DEVELOPING AN INTEGRATED RICE MANAGEMENT SYSTEM FOR IMPROVED YIELD AND NITROGEN USE EFFICIENCY IN NORTHEAST CHINA

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ABSTRACT

Site-specific nitrogen management (SSNM) strategy has been developed by scientists at International Rice Research Institute and evaluated across China for the past decade, with an average reduction of 32% of N fertilizers and 5% of grain yield increase compared with farmers' practices. Integrated rice management systems are needed to further improve grain yield for food security and sustainable development. The objective of this research is to develop an integrated rice management (IRM) system in Northeast China and evaluate it against Farmer's Practice. The IRM system increased transplanting density, decreased total N application, but split the application into 5 doses, with in-season adjustments based on chlorophyll meter diagnosis, and used modified alternative wetting and drying (AWD) irrigation systems. A randomized block experiment with 4 replications was conducted in 2010 and 2011 in Jiansanjiang, Heilongjiang Province to evaluate this integrated system against farmer's practice (FP). This experiment has 5 treatments: 1) CK, with 0 kg ha^{-1} of N; 2) Farmer's Practice (FP); 3) SSNM+AWD; 4) High Yield (HY) Management; and, 5) IRM. Preliminary analysis indicated that the IRM system could increase rice yield by an average of 9.9% in the two year experiment, as compared with FP. Partial Factor Productivity (PFP) was increased by an average of 51.17%, while agronomic N use efficiency was increased by an average of 94.62%.

Keywords: Site-specific nitrogen management, Chlorophyll meter, High yield and high efficiency, Integrated rice management

INTRODUCTION

China is facing one of the largest challenges in the twenty-first century to ensure food security with shrinking cropland and limited resources, while protecting the degrading environment (Miao et al., 2011). To address this challenge, Chinese agriculture needs to realize both high yield and high resource use efficiency simultaneously.

Rice is the most important food crop in China, with its harvesting area being 34.1% of all harvested cereal crop areas of China, and its yield being 40.3% of total cereal production（FAOSTAT，2008）. Due to the large population and limited land resources, China has always been focusing on improving rice yield per unit area, which has reached 6.55 t ha^{-1} and is 50% higher than world average yield（FAOSTAT，2008）. However, the high yield has been achieved with low resource use efficiencies. China's rice planting area is 19% of the world, and its total rice yield is 28%, however, rice in China consumes about 36% of the total N fertilizer used for rice production in the world (Heffer, 2008). Nitrogen application rates of 150 to 250 kg ha^{-1} are common and can reach over 300 $kgha^{-1}$ in some regions (Wang et al., 2001; Peng et al., 2006, 2010). Over-application of nitrogen can lead to decreased rice yield due to lodging and pests, and water pollution and eutrophication of rivers and lakes due to runoff and leaching (Peng et al., 2002; Wang et al., 2001). In addition to over-application, N application timing is also a problem. Most farmers apply all N fertilizers as basal and tillering fertilizers, resulting in oversupply of N in the earl growing season, but deficiency at later growth stages (Wang et al., 2001; Peng et al., 2006). It has been estimated that average N recovery efficiency for rice in China was about 28%, while this is much lower for farmer's practices in Jiangsu and Zhejiang Provinces（Li，2000; Wang et al., 2001).

To improve rice nitrogen use efficiency, scientists at Internal Rice Research Institute (IRRI) have developed a site-specific nitrogen management strategy (SSNM) (Peng et al., 2010). This strategy has been evaluated at different sites across Asia and can increase agronomic N efficiency and grain yield by an average of 30%~40%， and 7%~11%, respectively (Dobermann et al., 2002). In China, SSNM has been found to decrease N application by 32%, increased agronomic N use efficiency from 7.1 kg $kg^{-1}$to 13.4 $kgkg^{-1}$, but only increased yield by an average of 5% (Peng et al., 2010).

To meet the challenge of food security, it is necessary to not only increase resource use efficiency, but also continue to increase rice yield. However, during the past decade, rice yield has shown stagnant trend in most provinces in China (Fan et al., 2011). Therefore, the objectives of this research are to develop an integrated rice management system that combines SSNM with high yield management practices to realize the goal of both high yield and high efficiency compared with farmer's practices in Northeast China.

