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Short communication

Grain yield and apparent N recovery efficiency of dry direct-seeded rice under different N treatments aimed to reduce soil ammonia volatilization

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ABSTRACT

Soil ammonia volatilization induced by urea application at sowing negatively affects seed germination and early seedling growth of dry direct-seeded rice. Previous research suggests that ammonia volatilization can be reduced through nitrogen (N) management practices such as split application of urea, delaying the first urea application, and using N fertilizers which are less prone to volatilization. The objective of this study was to examine the impact of these N management practices on grain yield and nitrogen use efficiency of dry direct-seeded rice. Pot and field experiments were conducted under different N treatments. In the pot experiment, N treatments were 1.0 and 0.5 g N pot^{-1} as urea at sowing, 1.0 g N pot^{-1} as urea at 10 days after sowing (DAS), and 1.0 g N pot^{-1} as ammonium sulfate at sowing. In the field experiment five N treatments were used while keeping the total N rate as 150 kg N ha^{-1}. These treatments included reducing the rates of urea applied at sowing from 90 to 60 and 30 kg N ha^{-1}, delaying the first urea application to 10 DAS at 90 kg N ha^{-1}, and application of ammonium sulfate as 90 kg N ha^{-1} at sowing. Reducing rate of urea applied at sowing, delaying the first urea application, or application of ammonium sulfate significantly increased plant growth, grain yield, above-ground N uptake and apparent N recovery (ANR) efficiency of dry direct-seeded rice, compared with higher rate of urea application at sowing. Here we demonstrate that by adoption of proper N management practices, a grain yield of above 6 t ha^{-1} can be achieved in dry direct-seeded rice production system. Such findings may greatly help in the wide spread of dry direct-seeded rice technology, particularly in central China.

1. Introduction

The increasing scarcity of fresh-water resources for agriculture in many areas threatens the sustainability of the irrigated rice production systems. To assure food security and preserve water resources, there is a need to develop strategies to reduce water usage and increase water-use efficiency in rice production systems. A technology, "dry direct-seeded rice" has been proposed to reduce water input, save labor demand, and increase water productivity. For this system, dry seed is broadcast onto the soil surface and then incorporated either by ploughing or harrowing while the soil is still dry (Pandey and Velasco, 2002). Previous research has reported that grain yield of dry direct-seeded rice was not significantly different from that of traditionally transplanted flooded rice (Gupta et al., 2002; Kukal et al., 2005; Qureshi et al., 2006). In addition, direct-seeded rice substantially reduced the overall water demand for rice culture by avoiding the puddling and maintaining continuous moist soil conditions. Dry direct-seeded rice is thus seen as being a promising technology with potential to help ensure food security in areas facing water scarcity.

However, poor seed germination and reduced early seedling growth are major constraints which limit wide adoption of dry direct-seeded rice. The possible causes include improper soil water content, unsuitable sowing depth and ammonia toxicity due to urea application. The toxicity of ammonia volatilization has been pointed out to be the main cause responsible for poor seed germination and reduced early-seedling growth of dry direct-seeded rice, when urea fertilizer is applied at sowing (Bremner, 1995; Fan and Mackenzie, 1995; Haden et al., 2011; Qi et al., 2012a).

Nitrogen management practices known to reduce the risk of ammonia toxicity include split application of urea, delaying the first urea application, application of urease inhibitors, and using N fertilizers that are less prone to volatilization such as ammonium sulfate (Bremner, 1995; Dobermann and Fairhurst, 2000; Haden, 2010; Qi et al., 2012a,b). Qi et al. (2012b) reported that urease inhibitors significantly improved seed germination and early seedling growth of dry direct-seeded rice by reducing ammonia volatilization from added urea. Application of ammonium sulfate, instead of urea at

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sowing has the potential to mitigate poor crop establishment of dry direct-seeded rice (Qi et al., 2012a,b). However, the grain yield and nitrogen use efficiency of dry direct-seeded rice under these nitrogen management practices aimed to reduce soil ammonia volatilization are still unknown. The objectives of this study were (1) to evaluate the effectiveness of reducing rate of urea applied at sowing, delaying the first urea application, and application of ammonium sulfate at sowing in reducing soil ammonia volatilization in dry direct-seeded rice and (2) to examine the impact of these N management practices on grain yield and nitrogen use efficiency of dry direct-seeded rice.

2. Materials and methods

2.1. Pot experiment

A pot experiment was conducted in the greenhouse at Huazhong Agricultural University using soil taken from the top 25 cm layer of a field at the experimental station of Dajin County, Hubei Province, China (29°51′N 115°33′E). Dajin County is one of the three main rice producing areas in Hubei Province. The soil was gley soil with pH 5.56, 32.2 g kg^{-1} organic C, 1.72 g kg^{-1} total N, 31.1 mg kg^{-1} available P, 94.0 mg kg^{-1} available K, 8.8 cmol kg^{-1} cation exchange capacity, 10% clay, 26% silt and 64% sand.

