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Dense planting with less basal nitrogen fertilization might benefit rice cropping for high yield with less environmental impacts

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ABSTRACT

Dense planting and less basal nitrogen (N) fertilization have been recommended to further increase rice (*Oryza sativa* L.) grain yield and N use efficiency (NUE), respectively. The objective of this study was to evaluate the integrative impacts of dense planting with reduced basal N application (DR) on rice yield, NUE and greenhouse gas (GHG) emissions. Field experiments with one conventional sparse planting (CK) and four treatments of dense planting (increased seedlings per hill) with less basal N application were conducted in northeast China from 2012 to 2013. In addition, a two-factor experiment was conducted to isolate the effect of planting density and basal N rate on CH_4 emission in 2013. Our results show that an increase in planting density by about 50% with a correspondingly reduction in basal N rate by about 30% (DR1 and DR2) enhanced NUE by 14.3–50.6% and rice grain yield by 0.5–7.4% over CK. Meanwhile, DR1 and DR2 reduced GWP by 6.4–12.6% and yield-scaled GWP by 7.0–17.0% over CK. According to the two-factor experiment, soil CH_4 production and oxidation and CH_4 emission were not affected by planting density. However, reduced basal N rate decreased CH_4 emission due to it significantly reduced soil CH_4 production with a smaller reduction in soil CH_4 oxidation. The above results indicate that moderate dense planting with less basal N application might be an environment friendly mode for rice cropping for high yield and NUE with less GHG emissions.

1. Introduction

Planting density and nitrogen (N) fertilization are two critical agronomic practices in rice cropping system for high yield (Fagade and De Datta, 1971; Dobermann et al., 2002). Under traditional manual cropping, large rice seedling being transplanted with a low density (i.e. sparse planting) was widely applied as a good cropping mode for high yield (Surridge, 2004; Toriyama and Ando, 2011). Since the decrease in rural labor and the increase in labor cost, rice seedling becomes smaller and transplanting density is very low under manual cropping mode, resulting in critical limitation to rice yield improvement (Peng et al., 2002; Huang et al., 2013; Wu et al., 2013). Meanwhile, planting density is also not enough under mechanic transplanting system due to the very young seedling and the improper design of seedling spacing (Li et al., 2014). Thus, sparse planting is becoming one of the key factors limiting further increase of rice yield (Huang et al., 2013; Li et al., 2014). Recently, dense planting is widely recommended as a good cropping mode for yielding more grain (Zeng et al., 2012; Wu et al., 2013; Chen et al., 2014).

Under sparse planting, high or even over N input at the early vegetative stage (e.g. basal N) is commonly applied to promote rice tillering for high yield (Peng et al., 2002; Zhu and Jin, 2013). Under dense planting, however, if the rate of basal N keeps unchanged, it might result in too many tillers, which in turn detriments rice growth (Lin et al., 2009) and increases rice plant lodging (Mahamud et al., 2013). Meanwhile, high rate of basal N fertilization might cause a great of N loss because the lower demand and uptake capacity of rice seedling during the early growth stage (Peng and Cassman, 1998). Thus, a reduction in basal N application could significantly increase N use efficiency (NUE) (Bhatia et al., 2012; Peng et al., 2010). However, if only decreasing basal N application rate without increase in planting density, the rice population might be not big enough for high yield. Moreover, hard evidences have showed that N top-dressing at panicle initiation stage is an effective and necessary practice to enhance rice spikelet production for high yield (Kamiji et al., 2011; Sui et al., 2013). Thus, increasing planting density with a reduction in basal N application and an unchanged N

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top-dressing might benefit rice production for high yield with high NUE.

It is well known that flooded rice soils represent an important source of anthropogenic greenhouse gas (GHG) emissions of methane (CH_4) and nitrous oxide (N_2O) (Zou et al., 2009; IPCC, 2013). Recently, there are growing concerns about the impacts of rice cropping practices on GHG emissions (Linquist et al., 2012a; Ly et al., 2013; Zhan et al., 2010), Altering water, residue are widely suggested as options for mitigating GHG emissions in rice field. For the effects of planting density and N application on CH_4 emission, the conclusions from different studies are not consistent yet. It was reported that high planting density did not increase CH_4 emission in rice field (Wassmann et al., 2002), but lower CH_4 emissions was found in low density (8 hills m^{-2}) compared to that in high density (24 hills m^{-2}) (Chen et al., 2013). Generally, CH_4 emissions were not impacted by N inputs according to the latest data analysis of Pittelkow et al. (2014), but a moderate rate of N application could get less CH_4 emission in Chinese rice field (Feng et al., 2013). Fertilizer N strongly impacts N_2O emissions in rice systems (Pittelkow et al., 2013), direct N_2O emission increased with increasing N input in crop field (Kim et al., 2013). Few studies investigated the N_2O emissions under different planting densities in rice system, and existing study found that the effect of planting density on N_2O emission in rice field is relatively small (Chen et al., 2013). To our knowledge, however, the combined effects of dense planting with less N application on GHG emissions are not well documented.