MATERIAL AND METHODS

Study Site Description

The field experiment was conducted at the Science and Technology Park of Qixing Modern Agriculture Development Center, Jiansanjiang, Heilongjiang Province（47°15′46″N， 132°38′53″E）from 2010 and 2011. This field has been under rice production since 2002, and the soil is meadow albic soil, with organic matter , pH, total N, Olsen-P, and available K being 34 g kg-1, 6.4, 160 mg kg-1, 34.7 mg kg-1， and 72.5 mg kg-1， respectively.

Experiment Design

A randomized block design was used in this study, involving 5 treatments, with 4 replications. The 5 treatments are: 1) CK, with 0 kg ha^{-1} N application. The transplanting density was 30 x 13.2 cm, with 25 hills m^{-2}, and 4 plants $hill^{-1}$. Seedling leaf age was 3.1-3.5 at transplanting. Except mid-season drainage at about leaf age 7-8, rice was under flooded conditions during the rest of the growing season ; 2) Farmer’s practice (FP), with total N application rate of 150 kg ha^{-1}, and they were all applied as basal and tillering N. Transplanting density, seeding leaf age and irrigation were the same as CK; 3)SSNM+ADW: SSNM was adopted, with regional optimum N rate (RONR) of 100 kg ha^{-1} being used as the toal N rate, and applied at 4 splits (45%, 20%, 15% and 20% for basal, tillering, leaf age 7.5 and heading stages, respectively). The third and fourth application rates were adjusted based on chlorophyll meter readings. Modified alternate wetting and drying irrigation (AWD) was adopted. From transplanting to regreening, the soil was saturated, but no water was accumulated on the soil surface for 2-3 days, then 2-3 cm water table was maintained. From regreening to before tillering stage (N-n leaf age), intermittent wetting was used. From N-n leaf age to N-n+2 leaf age, alternate wetting and drying was adopted. From N-n+3 leaf age to 5 days after heading, intermittent wetting was used. From 5 days after heading to 40 days after heading, alternate wetting and drying was used. All other management practices were the same as FP; 4). High Yield Management (HY): Transplanting density was increased to 30 x 10 cm, with 33 hills m^{-2} and 4 seedlings $hill^{-1}$. Total N application rate was 140 kg ha^{-1}, and was split into five doses: before transplanting (basal application), tillering stage, panicle initiation, meiotic stage and heading. Irrigation practice was the same as OWNM treatment; 5). Integrated Rice Management (IRM): adopting the same transplanting density and irrigation practices as HY treatment, as well as SSNM.

The commonly planted japonica rice variety Kongyu 131 was used in this study, which has 11 leaves, 4 elongation nodes, and 127 maturity days. The transplanting dates were May 17 and 10 for 2010 and 2011, respectively. Each plot was 6m × 8m = $48m^2$. Phosphorus fertilizer in the form of $Ca(H_2PO_4)_2$ were incorporated into the soil before transplanting. Potassium fertilizers in the form of KSO4l were split into 2 doses: 50% as basal application and 50% was applied at 7.5 leaf age. The detailed application rates for different treatments can be found in Table 1.

Plant Sampling and analysis

At panicle initiation, heading and maturity stage, 6 hills or 3 hills (heading and maturity) were randomly selected for aboveground biomass measurement. After cleaning with water, the plants were oven dried for 30 minutes at 105℃ and then at 70℃ until constant weight, and then determined for dry biomass and analyzed for N, P and K concentrations.

At maturity stage, three 1m2 area were randomly identified in each plot and cut for estimating grain yield.

Statistical Analysis

Harvest Index = dry grain yield/Aboveground dry biomass

N recovery use efficiency (%)= (N uptake－N uptake at N omission plot) / N application rate；

N Agronomic (kg grain kg^{-1} N) = (Grain yield－Grain yield at N omission plot) / N application rate；

N Partial Factor Productivity (PFP) (kg grain kg^{-1} N)=grain yield / N application rate；

Analysis of variance was conducted using SAS software.

Table 1 Fertilizer application rates and timing in different rice management treatments.

