EVALUATING DIFFERENT NITROGEN MANAGEMENT STRATEGIES FOR THE INTENSIVE WHEAT-MAIZE SYSTEM IN NORTH CHINA PLAIN

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ABSTRACT

The sustainable agricultural development involves both environmental challenges and production goals to meet growing food demand. However, excessive nitrogen (N) applications are threatening the sustainability of intensive agriculture in the North China Plain (NCP). Improved N management should result in greater N use efficiency (NUE) and producer profit while reducing the risk of environmental contamination. Therefore, developing and disseminating feasible N management strategies that will achieve both high yields and high NUE are crucial. Many recently developed N management strategies have been successful in improving NUE and reducing N losses while achieving similar grain yield as farmer's practice. The objective of this study was to evaluate different N management strategies for the intensive wheat-maize double cropping system in NCP. Field experiments were conducted from 2008 to 2012 at Quzhou Experiment Station of China Agricultural University in Hebei Province. The six N management strategies evaluated were (i) no N fertilizer as control (N0), (ii) soil mineral N (N_{min}) test-based in-season root-zoon N management strategy (IRNM-soil N_{min}), (iii) GreenSeeker-based precision N management strategy (PNM-GS), (iv) green window-based in-season N management strategy

(INM-GW), (v) regional optimum N management strategy (RONM), (vi) farmer's N practice (FNP). The N fertilizer rate determined with IRNM-soil N_{min}, PNM-GS, INM-GW and RONM were significantly reduced by 45%, 62%, 46% and 40% compared to the FNP, respectively, without significant changes in grain yield. As a result, the IRNM-soil N_{min}, PNM-GS, INM-GW and RONM increased N use efficiency. Future studies are needed to integrate this strategy into high yield crop management system to achieve both high yield and high NUE simultaneously for food security and sustainable development.

Keywords: Precision nitrogen management, In-season nitrogen management, GreenSeeker sensor, Soil N_{min} test, Nitrogen use efficiency, Nitrogen losses

INTRODUCTION

Mismanagement of N fertilizers has been common (Miao et al., 2011) and NUE (referring to recovery efficiency of N, RE_N) has been declining consistently in China. Therefore, developing efficient N management strategies and technologies for crops in China is crucially important for agricultural sustainability and food security.

A first step to improve N management in China is to recommend a regional optimum N rate (RONR) for the whole region (a country or a township) based on multi-site-year N response experiments to avoid significant over- or under-application problems (Zhu, 2006). The RONR is a good starting point and does not require any soil or plant testing. However, it is still general in nature and does not predict site-specific or year-specific N requirements (Cui et al., 2013).

An in-season root-zoon N management (IRNM) system based on soil N_{min} tests has been developed for the intensive wheat-maize double cropping system in the NCP (Chen et al., 2006; Zhao et al., 2006). In this strategy, the total amount of N fertilizer is subdivided into several applications during the growing season, while the optimal N rate for each application is based on the soil nitrate-N tests in the root zone and a target N value in root soil layer for the corresponding growth period of the crop. Soil nitrate-N was analyzed by nitrate-N-test strips and reflectometer in the field.

Active crop canopy sensors can be used for real-time non-destructive diagnosis of crop N status, without the need of plant or soil testing. They are more efficient and practical for large area applications than soil or plant testing methods (Yao et al., 2012; Cao et al., 2013). Raun et al. (2001) successfully predicted in-season yield potential at critical growth stages for winter wheat using normalized difference vegetation index (NDVI) obtained with an active canopy sensor. A nitrogen fertilizer optimization algorithm (NFOA) was developed to make in-season N recommendation for winter wheat (Raun et al., 2002, 2005b). N fertilization based on this algorithm increased NUE more than 15% when compared to traditional practice (Raun et al., 2002). This strategy was further developed for winter wheat in an intensive agricultural region of NCP (Li et al., 2009) and for rice in Northeast China (Yao et al., 2012).

The need exists for a simple system that cereal grain producers can use to quickly estimate required N topdressing rates. The calibrations stamp consists of a simple apparatus and procedure that can be easily used by farmers to determine midseason N rates based on visual observation without an optical sensor or other instrumentation (Raun et al., 2005a). This approach is based on the realization that visually inspecting a group of plots with varying levels of preplant N will show which N rates achieve maximum forage production, which can be used to estimate the amount of additional N needed to achieve optimum grain yield.

