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Modifying nitrogen fertilizer practices can reduce greenhouse gas emissions from a Chinese double rice cropping system

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ABSTRACT

Practical nitrogen fertilizers are required that simultaneously increase yield and reduce greenhouse gas (GHG) emissions from rice (*Oryza sativa* L.) paddies. A field experiment was conducted to measure methane (CH_4) and nitrous oxide (N_2O) fluxes in situ during two double rice-winter fallow rotations (2012–2014) under five different nitrogen fertilizer treatments: traditional urea (CK), polymer-coated controlled release urea (CRU), urea with N-Sever nitrapyrin (NU), urea with 3,4-dimethylpyrazole phosphate (DMPP), and urea with effective microorganisms (EM). The results revealed that GHG emissions ranged between 77.2 and 178.2 kg CH_4 ha^{-1} and 4.18 and 10.11 kg N_2O ha^{-1} averagely over the whole rotation, and significant differences ($P < 0.05$) among treatments and seasons were found. N_2O emissions accounted for 26.6–36.9% of total GWP, and significant N_2O emissions were observed during the winter fallow period, ranging from 3.1 to 3.88 kg N_2O ha^{-1}. Compared to the GWP (7.66 and 8.85 Mg CO_2 ha^{-1}) and GHGI (0.52 and 0.63 Mg CO_2 Mg^{-1} grain) from CK in 2012 and 2013 rotation, respectively, CRU achieved the highest reduction (48.5% for GWP and 55.4% for GHGI) in 2012, NU achieved the highest reduction (37.6% for GWP and 43.1% for GHGI) in 2013, and other treatments also realized different levels of decrease. Thus, controlled release urea, nitrification inhibitor or effective microorganisms might be effective fertilization options for low-carbon rice production with high yield.

1. Introduction

Global warming is an indisputable fact, and greenhouse gas (GHG) emissions due to human activity are very likely to be the main cause of climate change (IPCC, 2013). CH_4 and N_2O are recognized as potent GHGs, with 34 and 298 times higher global warming potential (GWP) than CO_2 (100 years horizon) on a molar basis (IPCC, 2013). Rice paddies are one of the main CH_4 emission sources, accounting for 10–20% of annual global CH_4 emissions to the atmosphere (Yagi et al., 1997; Wassmann and Aulakh, 2000; Zou et al., 2005), and are also an important source of N_2O emissions (Xing and Zhu, 1997; Cai et al., 1997; Zou et al., 2007). Rice is the staple food for more than half of the world's population, so considering the likely increase in demand for rice in the future gives rise to concerns about rising GHG emissions from rice production (van Beek et al., 2010). There is often a trade-off between CH_4 and N_2O emissions, rice yield increase and GHG reduction (Hou et al., 2000; Shang et al., 2010). Thus, effective rice cropping practices which can reduce both CH_4 and N_2O emissions while supporting high yield output are of direct relevance for low-carbon rice production and mitigation of global warming.

China is the world's leading rice producer with 205×10^6 Mg grain yield in 2012 (FAO, 2012), and also the biggest nitrogen fertilizer consumer with more than 25×10^6 Mg nitrogen use (Peng et al., 2002). Application of nitrogen fertilizer can directly affect rice yield and GHG emissions (Zou et al., 2005; Liang et al., 2013). Controlled release urea, nitrification inhibitors and effective microorganisms have been developed that may offer the potential to simultaneously increase yield and reduce emissions. Compared with traditional urea, application of controlled release urea and nitrification inhibitors in rice paddies have a higher rate of nitrogen use efficiency, significantly increase yield, and have fewer N_2O emissions, but their effect on reducing CH_4 emissions is controversial (Pasda et al., 2001; Shoji et al., 2001; Majumdar, 2003; Li et al., 2008b). Urea with EM inoculums benefit rice growth and yield formation, but their influence on GHG emissions has rarely been studied (Hussain et al., 1999). Polymer-coated urea is a widely used controlled release fertilizer (Trenkel and Association,

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1997). Nitrapyrin and dimethylpyrazole phosphate are representative nitrification inhibitors (Crawford and Chalk, 1993; Zerulla et al., 2001). Effective microorganism (EM) inoculums are widely used in ecological agriculture in Asia (Higa and Wididana, 1991). Previous research on the effect of these fertilizers on CH_4 and N_2O reduction in rice paddies has been limited, so their abatement potential is uncertain and more investigations are recommended.

Furthermore, most existing studies (Cai et al., 2000; Yang et al., 2010; Li et al., 2011) have only considered the rice growing season, although several studies observed emissions in the winter fallow period and suggested that N_2O fluxes were significant and CH_4 fluxes were generally absent (Bronson et al., 1997; Liang et al., 2007). Few studies have determined the potential for reduction of CH_4, N_2O and GWP considering the winter fallow period using the nitrogen fertilizers mentioned above in the double rice cropping system (Majumdar, 2003; Shang et al., 2010; Ji et al., 2013). Assuming the absence of N_2O emissions in the winter fallow period may cause an underestimate of the GWP from rice paddy. It is also unclear whether rice soils with controlled release fertilizer and nitrification inhibitor release more N_2O in the fallow period, in which case emission reductions over the whole rotation may be reduced. Therefore, simultaneous measurements of CH_4 and N_2O emissions from the same paddy field throughout the whole rotation will provide useful information on the effects of these fertilizers on emission reduction potential, and provide data to support selection of fertilizer management practices to achieve the lowest yield-scaled GWP.