Treatment.	Basal N	1st Topdressing		2nd Topdressing		3rd Topdressing		4th Topdressing		N	P_2O_5	K_2O
		Leaf Age	N	Leaf Age	N	Leaf Age	N	Leaf Age	N			
	kg ha^{-1}		kg ha^{-1}		kgha^{-1}		kgha^{-1}		kgha^{-1}	--------kg ha^{-1}-------		
N0	-	-	-	-	-	-	-	-	-	0	30	60
FP	60	4	30	6	60	-	-	-	-	150	60	50
SSNM+ADW	45	4	20	7.5	15 *	10	20**	Heading	-	100	40	90
HY	50	4	25	7.5	20	10	30	Heading	15	140	75	120
IRM	45	4	20	7.5	15 *	10	20**	Heading	10	110	50	105

* N topdresing rate at panicle initiation (leaf age 7.5) was 20 kg ha^{-2} when the SAPD readings of the top 2 fully expanded leaf was < 38, and 15 kg ha-1 when SPADreading was 38～40, and 10 kg ha-1 when SPADreading was > 40.

**At leaf age 10, topdressing N rate was 30 kg ha-1 when SPAD < 38, and 20kg ha-1 when SPAD was 38-40, and when 10 kg ha-1 when SPAD>40.

SSNM+ADW: site-specific N management + alternative drying and wetting.

RESULTS AND DISCUSSION

Soils in Sanjiang Plain in Northeast China are very fertile, with high indigenous N supplies. The plot without any N application could produce about 7.5 t ha^{-1} rice yield. Farmer's practice (FP) produced 9.55 and 10.12 t ha^{-1} in 2010 and 2011, respectively. Optimized water and N management (OWNM) strategy achieved similar yield as FP, but saved 1/3 of N fertilizers. The high yield management (HY) strategy only slightly reduced the N rate, but split the N application into five doses. Together with improved water management and increased transplanting density, this HY strategy significantly increased rice yield (10.57 and 11.36 t ha^{-1} in 2010 and 2011, respectively). N recovery efficiency (RE) and agronomic efficiency (AE) were higher than either FP or OWNM strategy. The integrated rice management (IRM) strategy further improve N management over the HY strategy by combining high yield management practices with SSNM practice, and achieved similar yield as the HY strategy, but further improved N use efficiencies.

Table 3 Grain yield and its components in different treatments

Year	Treatment	1000-Grain Weight	Grain yield	Harvest index
		---g---	----t ha^{-1}---	
2010	N0	27.38a	7.61c	0.54ab
	FP	26.41c	9.55b	0.54ab
	SSNM+ADW	27.17ab	9.41b	0.51b
	HY	27.06ab	10.57a	0.55a
	IRM	26.82bc	10.29a	0.53ab
2011	N0	28.36a	7.46c	0.50b
	FP	27.38b	10.12b	0.53ab
	SSNM+ADW	27.39b	10.15b	0.56a
	HY	27.09b	11.36a	0.54ab
	IRM	27.26b	11.34a	0.54ab

Values followed by different letters in the same column are significantly different at the 0.05 probability level in the same year.

SSNM+ADW: site-specific nitrogen management + alternative drying and wetting.

Table 4 Efficiencies of N utilization and Maturity nitrogen concentration in different treatments

Year	Treatment	N Rate	RE	AE	PFP
		--kg ha^{-1}--	--%--	--$kgkg^{-1}$--	--$kgkg^{-1}$--
2010	CK	0			
	FP	150	24.6c	13.0c	63.7c
	SSNM+ADW	100	41.8b	18.0bc	94.4a
	HY	140	43.2ab	21.2ab	75.5b
	IRM	109	47.7a	24.5a	95.2a
2011	CK	0	-	-	-
	FP	150	25.3c	17.7c	67.5c
	SSNM+ADW	100	39.7b	26.9b	101.5a
	HY	140	50.8a	27.8b	81.1b
	IRM	110	50.7a	35.2a	103.1a

RE: N recovery efficiency; AE: Agronomic N use efficiency; PFP: Partial factor productivity of fertilizer-N.

Values followed by different letters are significantly different at the 0.05 probability level in the same year.

SSNM+ADW: site-specific nitrogen management + alternative drying and wetting.

CONCLUSION

In this study, we developed an integrated rice management system involving increased transplanting density, modified alternative drying and wetting irrigation and chlorophyll meter-based site-specific N management. This strategy significantly increased rice yield and nitrogen use efficiencies compared with farmer's practice. More studies are needed to evaluate crop canopy sensor-based integrated precision rice management systems in Northeast China.

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