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Effects of different controlled-release nitrogen fertilisers on ammonia volatilisation, nitrogen use efficiency and yield of blanket-seedling machine-transplanted rice

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ABSTRACT

Recently, a novel controlled-release N fertiliser (CRNF) application method using basal CRNF combined with urea top-dressing at the tillering stage has been proposed to enhance rice yield and N use efficiency (NUE). However, its effect on ammonia volatilisation (AV) loss and the yield and NUE of blanket-seedling machine-transplanted rice are unknown. A field experiment was performed to investigate the effect of three types of CRNF (slow-release blending fertiliser (BSRB), polymer-coated urea (PCU) and sulphur-coated urea (SCU)) and two fertilisation regimes (a single basal application (B) and a basal CRNF application combined with urea top-dressing at the tillering stage (BT)) on grain yield, NUE and AV loss from paddy soil of blanket-seedling machine-transplanted rice. Conventional high-yield fertilisation (four split applications of urea at 270 kg N ha^{-1} (CK)) and 0-N treatments were established as controls. The results demonstrated that the AV flux values from paddy soil varied in distinct patterns for the different CRNF treatments. The cumulative AV loss in the urea treatment during the basal (the first week) and tillering fertiliser (the second week) comprised the majority of the total AV loss, both accounting for 87.2% in each year. Compared with CK, B-BSRB significantly reduced AV loss during the first two weeks and the total AV loss by 24.7% and 27.9% in 2013 and 2014, respectively. B-SCU and B-PCU generally showed no benefits for reducing AV loss relative to urea. Compared with B-PCU and B-SCU, B-BSRB met the N demand of rice, substantially mitigated N loss via AV in paddy fields, and improved yield and NUE of Blanket-seedling Machine-Transplanted rice. The effect of BT for each CRNF on AV loss was not consistent. The BT-BSRB and the BT-SCU correspondingly mitigated AV loss to a certain extent in each year, mostly due to the relatively lower AV loss during the first week, and no significant increase in AV loss at the second week. The BT-BSRB incurred not only the lowest AV loss of 39.7 kg N ha^{-1} and 37.8 kg N ha^{-1} but also the highest yield of 11.6 t ha^{-1} and 10.1 t ha^{-1} and an NRF of 48.8% and 52.4% in 2013 and 2014, respectively. Our results suggested that combining BSRB and BT optimised rice yield and nitrogen use efficiency while decreasing ammonia volatilization from paddy soil of blanket-seedling machine-transplanted rice.

1. Introduction

As one of the most important food crops in the world, rice provides the food supply for more than 3 billion people (IRRI, 2010). By 2025, rice production must increase by 60% relative to that in 2006 to meet the increasing food demands of continuously growing human populations (Fageria, 2007). High rice yield has been the top priority of agricultural production policies in China.

The application of fertilisers, particularly nitrogen (N) fertiliser, is the primary means of increasing rice production and addressing the problem of population growth and the food supply (Cassman

Abbreviations: CRNF, controlled-release nitrogen fertilisers; BSRB, slow-release blending fertiliser; PCU, polymer-coated urea; SCU, sulphur-coated urea; B, a single basal application; BT, basal application of CRNF combined with urea top-dressing at the tillering stage; NUE, N use efficiency; AV, ammonia volatilisation; CK, conventional high-yield fertilisation.

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et al., 2003; Qiao et al., 2013; Spiertz, 2010). Over the past several decades, chemical N fertiliser input has continuously increased and has far exceeded crop demand, especially in the Taihu Lake region (Ju et al., 2009; Peng et al., 2011). Roelcke et al. (2004) reported that the N input for rice production in the Taihu Lake region was approximately 280–360 kg N ha^{-1}. However, fertiliser N use efficiency (NUE) decreases with increasing N fertiliser inputs, which has harmful repercussions such as surplus soil N, nitrate leaching, mineral N runoff and agricultural greenhouse gas emissions that lead to eco-environmental problems, including acid rain, soil acidification and water eutrophication (Han et al., 2014; Shi et al., 2012; Zhang et al., 2015; Zhao et al., 2012).

Ammonia volatilisation (AV) is one of the major pathways of gaseous N emission in rice paddy soils, equating to up to 10–60% of the N fertiliser applied (Fillery and Datta, 1986; Xu et al., 2012, 2013). Previous researches have suggested that AV flux has a significant positive correlation with soil NH_4^+-N content and temperature (Hayashi et al., 2008; Li et al., 2008), and AV flux increases with soil pH and wind speed. N fertiliser types and application methods are the two major management factors affecting AV loss from paddy soil (Xu et al., 2013). In developing countries such as China, urea is widely applied because of its high N content (46%) and low production cost, yet is rapidly hydrolysed by urease when applied to soil, resulting in substantial N loss due to increase pH and surface soil/water NH_4^+-concentrations (Glibert et al., 2006; Li et al., 2014). In general, AV flux reaches a maximum immediately after urea application and substantial N loss occurs within a week after fertilisation (Qiao et al., 2013; Xu et al., 2013). In addition, the improper timing of N application by farmers, with a large proportion of total N applied in the first 10 days after transplanting, may increase AV loss from paddy fields. In addition, the higher mean temperature of the rice growth period, particularly the period from June to July, when N is applied, may increase the potential for AV loss. AV emissions from urea are estimated to account for 64.3% of the 2005 total in china (Zhang et al., 2011). With a background of high N application and mean summer temperature, the Taihu region has the highest AV loss in all of China (Zhang et al., 2011). Investigating the underlying mechanisms of AV in paddy fields can potentially mitigate AV loss and yield great economic and ecological benefits.