Northeast is one of the major Chinese rice cropping regions, accounting for 14.7% and 15.0% of the total Chinese rice area and production in 2012, respectively. Sparse planting with a high rate of basal N application has been widely conducted in the region (Jin et al., 2005; Su et al., 2012), resulting in high risks of yield loss with great environmental concerns. Therefore, a two-year experiment was conducted to detect the combined impacts of planting density and basal N input on rice yield, NUE and GHG emissions. Our objectives are to provide important references to environment friendly rice cropping.

2. Materials and methods

2.1. Site description

Field experiments were conducted from 2012 to 2013 in a farmer's field (42°05′N, 123°21′E), Shenyang city, Liaoning province in China. The experimental site is located in northeast of the country with an annual single rice cropping system. Soil at the site is classified as the Cambisols (IUSS Working Group WRB 2006). Soil characteristics for the 0–20 cm layer are: 6.2 pH, 26.7 g kg^{-1} soil organic matter, 1.5 g kg^{-1} total N, 148.7 mg kg^{-1} available N, 32.4 mg kg^{-1} Olson P and 135.6 mg kg^{-1} available K. The climate is a typical northern temperate continental monsoon climate with a mean annual temperature of about 8.3 °C and a precipitation of 716 mm, and rainfall occurs primarily during rice growing season. The mean daily air temperature and precipitation during growing seasons for two years were listed in Fig. 1. In this site, the field was fallow after rice harvest, and the rice residues were removed and used as biofuels for warmth.

2.2. Experiment design

Two field experiments were conducted in the study site. One was single factor of cropping mode experiment for the dense planting with less basal N input in both 2012 and 2013. This experiment was a randomized block design with three replications. Each plot was 24 m^2 in size. Five cropping modes were involved in this experiment, including one traditional cropping pattern for high yield (CK) and four modes of dense planting with less basal N application (DR). An increase in seedlings per hill was used to increase planting density for the dense planting modes. Traditionally, the common planting density was 3 seedlings per hill with a rate of basal N application of 202.5 kg ha^{-1} (including N applied at pretransplanting and early tillering). Taking the traditional cropping mode as the CK, the planting densities of the four dense planting modes were 4, 5, 6 and 7 seedlings per hill correspondingly with about 20, 40, 60 and 80% reduction in basal N as comparison with the CK (i.e. DR1, DR2, DR3 and DR4 correspondingly). The top-dressing N rates at panicle initiation stage for all DR treatments were kept the same with CK. The detailed information about the planting density and N application is listed in Table 1.

In order to explore the underlying mechanisms of the effect of DR mode on GHG emissions, a two-factor experiment was conducted at the same field with cropping mode experiment in 2013. This experiment was a split-plot experiment design with three replications. The main plot was planting density (i.e. standard density: SD; high density: HD), and the sub-plot was the application rate of basal N (i.e. standard rate: SN; low rate: LN). Each sub-plot was 24 m^2 in size. The planting densities for SD and HD were the same with CK and DR4 in cropping mode experiment, respectively. And the basal N rates in SN and LN were the same with CK and DR4, respectively. The top-dressing N rates at panicle initiation stage in all treatments of two-factor experiment were kept the same with DR treatments in cropping mode experiment.

One conventional Japonica rice cultivar Liaoxing 1 was used in two experiments. The agronomic practices including transplanting, water management and phosphorus and potassium management

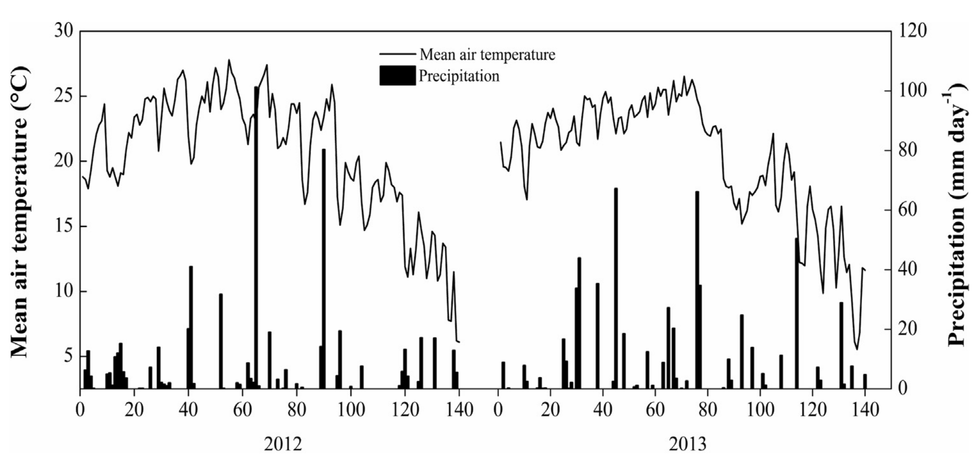

Fig. 1. Mean air temperature and precipitation during rice growing seasons in 2012 and 2013.