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Controlled irrigation mitigates the annual integrative global warming potential of methane and nitrous oxide from the rice–winter wheat rotation systems in Southeast China

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ABSTRACT

Irrigation mode is an important factor in regulating CH_4 and N_2O emissions from croplands. However, there are no studies on the effects of irrigation mode practiced during the rice season on the annual integrative global warming potential (GWP) of CH_4 and N_2O in the rice–winter wheat rotation systems. Thus, a field experiment was designed to study the effects of controlled irrigation (CI) during the rice season on the annual integrative GWP of CH_4 and N_2O emissions from the rice–winter wheat rotation systems, with traditional irrigation (TI) as the control. A notable trade-off relationship between CH_4 and N_2O emissions was observed in the rice–wheat rotation systems under both CI and TI of rice. CI during the rice season had obvious subsequent effects on CH_4 and N_2O emissions from the following winter wheat season. Over the whole annual cycle, CI significantly reduced the cumulative CH_4 emission (13.27 kg ha^{-1}) by 80.6% than that from the TI fields ($p < 0.001$), but did not cause a significant difference on the cumulative N_2O emission ($p > 0.05$). The integrative GWP of CH_4 and N_2O on a 100-year horizon for the CI rotation systems was 2720.35 kg CO_2 ha^{-1}, which was 41.1% lower than that for the TI fields ($p < 0.05$). Moreover, the difference of rice and wheat yields between the CI and TI fields was not significant ($p > 0.05$). This is the first study to investigate the effects of CI during the rice season on the annual integrative GWP of CH_4 and N_2O in a rice–winter wheat rotation system. Our results suggest that CI can significantly mitigate the annual integrative greenhouse effect caused by CH_4 and N_2O from the rice–winter wheat rotation systems, while ensuring the crop yields.

1. Introduction

Continuous emissions of greenhouse gases (GHGs) will cause further warming and changes in all components of the climate system. The atmospheric concentrations of the GHGs increased since 1750 due to human activity. Methane (CH_4) and nitrous oxide (N_2O) are important GHGs, which global warming potentials (GWPs) on a 100-year horizon is 34 and 298 times that of carbon dioxide (CO_2), respectively (IPCC, 2013). In 2011 the concentrations of CO_2, CH_4 and N_2O were 391 ppm, 1803 ppb, and 324 ppb, about 40%, 150%, and 20% higher than the pre-industrial levels (IPCC, 2013). Agriculture is one of the dominant sources of CH_4 and N_2O. It was estimated that approximately 84% of N_2O and 52% of CH_4 emitted from agriculture activities (Smith et al., 2008). Agricultural CH_4 and N_2O emissions have increased by nearly 17% from 1990 to 2005 (IPCC, 2007).

China is a major rice-producing country in the world; it accounted for 16% and 28% of the global rice area and global rice production in 2012 (FAO, 2013), respectively. In China, rice-growing season is conventionally followed by an upland cropping season. Sixteen percent of these rotation systems is typically dominated by an annual rice–winter wheat rotation in China (Liu et al., 2010). Studies on CH_4 and N_2O emissions from rice–winter wheat rotation systems in China are of national and global significance for both mitigation and adaption of agriculture to climate change.

Irrigation management has been recognized as an important factor in regulating CH_4 and N_2O emissions from paddy fields (Zou et al., 2005; Jiao et al., 2006; Xiong et al., 2007; Hadi et al., 2010; Liu et al., 2010). In China, several different water-saving irrigation (WSI) practices have been widely studied, such as intermittent irrigation, alternating wetting and drying irrigation (AWD) and controlled irrigation (CI). To our knowledge, the influence of water management on CH_4 and N_2O emission from paddy fields under

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continuous flooding, midseason drainage, intermittent irrigation and AWD has been well documented in literature (Zou et al., 2005; Hadi et al., 2010; Liu et al., 2010; Tyagi et al., 2010; Ahn et al., 2014; Kim et al., 2014; Minamikawa et al., 2014; Win et al., 2015; Xu et al., 2015). A trade-off relationship between CH_4 and N_2O emissions has been well documented in paddy studies. Alternating wetting and drying irrigation and midseason drainage in paddy fields mitigate CH_4 emissions, but trigger substantial N_2O emission, in contrast with continuous flooding. Ahn et al. (2014) reported that water-saving irrigation decreased CH_4 emissions by 78% and increased N_2O emissions by 533%, resulting in 78% reduction of GWP compared with the continuous flooding irrigation. Xu et al. (2015) reported that water-saving irrigation significantly mitigated CH_4 emission by 65% and enhanced N_2O emission slightly, in contrast with continuous flooding. However, most studies on the effects of water management practiced during the rice season on CH_4 and N_2O emissions are limited during the rice season. Only few studies have been dedicated to the effects of water management practiced during the rice season on N_2O emissions from a whole annual rice-upland cropping rotation (Pathak et al., 2002; Liu et al., 2010). Liu et al. (2010) reported that during the non-rice season, N_2O emissions from plots preceded by the water regime of FDFM (flooding-midseason drainage-reflooding-moist intermittent irrigation but without water logging) were generally lower than those preceded by the FDF (flooding-midseason drainage-frequent water logging with intermittent irrigation) water regime and continuous flooding during the rice-growing season. No studies have been dedicated to the effects of water management practiced during the rice season on CH_4 emissions from a whole annual rice-upland cropping rotation.