Controlled-release N fertiliser (CRNF) is considered an effective way to improve N use efficiency (NUE) and rice yield and reduce N loss through denitrification, AV, leaching and surface runoff by slowly releasing this nutrient from the coated fertiliser (Azeem et al., 2014; Geng et al., 2015a; Geng et al., 2015b; Guan et al., 2014; Timilsena et al., 2015; Wang et al., 2011). Furthermore, CRNF provides lower labour/time costs and fertiliser use relative to conventional urea-N fertiliser split application (Azeem et al., 2014; Geng et al., 2015b; Guertal, 2000). Theoretically, the cumulative N release curve of CRNF under paddy field conditions is “S” shaped, which may synchronize N release with the N requirement patterns of rice plants (Yang et al., 2012). Ye et al. (2013) suggested that polymer-coated urea (PCU) significantly increased rice yield and NUE compared with conventional urea applied at the same N rate. Xu et al. (2012) reported that seasonal AV loss using CRNF was 81.0% lower compared with fertilisation practices from non-flooding controlled irrigation paddies. Note that the release of nutrients from CRNF commonly depends on the temperature, the soil moisture and the composition and thickness of the coating materials. A single basal application of CRNF may not be sufficient to meet the N requirements of rice throughout all growth stages (Grant et al., 2012). Wang et al. (2015) demonstrated that ^{15}N release from a single basal application of PCU did not correspond well to the N demand patterns of rice plants in plot and ^{15}N microplot experiments. The latter agrees with more recent studies showing that a basal application CRNF with a single component may not be sufficient to provide a balanced N supply. Strategies for improving the efficiency of CRNF use have attracted the attention of agricultural scientists.

Recently, a new type of slow-release blending fertiliser (BSRB), which mixes a certain proportion of CRNF with ordinary NPK fertiliser, has been designed for a balanced N supply (Ye et al., 2013; Wang et al., 2015). In addition, a novel CRNF application method using basal CRNF combined with urea top-dressing at the tillering stage (BT) was proposed to further enhance N use efficiency and rice yield. Our previous research demonstrated that BSRB could meet rice N demands and improve rice yields and NUE of bowl-seedling machine-transplanted rice, and the BT-BSRB was the best system (Miao et al., 2016). However, the development of bowl-seedling machine-transplanted rice has been suppressed by the high mechanical and labour costs and low work efficiency (Zhang and Gong, 2014). By comparison, blanket-seedling machine transplantation has been widely used for machine-transplanted rice in the past three decades (Hu et al., 2014). Unfortunately, this process damages more plants and the roots of rice seedling during transplantation, thus causing a longer reviving stage and higher yield loss (Hu et al., 2014). Improve grain yield and NUE of blanket-seedling machine-transplanted rice by optimizing CRNF management is therefore a major concern.

At present, there is limited data available showing the effects of optimised CRNF type and application method on the yield and NUE of blanket-seedling machine-transplanted rice. Besides, given the addition of urea in both the optimized CRNF type and application method, the effects in AV loss are unknown. Thus, the objectives of this study were to evaluate the effects of three types of CRNF (BSRB, PCU and SCU) under two fertilisation regimes on rice yield, NUE and AV losses from paddy soil and to derive management options for reducing AV losses while improving rice yield and NUE of the blanket-seedling machine-transplanted rice in the Taihu region of China.

2. Materials and methods

2.1. Study site and N sources

The field experiments were performed over two rice growing seasons (2013 and 2014) in the Taihu region of China, at an experimental farm located in Yanling Town of Danyang City, Jiangsu Province (32°00′N, 119°32′E, 7 m above sea level). The study area has a subtropical monsoon climate, and the mean annual air temperature and rainfall are 16.4 °C and 882 mm, respectively. The meteorological data came from the meteorological station (Watch Dog 2900ET, SPECTRUM, USA) installed 100 m from the experimental station. The soil at the experiment site was classified as Orthic Acrisol (FAO soil taxonomy in 1974), and analyses of the topsoil horizon (0–20 cm) at the start of the experiment indicated that the soil had the following characteristics: a pH of 6.80, an organic matter of 17.2 g kg^{-1}, a total N of 0.99 g kg^{-1}, a mineral N of 86.4 mg kg^{-1}, an Olsens-P of 13.6 mg kg^{-1} and an NH_4OAc-extractable K of 93.5 mg kg^{-1}.

The following three types of CRNF were used in this study: PCU (43% N), SCU (37% N) and BSRB (20% N). The BSRB was a blend of 10% N from ammonium phosphate and 90% from two types of PCU, 2% and 4% coating at an application ratio of 1:1. In addition, urea (46% N) and NPK compound fertiliser (N:P:K = 15:15:15) were used as conventional N fertilisers.

2.2. Experimental design

The eight N fertiliser treatments were as follows: a control treatment with no N application (N_0), conventional fertilisation (CK, four spilt applications of urea), a single basal application of each