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RESEARCH ARTICLE

Optimize nitrogen fertilization location in root-growing zone to increase grain yield and nitrogen use efficiency of transplanted rice in subtropical China

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Abstract

The optimized nitrogen fertilization location differs in different rice-growing regions. We optimized nitrogen deep-point application in root-growing zone (NARZ) for transplanted rice in subtropical China. Field plot experiments were conducted over two years (2014–2015) in a double-rice cropping system to evaluate the effects of nitrogen (N) fertilizer location on grain yield and N use efficiency (NUE). Four different nitrogen deep-point application methods (DN) were compared with traditional broadcast application (BN) using granular urea. The results showed that grain yield, recovery efficiency of N (RE_N), agronomic efficiency of N (AE_N), and partial factor productivity of N (PFP_N) significantly increased 10.3–63.4, 13.7–56.7, 24.7–201.9 and 10.2–63.4%, respectively, in DN treatment compared to BN, respectively. We also find that DN treatments increased grain yield as well as grain N content, and thus grain quality, in comparison with conventional BN treatment. Correlation analysis indicated that significant improvement in grain yield and NUE mainly resulted from increases in productive panicle number and grain N content. In our proposed NARZ method, granular urea should be placed 0 to 5 cm around the rice seeding at a 12-cm depth druing rice transplanting. In NARZ, balanced application of N, P and K further improved grain yield and NUE over treatments with a single N deep-point application. High N uptake by the rice plant did not cause significant soil fertility depletion, demonstrating that this method could guarantee sustainable rice production.

Keywords: N recovery efficiency, grain yield, deep-point application, N application in root-growing zone

1. Introduction

To meet the food demand of a growing population, crop yield improvement is an urgent issue on both global and local scales. Nitrogen (N) fertilizer plays an important role in increasing crop yield because of the tight relationship between yield and plant N uptake (Cassman *et al.* 2003). Thus farmers typically apply excessive N fertilizer to obtain a high yield ignoring the appropriate requirement for crop growth in China (Peng *et al.* 2006). However, because of

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the ammonia volatilization, denitrification, surface runoff and leaching in paddy cultivation systems, N fertilizer recovery efficiency is relatively low and has become a threat to the environment in China.

Several methods, such as adjustment of fertilizer rate, regulation of fertilizer and irrigated water, deep or split application and balanced fertilization were proposed to improve N use efficiency (NUE), reduce nutrient losses and guarantee stable or high crop yield (Yan *et al.* 2008). Among the methods, deep placement of N has been proposed for a long time, and has been found to reduce ammonia volatilization and increase N use efficiency for irrigated rice (Bautista *et al.* 2001). Although broadcast application of N fertilizers is still the most common practice for irrigated rice in China, mechanical deep N application is now drawing more and more attention and is encouraged by the Chinese government.

Before widespread promotion and mechanical adoption, N deep application should be well-studied and optimized for specific crops in China. In many previous field experiments, deep fertilization is always mechanically applied only during the seedling stage in direct seeding rice fields, then the remaining urea is broadcasted in the tillering, jointing, and earring stages (Liu *et al.* 2015). However, much N is lost in the broadcast stage using this method. Several studies have emphasized the use of modified N materials with different granularities, such as urea supergranules (USG) and briquette N for deep placement (Mohanty *et al.* 1999; Gaudin and D'Onofrio 2015). However, most farmers are reluctant to use these materials because of added cost or labor needed prior to the actual use. Commercially available, granular N is the most practical solution. The depths requirements for N fertilizer placement are quite different depending on region. For example, the placement is 5–10 cm in India (Mohanty *et al.* 1999), 7–10 cm in Madagascar (Gaudin 2012), and down to 40 cm in Bangladesh (Huda *et al.* 2016). Those previous researches indicate that the optimized fertilization depth varies in different soils.

To optimize the position of N fertilizer deep application in subtropical China, we believe the key strategy is to synchronize N fertilizer diffusion and rice root extension over the rice growing. Here we propose an accurate deep-point N fertilizer application method during rice transplanting which is named as "nitrogen deep-point application in root-growing zone (NARZ)". The central concept of NARZ is to apply N fertilizer close to rice seedling root at an appropriate distance to ensure that N fertilizer diffusion matches the rice root growth rate over the course of the rice growing season. We propose this method will produce high grain yield and improve NUE. To test our hypothesis, we carried out field plot experiments over two years (from April 2014 to November 2015), using granular urea, to examine the effects of NARZ on double-rice (*Oryza sativa* L.) cropping systems in subtropical China. Grain yield, NUE and soil nutrient contents were determined. The effects of NARZ on increasing these soil fertility metrics are further discussed here.

2. Materials and methods

2.1. Field experiment description

The field site was located in Sixi Town, Jiangxi Province of China (115°09´32´´E, 28°32´29´´N). This region has a typical monsoon climate and annual precipitation is 1 700 mm, annual average temperature of 17.6°C, and a frost free season of 276 days. Soil in the test field was paddy soil derived from river alluvial deposit, classified as Fe-accumul-Stagnic Anthrosols. Soil physico-chemical characteristics include a pH of 4.96, soil organic carbon (SOC) 20.5 g kg^{-1}, total N 1.75 g kg^{-1}, total phosphorus (P) 0.65 g kg^{-1}, total potassium (K) 27.7 g kg^{-1}, available N 191 mg kg^{-1}, available P 42.6 mg kg^{-1}, and available K 92.0 mg kg^{-1}. Double-rice (*O. sativa* L.) was planted in both 2014 and 2015 in present study. Early rice (conventional *indica* rice, Zhongjiazao 17) was transplanted in late April and was harvested at late July. Late rice (conventional *indica* rice, Wufengyo T025) was transplanted immediately after early rice and harvested in November.

The six treatments, with four random replicates in the field experiment were as follows: no N application (CK), N conventional broadcast application (BN), N deep application (12 cm below soil surface with the rice seedling, DN+RB12), N deep application (5 cm away from the rice seedling and 7 cm below surface, DN+A5B7), N deep application in one point (5 cm away from the rice seedling and 12 cm below surface, DN+A5B12), and NPK deep application (12 cm right below soil surface with the rice seedling, DNPK+RB12).

Treatment plots for CK and BN was 6 m×7 m and 2 m×2 m for DN+RB12, DN+A5B7, DN+A5B12 and DNPK+A5B12 treatments. The treatment plots were laid out in a completely randomized design for field experiments. Planting density in each plot was consistent and equivalent to 1.8×10^5 basic seedlings ha^{-1}. N fertilizer was a commercial granular urea. N was applied at a rate of 135 and 165 kg ha^{-1} for early and late rice, respectively, using a conventional N fertilization method. Split N fertilization was performed using a conventional method (treatment BN) with 40% basal, 30% tiller, and 30% booting N input for early and late rice, while urea was applied as a single basal fertilizer in DN treatments. Calcium-magnesium phosphate (P_2O_5, 90 kg ha^{-1}) and KCl (K_2O, 150 kg ha^{-1}) were also amended as single basal fertilizer to each plot.

Urea, calcium-magnesium phosphate, and KCl were blended and broadcasted evenly to the soil surface after flooding and rice transplanting in BN and CK (excluding