existed between the treatments and years. The means for treatments and years were compared with the least significant difference (LSD) test at the 0.05 probability level (at $p<0.05$).

Results

Grain yield

Rice yield was significantly influenced by rice management practices and two varieties had the same trend in three-year field experiments (Table 1). Across these three years and varieties, the GS-PRM system consistently achieved the highest yield (with an average of 10.5 t ha^{-1}), which was significantly increased by an average of 12% over the FP system (average 9.4 t ha^{-1}). The CK treatment achieved the lowest yield in three years, with an average of 6.5 t ha^{-1}.

Nitrogen use efficiency

The PRM systems significantly decreased N rate by an average of 27%, 25% and 27% over FP in 2011-2013, respectively (Table 2), and significantly increased N use efficiency over FP (Table 2). Across two varieties and the three years, the ACS-PRM system had the highest N efficiency, which increased N RE, AE and PFP by an average of 63%, 89% and 53% over FP, respectively.

Table 1 Grain yield of different rice management treatments for two varieties (Kongyu 131 and Longjing 21) in 2011-2013.

Treatment[a]	Kongyu 131			Longjing 21		
	2011	2012	2013	2011	2012	2013
CK	6.5 c	6.3c	5.5c	7.4c	7.1c	5.9c
FP	9.0 b	9.5b	8.5b	10.1b	10.6b	8.7b
ACS-PRM	10.1 a	10.8a	9.3a	11.3a	11.7a	9.8a

[a] CK, check; FP, farmer's practice; ACS-PRM, Active canopy sensor-based precision rice management.

Table 2 Nitrogen use efficiencies of different rice management treatmentsfor two varieties (Kongyu 131 and Longjing 21) in 2011-2013.

Variety		N Rate (kg ha^{-1})			RE (%)	AE (kg kg^{-1})	PFP (kg kg^{-1})
		2011	2012	2013			
Kongyu 131	CK		0				
	FP		150		39.8b	19.4b	60.3b
	PRM	108	109	110	59.8a	36.4a	92.8a
Longjing 21	CK		0				
	FP		150		37.2b	19.9b	65.2b
	PRM	108	112	112	65.1a	37.7a	99.3a

[a] CK, check; FP, farmer's practice; ACS-PRM, Active canopy sensor-based precision rice management. Within a column for each year, values followed by different letters are significantly different ($P < 0.05$).

Water use efficiency

The PRM strategy significantly reduced about of irrigation water by 29-31%, and as a result, increased water use efficiency by 59-60%, compared with FP (Table 3).

Table 3 Water use efficiency of different rice management treatments for two varieties (Kongyu 131 and Longjing 21) in 2011-2013.

Variety	Strategy	Irrigation amount (m3 ha^{-1})	Water use efficiency (kg grain m^{-3})
Kongyu 131	CK	5360 c	1.14 b
	FP	8194 a	1.11 b
	PRM	5679 b	1.78 a
Longjing 21	CK	5509 c	1.24 b
	FP	8219 a	1.19 b
	PRM	5816 b	1.89 a

[a] CK, check; FP, farmer's practice; PRM, GreenSeeker-based precision rice management.

Conclusion

The active sensor-based precision rice management system significantly increased rice grain yield, N use efficiency and water use efficiency by an average of 12%, 53-89% and 59-60%, respectively, as compared with conventional farmer's system. It has a great potential to contribute to both food security and sustainable development. More studies are needed to further evaluate this precision management systems under diverse on-farm and weather conditions.

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