In the present study, a high-frequency monitoring of CH_4 and N_2O fluxes from rice paddies were conducted over two rotations, with five different nitrogen fertilizers used. Our objectives were to (1) investigate the impacts of different fertilizers on CH_4 and N_2O emissions, (2) identify the proportions of GWP contributed by CH_4 and N_2O emissions during the rice growing season and the winter fallow period, and (3) evaluate the potential of these fertilizers to reduce GWP and increase yields.

2. Materials and methods

2.1. Site description

Field experiments were conducted at Jingzhou Agrometeorological Experimental Station, Hubei province, China (30°21′N, 112°09′E), from May 3rd, 2012 to April 28th, 2014. The site is located in the Jianghan Plain region, which has a subtropical monsoon climate, and a cropping system dominated by double rice-winter fallow rotation. The soil is hydragric paddy soil after years of rice cultivation, texture is medium loam, with the following basic physical and chemical characteristics (0–20 cm depth): bulk density, 1.44 g cm^{-3}; pH (H_2O), 7.8; organic carbon content, 26.88 g kg^{-1}; total nitrogen, 1.09 g kg^{-1}; rapidly available potassium, 56.3 mg kg^{-1}; rapidly available phosphorus, 9.7 mg kg^{-1}; clay content, 197 g kg^{-1}; silt content, 542 g kg^{-1}; and sand content, 261 g kg^{-1}.

Daily mean air temperature and precipitation were collected from meteorological station, which is 100 m away from the experimental site shown in Fig. 1. The average daily air temperature and total precipitation were 16.7 °C and 927 mm during the 2012 rotation (May 3rd, 2012–April 25th, 2013), and 17.8 °C and 1184 mm during the 2013 rotation (April 26th, 2013–April 28th, 2014).

2.2. Experimental design

The experiment adopted a single factor randomized complete block design, with five different fertilization treatments, with three replications of each treatment in plots of 6 × 4.5 m. The treatments were: (1) Urea ($N \geq 46\%$) was used as the control group (CK), applied using conventional practices in the study area; (2) Polymer-coated controlled release urea ($N \geq 42\%$, release period 90d) (CRU), provided by Shandong Kingenta Ecological Engineering Group Co., Ltd.; (3) N-Sever ($N \geq 46\%$) (NU), which is a synthetic urea mixed with 0.5% nitrapyrin in production, provided by Shanghai Bi-Jing Agricultural Science and Technology Co., Ltd.; (4) Urea with 1% nitrification inhibitor 3,4-dimethylpyrazole phosphate (DMPP) added; and (5) Urea with an equiponderate culture solution of effective microorganisms (EM) consisting of photosynthetic bacteria, lactobacilli, yeast, ray fungi and bacillus, 10 genera and 80 different species, and a microbial content of $\geq 2 \times 10^9$ colony-forming unit per milliliter diluted 200 times. Phosphate fertilizer was applied to all treatments as ordinary superphosphate ($P_2O_5 \geq 12\%$), and potassium fertilizer was applied as potassium chloride ($K_2O \geq 60\%$) to all treatments.

The fertilizers were applied three times in each growing season. Basal fertilizers were applied just before transplantation of rice, and top-dressing fertilizer was applied twice, once in the tillering stage and once in the earing stage. The amount of nitrogen applied in all treatments was the same: 165 kg N ha^{-1} for early rice and 180 kg N ha^{-1} for late rice (Table 1), which is the optimum fertilizer application recommended in the local area (Wang et al., 2010). The amount of nitrogen applied in each stage was determined according to the type and characteristics of each fertilizer. Considering the slow release of nutrients over 90d by polymer-coated controlled release urea, CRU was applied as basal and top-dressing fertilizer only twice, which ensures that the treatment

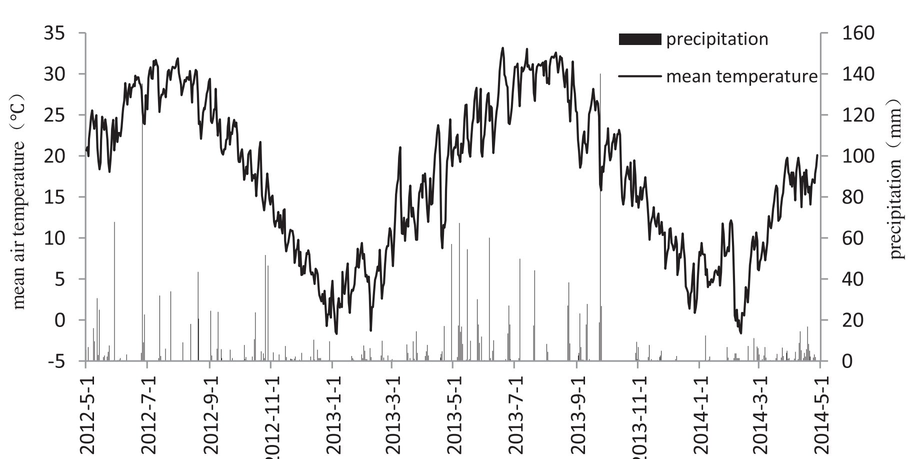

Fig. 1. Daily mean air temperature and precipitation during two cycles of double rice-winter fallow rotation in Jingzhou, China.