Before filling the pots, the soil was air-dried, pulverized, and well mixed. Two-liter plastic pots were filled with 2.0 kg of air-dried soil. One day before sowing, fertilizers were applied to the pots and mixed well with soil and then the soil was soaked with tap water. The N treatments were T_P1 (1.0 g N pot^{-1} as urea at sowing), T_P2 (0.5 g N pot^{-1} as urea at sowing), T_P3 (1.0 g N pot^{-1} as urea at 10 days after sowing), and T_P4 (1.0 g N pot^{-1} as ammonium sulfate at sowing). Lvhan-1, a recently developed inbred aerobic rice variety with high grain yield and tolerance to drought was used. Each treatment was replicated five times with one pot per replication and pots were arranged in a completely randomized design. Distance between pots was kept at 25 cm to avoid shading. Ten dry seeds were sown in each pot on 5th August 2011 and pots were kept saturated with water for one week after sowing to promote good crop establishment after which the pots were kept under aerobic condition. Seedlings were thinned one week after sowing to five uniform seedlings per pot. All pots were watered once every 1–3 days whenever drying of soil surface was observed, which corresponded to the soil moisture tension at 15 cm depth of −15 to −25 kPa. The soil water content in the pots was not controlled rigorously, but frequent irrigation made sure that plants did not experience drought stress and no standing water was kept in the pots throughout the experiment. Pesticides were sprayed 3–4 times to control insect damage. Weeds were removed manually.

The plants were sampled at 33 days after sowing. Before plant sampling, stem number per pot was counted and plant height from plant base to the tallest leaf tip in each pot was measured. After cutting, plants were divided into aboveground part and roots. Soil was removed by placing roots over a sieve and washing with tap water. Dry weights of plant organs were determined after oven drying at 70 °C to constant weight.

2.2. Field experiment

A field experiment was conducted at the experimental station of Dajin County in the same field from where the soil for pot experiment was collected. The same variety Lvhan-1 was used in the field trial. Plots were dry ploughed and harrowed during land preparation. The treatments were arranged in a randomized complete block design with four replications and a plot area of 30.0 m^2 (6 m × 5 m). Dry seeds were directly sown in furrows manually with row spacing of 25 cm on 28th May 2011 with a sowing rate of 60 kg ha^{-1}. Immediately after sowing, urea or ammonium sulfate was incorporated in the soil near the seed rows. Phosphorus and potassium were applied at the rates of 40 kg P ha^{-1} as calcium superphosphate and 100 kg K ha^{-1} as potassium chloride, respectively. For all the plots, fertilizer N was applied in three splits while keeping the total N rate as 150 kg N ha^{-1}. The five N treatments were T_F1 [90 kg N ha^{-1} (at sowing) + 30 kg N ha^{-1} (at 44 DAS) + 30 kg N ha^{-1} (at 65 DAS) as urea], T_F2 [60 kg N ha^{-1} (at sowing) + 45 kg N ha^{-1} (at 44 DAS) + 45 kg N ha^{-1} (at 65 DAS) as urea], T_F3 [30 kg N ha^{-1} (at sowing) + 60 kg N ha^{-1} (at 44 DAS) + 60 kg N ha^{-1} (at 65 DAS) as urea], T_F4 [90 kg N ha^{-1} (at 10 DAS) + 30 kg N ha^{-1} (at 44 DAS) + 30 kg N ha^{-1} (at 65 DAS) as urea], and T_F5 [90 kg N ha^{-1} (at sowing) + 30 kg N ha^{-1} (at 44 DAS) + 30 kg N ha^{-1} (at 65 DAS) as ammonium sulfate]. The sown seeds and applied fertilizers were then covered with soil. Soil was kept wet for one week after sowing to promote good establishment after which the field was kept under rainfed conditions. Pests, diseases and weeds were intensively controlled.

At maturity, plants were sampled from 0.5 m^2 (one meter along the adjacent two rows) and divided into 10 sub-samples equally to determine aboveground total biomass, harvest index, and yield components. Panicle number of each part was counted to determine the panicle number per m^2. Plants were separated into straw and panicles. Straw dry weight was determined after oven-drying at 70 °C to constant weight. Panicles were hand-threshed and filled spikelets were separated from unfilled spikelets by submerging them in tap water. Three sub-samples each of 30-g filled spikelets and 2-g unfilled spikelets were taken to count the number of spikelets. Dry weights of rachis and filled and unfilled spikelets were determined after oven-drying at 70 °C to constant weight. Aboveground total biomass was the total dry matter of straw, rachis, and filled plus unfilled spikelets. Spikelets per panicle, grain-filling percentage (100 × filled spikelet number/total spikelet number), and harvest index (100 × filled spikelet weight/aboveground total biomass) were also calculated. Grain yield was determined from a 5-m^2 sampling area within each plot and adjusted to a moisture content of 0.14 g H_2O g^{-1} fresh weight.

2.3. Measurement of soil ammonia volatilization

In both experiments, soil ammonia volatilization was evaluated using the method of Conway microdiffusion incubation adapted for soil by Bremner and Krogmeier (1989). For the pot experiment, an uncovered Petri-dish (diameter = 7.5 cm) containing 20 ml of 2% boric acid solution and 1–2 drops of mixture indicators (bromcresol green and methyl red) was put on the soil surface. Then the pot was sealed so that the ammonia gas could be trapped by the boric acid solution without gas leakage from this system. For the field experiment, an airproof container with a diameter of 15 cm was put on the soil surface, inside which an uncovered Petri-dish (diameter = 7.5 cm) with 20 ml of 2% boric acid solution and 1–2 drops of mixture indicators was put on the soil surface. A wooden board was placed on the container to avoid gas leakage from the system, to provide shade so that the inner temperature is kept at minimum and to support the container so that the strong wind may not displace it. The ammonia volatilized from soil was trapped by boric acid solution and then titrated by 0.01 N HCl every day since one day after sowing. The boric acid solution was replaced after titration by HCl until the emission was negligible (Bremner and Mulvaney, 1982). In both pot and field experiments the boric acid solution was replaced 9 times. Total ammonia volatilization was the sum of the ammonia volatilized during each day.