Some on-farm experiments were conducted to evaluate different N management strategy for different crops (Li et al., 2009; Yao et al., 2012). However, review of the literature indicated that there are no reported studies that have focused on evaluating all these different N management strategies for intensive and high-input agricultural production systems in NCP. Therefore, the objectives of the study were to evaluate the potentials of the RONM, IRNM-Soil N_{min}, PNM-GS, INM-GW, and FNP for the winter wheat- summer maize double cropping system in an intensive agricultural region of NCP.

MATERIALS AND METHODS

Study Site and Experiment Design

A field experiment was conducted from October 2008 to June 2012 at the Quzhou Experiment Station, China Agriculture Universtiy (QZ, 115.0°E, 36.5°N, 37m above sea level), located in Quzhou Country, Hebei Province. Quzhou Country is typical area of the NCP, where winter wheat and summer maize annual rotation is the most important agricultural production system.

A winter wheat and summer maize rotation system was used for this study and seven successive crops were grown on the same plots over the four years period. Winter wheat was generally planted in early October using a seeder with a row spacing of 0.15 m and seeding rate of 300 kg ha-1 and harvested in early June of the following year. After winter wheat harvest, summer maize was planted immediately with a row spacing of 0.6 m and the final density of maize was 6.5-7 plants m^{-2} and harvested in early October each year. The cultivars used in this study were Liangxing 99 and Zhengdan 958 for winter wheat and summer maize, respectively. Both cultivars were commonly used in this region. A randomized complete block design was employed with six different N management strategies treatments and four replications and the plot size was 54 (6×9) m^2. The treatments included (i) N0, (ii) IRNM-soil N_{min}, (iii) PNM-GS, (iv) INM-GW, (v) RONM, (vi) FNP. The IRNM-soil N_{min} treatment followed the in-season root-zone N management for the NCP reported elsewhere (Chen et al., 2006; Cui et al., 2008). The amount of N fertilizer applied at the beginning of each growing period was determined by deducting the amount of soil N_{min} in the root zoon from the target N value, which was estimated based on yield target and crop N uptake. For the PNM-GS treatment, the topdressing N rate was estimated based on the GreenSeeker sensor-based method. For the INM-GW treatment, the topdressing N rate was based on mid-season visual estimation of additional fertilizer N needed. The RONM treatment was the method recommended by Chinese agronomists and has been proved capable of achieving good yield. The IRNM-soil N_{min} treatment, PNM-GS treatment, INM-GW treatment and RONM treatment received the same basal N rate. The FNP treatment received 150 kg N ha^{-1} before planting and 150 kg N ha^{-1} at shooting stage for winter wheat and at ten-leaf stage for summer maize, which is typical for Hebei province. The total chemical N input of the different N management strategies from 2008 to 2012 is listed in Table 1, which as urea were applied as two splits for all plots: basal N before planting and topdressing N at shooting stage for winter wheat and at ten-leaf stage for summer maize.

Sampling and Laboratory Procedures

Five soil samples were taken in each plot at 30 cm increments to a depth of 90 cm before planting, N application, and after harvest. Soil samples, before planting and after harvest, were sieved to pass a 2 mm screen, mixed and extracted with 0.01 mol L^{-1} $CaCl_2$ solution, and analyzed for soil mineral N (NH_4-N + NO_3-N) using Continuous Flow Analysis (TRAACS 2000 system, Bran and Luebbe, Norderstedt, Germany) in the laboratory. Soil water content was also determined at the same time after oven-drying at 105℃ to a constant weight. Soil samples before N application were extracted with 1:1 ratio of soil to distilled water. Nitrate-N-test strips and reflectometer were used to analyze soil nitrate-N content and calculated the optimum N rate in the field. Soil water content was measured by alcohol burning method.

