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Effect of nitrogen management during the panicle stage in rice on the nitrogen utilization of rice and succeeding wheat crops

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ABSTRACT

Background and aims: The main objectives of this paper were to investigate the absorption and utilization of nitrogen applied at the panicle stage in rice for promoting and protecting spikelet and the effect of residual nitrogen on the utilization of nitrogen in the succeeding wheat crop in the rotation system.
Methods: A field experiment was combined with a mini-plot experiment with ^{15}N labelled urea applied at the panicle stage in rice. The experiments included three nutrient management treatments: F, S1 and S2. 126 kg N ha^{-1}, 120 kg N ha^{-1}, 72 kg N ha^{-1} labeled with 30 atom% excess ^{15}N were applied in rice, respectively.
Results: (1) Compare to conventional fertilizer management (F), the optimized fertilizer management (S1&S2) reduced the amount of nitrogen applications, whereas the rice and wheat yield did not decrease, and nitrogen use efficiency was improved. (2) At rice harvest, 4.7–10.7% of the fertilizer ^{15}N was found in the 0–20 cm profile. The fertilizer ^{15}N absorbed by the wheat during the period from jointing to heading accounted for 37.0%-51.1% of the total ^{15}N absorbed. (3) The sum of the ratio of nitrogen absorption from the rice panicle fertilizer applied to the crops (rice and wheat) and ratio of soil residue nitrogen in the wheat field were ordered S2 > S1 > F.
Conclusion: The optimized fertilization management reduced the loss of the rice nitrogen in the rice–wheat rotation system through improved recycling of rice panicle nitrogen applied in the crop-soil system.

1. Introduction

Rice–wheat rotation is widely adopted in the Yangtze River Valley in China, and its sustainable production directly impacts national food security (Zhang et al., 2005). Changing hydrothermal conditions led to rice–wheat rotation system in nutrient cycling are obviously different from the single upland or wetland ecosystems (Fan et al., 2008). Nutrient management aimed to use a combination of nutrients by taking measures to ensure that production increased in order to achieve or maintain a target, while coordinating the efficient use and environment friendly nutrient resources, and steadily improve soil productivity (Anil, 2009; Akram et al., 2007; Walia et al., 2010). However, several problems have occurred in the current rice–wheat rotation system, including a low nutrient utilization efficiency and nutrient resource loss caused by high nutrient inputs and decreased soil nutrient supply capacity (Fan et al., 2008; Penget al. 2002; Shi 2003; Zhang et al., 2007). Therefore, it is meaningful to study the nutrient cycling in rice–wheat rotation system.

Nitrogen is the primary limiting nutrient for crop yield; however, excessive application of nitrogen fertilizer leads to a reduction of nitrogen utilization efficiency and environmental problems. The fate of nitrogen after fertilizer application primarily follows three routes: uptake by crop, residues in soil, and losses by leaching and volatilization (Kowalenko, 1989; Zhu, 2008), with all three interconnected. Determining the fate of nitrogen is important for

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determining optimum nitrogen management so that crop production and environmental protection can be coordinated.

A number of previous studies have addressed the fate of nitrogen in farmland, and the results have shown that in China, the residual fertilizer nitrogen in the soil from the current season usually accounts for 15–30% of the amount of applied nitrogen, whereas the ammonia volatilization of nitrogen accounted for 1–47% (Zhu, 2002), which indicates that the nitrogen uptake efficiency of the crops in China is far below the international level 40–60% and even significantly lower than what was observed in the 1980s (Zhang et al., 2008). The fate of fertilizer nitrogen is affected by many factors, including different crop systems, climate and soil conditions and fertilization, cultivation and management practices; however, the fate of nitrogen from rice panicle fertilizer in rice–wheat rotation systems under different nutrient management practices has rarely been investigated. In addition, the effectiveness of the nitrogen residues for the succeeding crop varies widely with the crop species, nitrogen fertilizer and rate and nitrogen fertilizer application method (Huang et al., 2002; Li et al., 1995). Ju et al. (2003) found that residual nitrogen was partially absorbed by the succeeding crop, and the recovery rate of the residual nitrogen accounted for 7.5% of the total nitrogen application. Applying the appropriate amount of nitrogen fertilizer and making full use of the residual nitrogen fertilizer can sustain high yields in crops while reducing scavenging of the soil nutrients by crops and eliminating large quantities of residue in soil and losses.

Under various crop rotation conditions, investigations on the effect of residual nitrogen fertilizer could provide a theoretical basis for determining appropriate fertilization rates for succeeding crops. Therefore, the fate of fertilizer nitrogen applied to the panicle of current season rice and its influence on the absorption and utilization of nitrogen in succeeding wheat crops under different nutrient managements were studied.

