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Improved water management to reduce greenhouse gas emissions in no-till rapeseed–rice rotations in Central China

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ABSTRACT

Although effects of water regimes on emissions of greenhouse gases (GHGs) in the growing season of rice have been well stated, it is not well documented how water regimes practiced in rice season influence GHGs and their global warming potential (GWP) over the whole annual cycle of paddy-upland crop rotation in Central China. Three water regimes during the growing season of a drought resistant rice cultivar (*Oryza sativa* L. subsp. *indica*), including continuous flooding (CF), flooded and wet intermittent irrigation (FWI), and rain-fed with limited irrigation for fertilizer application and in the case of serious drought (RFL), were initiated in 2012 in Hubei province, China. Emissions of GHGs were monitored from sowing of rapeseed (*Brassica napus* L.) to rice harvest in 2014, and the GWP and yield-scaled GWP were estimated from an annual rapeseed–rice rotation. Compared with CF, over the two rice seasons, FWI and RFL treatments significantly reduced methane (CH_4) emissions, while apparently increased nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions. FWI and RFL treatments practiced in rice season did not trigger significant CO_2 emissions in the following rapeseed season. However, N_2O emissions in the rapeseed season were significantly reduced by FWI and RFL treatments, thus there were no significantly difference in annual N_2O emissions among three treatments. Although the rapeseed season showed a weak source of CH_4 emission, the plots preceded by water-saving treatments continuously presented a reduction tendency in CH_4 emissions in rapeseed season. Totally, in comparison to CF treatment, the averaged annual GWP over the whole rotation cycle were significantly decreased by 21% and 24% under FWI and the RFL treatments, respectively. Water-saving irrigation treatments obtained lower annual yield-scaled GWP than CF treatment. Compared with CF treatment, FWI treatment did not exhibit a yield loss in rice or rapeseed across both years. In conclusion, from a sustainable agricultural perspective, using water-saving irrigation like FWI treatment could be an effective and safe option for simultaneously realizing the three goals of saving water, mitigating GHGs and maintaining sustainable rapeseed–rice production.

1. Introduction

Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are all important anthropogenic greenhouse gases (GHGs) (Montzka et al., 2011; Savage et al., 2014). It is estimated that agriculture accounts for approximately 10–12% of the total global anthropogenic emission of GHGs, while 50% and 60% of CH_4 and N_2O are emitted from agriculture, respectively (Smith et al., 2007). The flooded rice system is one of the largest anthropogenic sources of global CH_4 emission (Feng et al., 2012), and thus, strategies to reduce GHG emissions from paddy fields are needed to ease global warming (Feng et al., 2012; Linquist et al., 2012).

China is the largest rice producing country, with approximately 160 million hectares of rice paddies, which accounted for approximately 28% of global rice production in 2013 (FAO, 2014). More than 75% of the world's annual rice production comes from 79 million hectares of irrigated land (Bouman, 2001). Zhang (2007) estimated that approximately 70% of water used in agriculture was consumed by rice production alone. With the

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increasing shortage of water resources, alternative practices to reduce water inputs and increase water productivity in paddies have been developed (Nie et al., 2011), including the development of water-saving and drought-resistance rice varieties (Luo, 2010; Nie et al., 2011; Serraj et al., 2011). Water management has been recognized as one of the most important factors influencing CH_4 and N_2O emissions in rice production (Zou et al., 2005). Some studies have indicated that N_2O emissions increase with a decrease in CH_4 emissions caused by management to save water (Cai et al., 1999; Hou et al., 2000; Jiao et al., 2006; Johnson-Beebout et al., 2009). Therefore, it is important to accumulate data on both CH_4 and N_2O emissions in rice paddies with water-saving management practices to resolve global warming (Win et al., 2013).

The flux of GHGs varies with management practices in fields. An effective agricultural management strategy to mitigate GHGs requires considering multiple GHGs simultaneously when evaluating the impacts on radiative forcing (Frolking et al., 2004; Mosier et al., 2006). The global warming potential (GWP) was introduced to estimate the potential future impacts of emissions of different gases on the climate system and radiative properties (Lashof and Ahuja, 1990). Another concept for relating agricultural practices to the GWP is yield-scaled GWP. This term is calculated by dividing the GWP by crop yield and was introduced to assess climatic impacts of agriculture per kg of a yield (Li et al., 2006; Mosier et al., 2006; Qin et al., 2010; Shang et al., 2011).

