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RESEARCH ARTICLE

Using side-dressing technique to reduce nitrogen leaching and improve nitrogen recovery efficiency under an irrigated rice system in the upper reaches of Yellow River Basin, Northwest China

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Abstract

The excessive nitrogen (N) fertilizer input coupled with flood irrigation might result in higher N leaching and lower nitrogen recovery efficiency (NRE). Under an intensive rice system in the Ningxia irrigation region, China, environmental friendly N management practices are heavily needed to balance the amount of N input for optimum crop production while minimize the nitrogen loss. The objective of this study was to determine the influences of side-dressing (SD) technique in mechanical transplanting systems on the NRE, N leaching losses and rice yield in anthropogenic-alluvial soil during two rice growing seasons (2010–2011). Four fertilizer N treatments were established, including conventional urea rate (CU, 300 kg ha^{-1} yr^{-1}); higher SD of controlled-release N fertilizer rate (SD1, 176 kg ha^{-1} yr^{-1}); lower SD of controlled-release N fertilizer rate (SD2, 125 kg ha^{-1} yr^{-1}); and control (CK, no N fertilizer). Field lysimeters were used to quantify drainage from undisturbed soil during six rice growing stages. Meanwhile, the temporal variations of total nitrigen (TN), NO_3^--N, and NH_4^+-N concentrations in percolation water were examined. The results showed that SD1 substantially improved NRE and reduced N leaching losses while maintaining rice yields. Across two years, the averaged NRE under SD1 treatment increased by 25.5% as relative to CU, but yet the rice yield was similar between two treatments. On average, the nitrogen loss defined as TN, NH_4^+-N, and NO_3^--N under the SD1 treatment reduced by 27.4, 37.2 and 24.1%, respectively, when compared with CU during the study periods. Although the SD2 treatment could further reduce N leaching loss to some extent, this technique would sharply decline rice yield, with the magnitude of as high as 21.0% relative to CU treatment. Additionally, the average NRE under SD2 was 11.2% lower than that under SD1 treatment. Overall, the present study concluded that the SD technique is an effective strategy to reduce N leaching and increase NRE, thus potentially mitigate local environmental threat. We propose SD1 as a novel alternative fertilizer technique under an irrigated rice-based system in Ningxia irrigation region when higher yields are under consideration.

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1. Introduction

Ningxia irrigation region with an irrigation area of 9 697 km^2 is one of the oldest and largest irrigation areas in Northwest China, and is one marketable grain base in China. To meet increased grain demands in the world, more mineral fertilizer was utilized to ensure higher grain production. From 1980 to 2012, the mineral fertilizer consumption had increased about six times, with ranging from 0.171 to 1.03 million ton, while total annual grain production has nearly tripled from 1.20 to 3.59 million ton (Statistical Bureau of Ningxia Hui Autonomous Region 2013). As the dominant chemical fertilizer, N fertilization had increased by 533 thousand ton, about 38% of which was applied for rice production (Statistical Bureau of Ningxia Hui Autonomous Region 2013). As a staple crop, rice is the largest water and fertilizer consumer grown in Ningxia irrigation region. Currently, the annual application rate of synthetic N fertilizer in this region is far above the average application rate of 180 kg ha^{-1} yr^{-1} in China, reaching 300 kg ha^{-1} yr^{-1} (Peng *et al.* 2006). *In virtue* of the low rainfall and high evaporation, about 7 billion m^3 water is drawn from the Yellow River and 2.5 billion m^3 is returned annually (Zhang *et al.* 2012). Over 93–95% of the pumped water is used for agriculture and a total of 1 400–1 600 m^3 water per ha was applied during the rice-growing season. Therefore, the overuse N fertilizer in the irrigated rice system should be responsible for various environmental problems such as surface and groundwater contamination.

A growing body of evidences have shown that excessive application of N fertilizers may not only reduce nitrogen recovery efficiency (NRE), but also threaten the surrounding environment through leaching in water bodies, ammonia volatilization or N_2O emissions to the atmosphere (Di and Cameron 2002; Blicher-Mathiesen *et al.* 2014). Alternatively, to reduce N fertilizer rates or increase the proportion of applied N removed in the harvested portion of the crop, maintaining higher NRE could be potentially achieved (Gerwing *et al.* 1979; Canalia *et al.* 2014). Strategies to minimize N fertilizer have been conducted around the world (Ventura and Watanabe 1993; Martin *et al.* 1994; Moreno *et al.* 1996; Meng *et al.* 2014). In China, the irrigated rice systems accounting for nearly 30% of global rice production have consumed about 37% of global N fertilizer, but the nationwide average NRE for rice is only 30% (Peng *et al.* 2002). This case indicates that nearly 70% of the N input is lost. Consequently, massive N fertilizer consumption has caused huge N leaching into the water bodies, which is becoming one of the key non-point pollution sources to the Yellow River (Zhang *et al.* 2012).

In Ningxia irrigation region, many previous studies have been exerted to improve N fertilizer management. These efforts include identifying the most appropriate timing of split applications at specific growth stages (Zhang *et al.* 2007; Liu *et al.* 2012), using organic fertilizer (Yang *et al.* 2014) and balancing nutrition (Zhao *et al.* 2010). However, limited studies have paid attention to the fertilization technique. Therefore, there is an urgent need to explore the optimizing N application techniques to improve N use efficiency and reduce N leaching loss.

Various improved practices that better match spatial and temporal N supply with plant N demand can effectively increase N use efficiency, thus modulating the accumulation of N in the soil profile and reducing N leaching (Peng *et al.* 2002, 2009; Ju *et al.* 2009; Van der Laana *et al.* 2014). For example, the side-dressing (SD) technique is an effective fertilization technique to increase N use efficiency by aligning fertilization with rice requirement (Yuichi *et al.* 1992). This technique applies all controlled-release fertilizer to 5–8 cm depth of the seedling side once while transplant rice seedlings were transplanted by an exclusive rice transplanter. It could create a nutrient stock around the rice rhizosphere, ensuring effective storage and sufficient supply of fertilizer N within the root zone throughout the growing season (Wang *et al.* 1998). The nutrients stock may gradually release nutrients to meet with the rice growth demand synchronously and the fertilizer use efficiency can thus be improved. However, the performance of this technique depends on climate conditions and soil types, and its effect on N leaching remains further studies. The objectives of this study were therefore to (i) examine the temporal variation of N concentrations in percolation water and the characteristics of N leaching during rice growing stage and (ii) evaluate the effectiveness of SD technique on rice yield and NRE in irrigated rice system in Ningxia irrigation region. We hope to recommend practical fertilization techniques which could both improve NRE of applied N-fertilizer and maintain rice yield.

2. Results

2.1. Effect of side-dressing technique on N leaching

The patterns of total nitrogen (TN) concentrations in leachate are shown in Fig. 1. Overall, the TN concentrations declined