CI is one of the major WSI practices, and has been widely applied. During the rice season, the soil in CI paddy fields remains non-flooded for 60–80% of the rice season (Peng et al., 2011a, 2011c). That was similar to that observed in the water management strategy used in the System of Rice Intensification (Chapagain and Yamaji, 2010; Miyazato et al., 2010; Sato et al., 2011). CI leads to remarkable changes in soil properties and soil biochemical processes, compared with traditional irrigation (TI), which consequently induce changes in CH_4 and N_2O emissions. Studies on CH_4 and N_2O emissions from CI paddy fields also have been reported in few papers (Peng et al., 2011b; Hou et al., 2012). However, there are no studies on the effects of CI practiced during the rice season on the integrative GWP of CH_4 and N_2O in the rice–winter wheat rotation systems. It is unknown that whether the trade-off relationship between CH_4 and N_2O emissions occurs in the following winter wheat croplands. Whether CI can mitigate the annual integrative GWP of CH_4 and N_2O in the rice–winter wheat rotation systems is worthy of further study.

Thus, a field experiment was conducted to reveal the effects of CI on the annual integrative GWP of CH_4 and N_2O in the rice–winter wheat rotation systems. The objectives of this study are (1) to quantify CH_4 and N_2O emissions from annual rice–winter wheat rotation systems as affected by CI during the rice season, (2) to assess the subsequent effect of CI on CH_4 and N_2O emissions from the following winter wheat season, and (3) to evaluate the annual integrative GWP of CH_4 and N_2O in the rice–winter wheat rotation systems under CI during the rice season.

2. Materials and methods

2.1. Experimental site

The experiment was conducted from June 2009 to June 2011 in drainage lysimeters at the Kunshan Irrigation and Drainage Experiment Station in the Taihu Lake region, Jiangsu Province, China (31°15′ N, 120°57′ E). Rice has been planted here for more than 4000 years and unique diagnostic horizons of paddy soils have been well developed (Zheng et al., 2000). The rice–winter wheat rotation farming method is the conventional rice growing way in the Taihu Lake region (Xia et al., 2014; Yang et al., 2015). Rice seedlings were transplanted to paddy fields at the end of June and harvested at the end of October. Winter wheat was planted after the rice harvest and harvested at early June the following year. This region has a subtropical monsoon climate with an average annual temperature of 15.5 °C and a mean annual precipitation of 1097.1 mm. According to local Meteorological Bureau, most of the rainfall occurs between April and August. The soil on the top layer is hydragric anthrosol soil in FAO/UNESCO system, which is typical in this region. The properties of the 0–20 cm soil in the experiment station are described as follows: organic matter, 21.9 g kg^{-1}; total nitrogen (N), 1.0 g kg^{-1}; total phosphorus, 1.4 g kg^{-1}; total potassium, 20.9 g kg^{-1}; and pH (1:2.5, soil:water) of 7.4.

2.2. Experimental design

To investigate the effects of irrigation mode during the rice season on CH_4 and N_2O emission from annual rice–winter wheat rotation systems, two irrigation treatments, namely CI and TI, were practiced in rice fields. Each irrigation mode was designed with three replications. The replicates were established in six lysimetres with an area of about 5 m^2 (2 m × 2.5 m) in a randomized block design. The lysimeters with a rainout shelter were located in a large rice field, and soil depth within the lysimeters was 1.2 m. The details of water management during the rice season have been reported in our previous study (Hou et al., 2012). The administering of soil moisture in each experiment plot was a continuous dynamic process. For the CI paddies, the irrigation water layer was not maintained except in the re-greening period. Irrigations were applied under two conditions. First, the soil moisture approached the lower threshold for irrigation at a certain stage (Table 1). Second, standing irrigation water up to 50 mm depth was maintained for less than 5 days for pesticide and fertilizer application. The pesticides used in this experiment were consistent with the usage of local farmers, including: chlorpyrifos, pymetrozine, validamycin and profurite-aminium. In the TI paddy fields, there was a 3–6 cm shallow water layer after transplanting except during the midseason drainage period (the later tillering stage of rice) and the yellow maturity stage of rice. The rainout shelter was used to exclude rainfall during the rice season, but was not during the wheat season. During the wheat season, there was no irrigation for both practices. The water table was maintained at 0.8 m to avoid water logging.

In the 2009–2010 experiment, rice seedlings were transplanted to paddy fields 5 seedlings per hill on June 23 and harvested on October 31, 2009. Winter wheat was planted on November 1, 2009 and harvested on June 8, 2010. In the 2010–2011 experiment, rice seedlings were transplanted on June 26 and harvested on October 28, 2010. Winter wheat was planted on October 29, 2010 and harvested on June 5, 2011. The local conventional fertilizer application method was adopted in this experiment (Table 2). The base fertilizers were mixed into muddy, while the other fertilizers were broadcast evenly onto the soil surface by hand.

2.3. Sampling and measurements

The gas samples were collected by the static chamber technique (Peng et al., 2011a). The chamber, consisting of two separate layers with the same size (0.5 m × 0.5 m × 0.6 m), was made of polyvinyl chloride. The bases for the chambers were installed in all plots before rice transplantation, and remained there until wheat harvesting. The chamber was wrapped with a layer of sponge and aluminum foil to minimize air temperature changes inside the