The annual rapeseed–rice rotation is one of the most dominant cropping systems in the middle reaches of the Yangtze River in Central China, where the area of planted rice accounts for approximately 39% of the total in China and the area of planted rapeseed accounts for approximately 48% of the total in China (National Bureau of Statistics of China, 2014). Moreover, over 60% of Chinese rice paddy fields are consistently cultivated with rice-upland crop rotation systems (i.e., rice–rapeseed and rice–wheat) (Liu et al., 2012). In the past decade, although the dependent nature of CH_4 and N_2O emissions on the water regime in rice paddies has been well documented, most experiments have focused only on the growing season of rice (Li et al., 2005; Towprayoon et al., 2005; Win et al., 2013; Xu et al., 2015; Yang et al., 2012; Zou et al., 2005) and little is known about the impact of agricultural management practices on GHG emissions over the whole annual rotation (Yao et al., 2013b). Liu et al. (2010) reported that flooding during the rice growing season would create soil moisture more beneficial to N_2O production in the following non-rice season. Moreover, field measurements of GHG emissions and their trade-offs have rarely been taken over a whole annual rice-upland cropping rotation (Zou et al., 2004), which leads to a lack of quantitative information regarding GHG emissions and their trade-offs during the following non-rice season. Therefore, it is necessary to extend previous studies by evaluating the estimate of GHG emissions and grain yield in the rapeseed–rice rotation system over the entire year, in which various water regimes were employed during the rice growing season. Meanwhile, some studies on the GWP and yield-scaled GWP of the rice–wheat annual rotation using modeling have been reported recently (Feng et al., 2013; Ma et al., 2013; Wang et al., 2012; Yang et al., 2015), but few reports were released on the no-till rapeseed–rice rotation. Therefore, to have a more accurate and scientific assessment of the GWP and yield-scaled GWP of the rapeseed–rice rotation, further information about whether the annual GWP and yield-scaled GWP depend on the water regimes practiced during the rice growing season is necessary. Our objectives were to (1) quantify direct GHG emissions during the rice growing season and the following rapeseed season as affected by water regimes practiced in the rice season; (2) assess the combined effects of the GWP and yield-scaled GWP created by agricultural management practices during the rice growing season and the following non-rice season; and (3) optimize paddy water management strategies for simultaneously sustaining grain yield and reducing the climatic impacts of rapeseed–rice production in Central China.

2. Material and methods

2.1. Experimental site

A field experiment was conducted on an experimental farm of Huazhong Agricultural University in the town of Huaqiao, Hubei Province, China (30°01′N, 115°74′E) from 2012 to 2014. The town is in the middle reaches of the plain of the Yangtze River. Its elevation is 30 m above sea level. This region has a humid mid-subtropical monsoon climate. The daily mean air temperature and precipitation during the experimental cropping seasons were collected from a nearby weather station, shown in Fig. 1a and b. The average air temperatures and total rainfall during the rapeseed growing seasons were, respectively, 11.4 °C and 579.8 mm from 2012 to 2013 and 11.9 °C and 555.5 mm from 2013 to 2014. During the rice growing seasons, the mean air temperatures and total precipitation were 27.3 °C and 458.8 mm in 2013 and 25.7 °C and 746.1 mm in 2014. The main cropping system in this region is drained rapeseed and flooded rice on an annual rotation. Bed-furrow bases are popular in Hubei province for improving rice root growth, reducing irrigation, and eliminating the need for tillage. The experimental site was cultivated with rapeseed and rice rotations for nearly a decade. The experimental soil derived from the alluvial soil of the Yangtze River is a subtropical sandy loam classified as Gleysol (FAO classification). The main soil properties (0–20 cm depth) of the site are as follows: pH is 7.0 (extracted by H_2O; soil: water = 1:2.5); organic carbon (C) is 14.25 g kg^{-1}; total nitrogen (N) is 1.56 g kg^{-1}; nitrate (NO_3^-) is 8.48 mg kg^{-1}; ammonium (NH_4^+) is 12.6 mg kg^{-1}; total phosphorus (P) is 0.52 g kg^{-1}; available P is 9.56 mg kg^{-1} (extracted by $NaHCO_3$); available potassium (K) is 93.72 mg kg^{-1} (extracted by CH_3COONH_4); and the soil bulk density is 1.27 g cm^{-3}.

2.2. Field experimental treatments and agronomic management practices

In 2012, the land was soaked for 4 days after the rapeseed harvest on May 18 and was subsequently ploughed and puddled. The bed-furrows were built with beds 1.5 m wide and furrows 0.3 m wide and 0.25 m deep before rice seeding. Rice seeds were sown on beds on June 1, 2012, and starting with the rice season in 2012, we converted the conventional tillage to no-tillage with a bed-furrow base for the following experimental cropping seasons.

To investigate the effects of water regimes during the rice growing season on GWPs from the annual rapeseed–rice rotation system, three types of water management practices were set up during the rice season in 2012: (1) continuous flooding (CF): flooded with 1–2 cm water until the rice attained the three-leaf stage, then continuously flooded with 2–5 cm water, and the irrigation stopped 15–20 days before rice harvest; (2) flooded and wet intermittent irrigation (FWI): flooded with 1–2 cm water until the rice attained the three-leaf stage, then it was irrigated to full furrow again once the water naturally disappeared in the furrow with wet-bed soil, and the cycle of full and no-furrow water was repeated until irrigation stopped 15–20 days before harvest, here, furrow water level and bed soil moisture were important indicators for re-irrigation; and (3) rain-fed with limited irrigation when fertilizer was applied and in the case of serious drought (RFL): flooded with 1–2 cm water until the rice attained the three-leaf stage, and then, there was no irrigation except during serious drought (the soil was too dry and rice leaves began withering) and fertilizer applications.