At the winter wheat harvested stage, three 1 m^2 in the middle of each plots were harvested manually to determine fresh grain yield. For summer maize final harvest, 18.8 m^2 (four rows, 7 m length) in the middle of each plots were harvested to determine fresh cob and stover yield. Six subsamples were randomly selected from the harvested summer maize plants and separated into stover and cob. All plant samples were oven dried at 70℃ in a forced-draft oven to constant weight for the determination of dry matter weight. Subsamples of grain and stover that passed through a 1 mm screen in a sample mill were analyzed for N content by the Kjedahl method. The plant N uptake was determined by multiplying plant N concentration by dry biomass. The N surplus was defined as N application rate minus aboveground N uptake.

Table 1. Annual chemical N fertilizer (kg ha^{-1}) input for winter wheat and summer maize from 2008 to 2012 in six different N management strategies.

Crop	Year	Different N management strategies					
		N0	IRNM-soil N_{min}	PNM-GS	INM-GW	RONM	FNP
Wheat	08/09	0	160	169	220	180	300
	09/10	0	170	85	180	180	300
	10/11	0	89	150	180	180	300
	11/12	0	175	90	180	180	300
	Average	0	149	123	190	180	300
Maize	09	0	208	165	140	180	300
	10	0	163	90	120	180	300
	11	0	190	90	120	180	300
	Average	0	187	115	127	180	300
All	Total	0	1155	808	1140	1260	2100

Data Analysis

Recovery nitrogen efficiency (RE_N), agronomic nitrogen efficiency (AE_N), and partial factor productivity (PFP_N) were calculated using Equations (1) to (3).

$$RE_N=(UN\text{-}U0)/N_{fer}\times 100 \quad (1)$$

$$AE_N=(YN\text{-}Y)/N_{fer} \quad (2)$$

$$PFP_N=YN/N_{fer} \quad (3)$$

where UN and U0 are crop N uptake in applied N plots and N0 plots, YN and Y0 are grain yield in N application plots and N0 plots, and N_{fer} is N from the applied fertilizer.

Data were analyzed following analysis of variance by SPSS 18.0 (SPSS Inc., Chicago, IL, USA), and means of N treatments were compared based on least significant difference (LSD) at 0.05 level of probability.

RESULTS AND DISCUSSION

Grain yield and

There was no significant difference of grain yields between the IRNM-soil Nmin, PNM-GS, INM-GW, RONM, and FNP treatments in all successive winter wheat and summer maize except for the 2008-2009 winter wheat season and 2009 summer maize season (Fig. 1). For the 2008-2009 winter wheat season, the IRNM-soil Nmin treatment was significantly less than other treatment except for RONM treatment, while for the 2009 summer maize season, the IRNM-soil Nmin treatment was only significantly less than FNP treatment and no significant difference with other treatment. The grain yield in the control treatment (N0) was significantly less than those in other different N management strategies treatments for all years, with an average of 2.8 Mg ha^{-1} for winter wheat and 5.8 Mg ha^{-1} for summer maize (Fig. 1).

Chemical N fertilizer input

Over the 4-year study period, the N application rate based on IRNM-soil N_{min}, PNM-GS, INM-GW, and RONM saved averaged 51%, 59%, 37%, and 40% for winter wheat compared with the chemical N applied in FNP, respectively. For summer maize, the N rates based on IRNM-soil N_{min}, PNM-GS, INM-GW, and RONM saved averaged 38%, 62%, 58%, and 40% compared with FNP, respectively. These results clearly indicate that the N management strategies can successfully decrease N rates while maintaining grain yield. These results clearly indicated that the PNM-GS strategy can successfully decrease N rates while maintaining grain yield.