2. Materials and methods

2.1. Experimental design

2.1.1. Field experiment

The field experiments were conducted at the Danyang test base of Nanjing Agricultural University (longitude 119°10′, latitude 34°36′). The soil type was yellow loam soil, and the main physicochemical properties were as follows: pH 6.80, organic matter 17.15 g kg^{-1}, total nitrogen 0.99 g kg^{-1}, rapidly available nitrogen 86.40 mg kg^{-1}, available phosphorus 13.6 mg kg^{-1}, and K 93.5 mg kg^{-1}.

The experiment was performed in a rice–wheat crop system from rice season in 2012 to wheat season in 2014. The rice variety was Wuyunjing 23, and it was sown on May 30, 2012 and May 28, 2013 and transplanted on June 28, 2012 and June 27, 2013. The planting density was 25 plantings m^{-2} in the row and 30 cm × 13 cm spacings at 3 seedlings per planting. The plots were separated by ridges embedded with plastic film to form a plot size of 4.5 m × 7 m. The wheat variety was Yangmai 16, and it was sown on November 11, 2012 and November 6, 2013 by broadcast sowing at a rate of 225 kg hm^{-2}. The experiments included three nutrient management treatments: conventional nutrient management, which is widely adopted by the local farmers (F), nutrition optimization management 1 (S1, achieving high yield through optimal application times) and nutrition optimization management 2 (S2, achieving high yield and high nitrogen efficiency through optimal application times and reduced application rates); the application rates are listed in Table 1. A blank control (CK) was included in which nitrogen fertilizer was not applied. The experiment adopted a randomized block design with three replicates.

Table 1
Fertilizer application rates for experimental treatments at different growth stages of rice and wheat (kg hm^{-2}).

Treatment	Rice			Wheat		
	F	S1	S2	F	S1	S2
Total nitrogen	315	300	180	190	225	180
Basal	126	120	72	102.5	90	72
Tillering	63	60	36	-	45	36
Spikelets-promoting	126	60	36	87.5	45	36
Spikelets-protecting	-	60	36	-	45	36
Total phosphorous(P_2O_5)	75	90	75	67.5	105	90
Basal	75	90	75	67.5	60	45
Jointing	-	-	-	-	45	45
Total potassium(K_2O)	75	120	75	67.5	105	90
Basal	75	60	-	67.5	60	45
Jointing	-	60	75	-	45	45

F: conventional nutrient management. S1: nutrition optimization management 1. S2: nutrition optimization management 2.

2.1.2. ^{15}N fertilizer mini-plot experiment

We will use the following terminology for the different fertilizing period of the experiment. 'Panicle fertilizer' is the fertilizer aiming to promote and protect spikelet and applied at panicle growth stage in rice. A mini-plot ^{15}N-labelled test was performed at the same position in each of the plots. The mini-plot used a PVC cylinder 50 cm in diameter and 40 cm in height, and approximately 20 cm of the cylinder was inserted underground to reach the plough pan. The planting density and fertilizer rate in the mini-plot were the same as those in the plot. Irrigation in the rice season, basal fertilizer and tillering fertilizer in the mini-plot were the same as those managed in the field plot. Panicle fertilizer was applied using ^{15}N-labelled urea with 30% isotope abundance. The fertilizer in the succeeding wheat season was the same as that of the field with ordinary fertilizer.

2.2. Meteorological conditions

Seasonal changes in the daily average temperature and relative humidity are shown in Fig. 1. The average daily temperatures, maximum and minimum average daily temperatures during the rice growing season in 2012 were 24.4 °C, 29.4 °C, 20.9 °C, respectively, but in 2013 those were 29.0 °C, 33.7 °C, 19.4 °C, respectively. The precipitation during the rice season in 2012 tended to be distributed in vegetative stage while that was well-distributed from June to September in 2013. The average daily temperatures, maximum and minimum average daily temperatures during the wheat growing season in 2013 were 10.3 °C, 15.5 °C, 6 °C, while in 2014 those were 11.3 °C,17.3 °C, 6.8 °C. Compared with 2013, 2014 had more precipitation before heading stage in wheat, and less precipitation in kernel-filling period.

2.3. Sample collection and analysis

An analysis of the above ground biomass and nitrogen content of the plants was conducted at the inverse fourth leaf stage (jointing stage of rice), heading stage and maturity stage, in which 60 hills per plot were investigated and the average number of tillers per hill was counted. Three representative hills were selected from each plot based on the average number of tillers in the field, and the stem and sheath, blade and spike were separated and desiccated at 105 °C for 30 min and then dried at 80 °C for 72 h until constant weight, which was measured. The plant samples from the mini-plot were collected and replanted to maintain the appropriate population density. The samples were digested with H_2SO_4-H_2O_2 and analyzed for total nitrogen using the Kjeldahl method. Soil samples from the 0–20 cm layer were collected after each harvest and