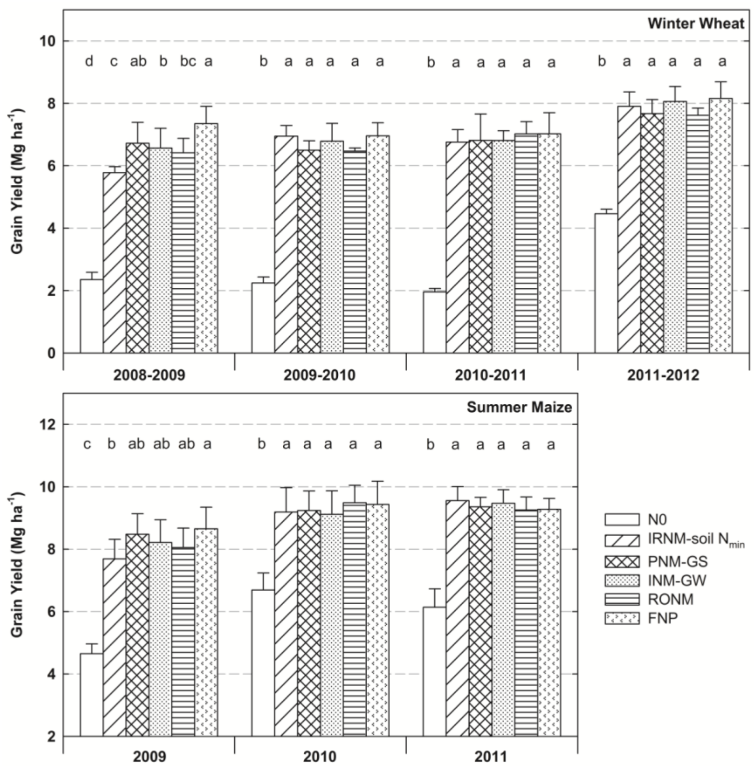

Fig. 1. Effect of different N management strategies on grain yields of winter wheat and summer maize in the 4 experimental years. Different letters indicate significant differences among treatments at P=0.05.

N Use Efficiency

All the four N management strategies increased N use efficiency over FNP for both winter wheat and summer maize (Table 2). Across the four following seasons for winter wheat, the highest PFP_N, RE_N and AE_N were obtained by the PNM-GS strategy with a value of 54.9 kg kg^{-1}, 70.6% and 32.5 kg kg^{-1}, while the lowest PFP_N, RE_N and AE_N were observed by FNP treatment with a value of only 24.6 kg kg^{-1}, 42.1% and 15.4 kg kg^{-1}, respectively. The PNM-GS strategy increased PFP_N, RE_N and AE_N by an average of 123%, 68% and 111% over FNP, respectively. Other N management strategies almost had the similar N use efficiency. For summer maize, the highest PFP_N and AE_N were also obtained by the PNM-GS strategy with a value of 78.5 kg kg^{-1} and 27.8 kg kg^{-1}, respectively, which were an increase of 158% and 153% over FNP treatment. The highest value of RE_N was 58.6%, which observed by INM-GW strategy and increased 113% compared to FNP treatment. Similar to winter wheat, the FNP treatment had the lowest PFPN, REN and AEN with a value of only 30.4 kg kg^{-1}, 27.5% and 11.0 kg kg^{-1}, respectively. The IRNM-soil N_{min} and the RONR treatments had the similar value of PFP_N, RE_N and AE_N, which lower than the PNM-GS and the INM-GW strategies but still higher than FNP treatment. Overall, these results clearly indicated that the PNM-GS strategy has good potential to increase N use efficiency for both winter wheat and summer maize.

Table 2 Average N application rate, grain yield, N uptake, and N use efficiency of six different N management treatments for winter wheat in four seasons and summer maize in three seasons.

Crop	Treatment	Partial factor productivity ($kg\ kg^{-1}$)	Recovery efficiency (%)	Agronomic efficiency ($kg\ kg^{-1}$)
Winter Wheat				
	N0	-	-	-
	IRNM-soil N_{min}	44.6	67.3	26.0
	PNM-GS	54.9	70.6	32.5
	INM-GW	37.1	59.8	22.6
	RONR	38.2	59.0	22.9
	FNP	24.6	42.1	15.4
Summer Maize				
	N0	-	-	-
	IRNM-soil N_{min}	47.1	30.8	16.0
	PNM-GS	78.5	56.4	27.8
	INM-GW	70.3	58.6	24.5
	RONR	49.6	40.5	17.3
	FNP	30.4	27.5	11.0

CONSLUSIONS

The results of this study indicated that the N fertilizer rate determined with IRNM-soil N_{min}, PNM-GS, INM-GW and RONM were significantly reduced 45%, 62%, 46% and 40% compared to the FNP, respectively, without significant change in grain yield. As a result, the IRNM-soil N_{min}, PNM-GS, INM-GW and RONM increased N use efficiency. Future studies are needed to integrate this strategy into high yield crop management system to achieve both high yield and high NUE simultaneously for food security and sustainable development.

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