Agriculture, Ecosystems and Environment 233 (2016) 270–281

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Drainage, no-tillage and crop rotation decreases annual cumulative emissions of methane and nitrous oxide from a rice field in Southwest China

Qingju Hao[a], Changsheng Jiang[a,*], Xuesi Chai[a], Zhe Huang[a], Zhiwei Fan[a], Deti Xie[a], Xinhua He[a,b]

[a] Key Laboratory of Eco-environments in Three Gorges Reservoir Region (Ministry of Education), College of Resources and Environment, Southwest University, Chongqing 400715, China
[b] School of Plant Biology, University of Western Australia, Crawley, WA 6009, Australia

ARTICLE INFO

Article history:
Received 30 January 2016
Received in revised form 16 September 2016
Accepted 22 September 2016
Available online xxx

Keywords:
CH_4
N_2O
Brassica napus
Oryza sativa
Paddy fields
Ridge cultivation

ABSTRACT

Permanently flooded rice fields, a special kind of all year-round flooded rice fields in China, where the crop system is summer rice (*Oryza sativa* 'Q You 6') with winter fallow, contribute to both CH_4 and N_2O emissions. To investigate their CH_4 and N_2O emissions over a whole year (November 2009 to October 2010) and responses to long-term tillage-cropping systems, four treatments after the conversion of such rice fields were examined: conventional tillage with a single summer rice and floodwater winter fallow (CTRF) or drained winter rapeseed (*Brassica napus* 'W You 25') (CTRR), no-tillage narrow- or wide-ridge with a rice and rapeseed rotation (NTNRR or NTWRR). Results showed that CTRF emitted the highest CH_4 owing to permanently flooding water layer and higher soil organic carbon concentrations. Compared to CTRF, CH_4 emissions under other three tillage-cropping systems were decreased not only in the winter season but also in the rice-growing season. In contrast, N_2O emissions over a whole one-year rice-rapeseed rotation cycle were almost equivalent to each other under these four tillage-cropping systems. Also compared to CTRR, the two no-tillage-cropping systems tended to enhance CH_4 while decrease N_2O emissions, though with insignificant effects. The annual cumulative emissions of CH_4 and N_2O were highest under CTRF (1.07 ± 0.20 kg CO_2-eq ha^{-1} kg^{-1} yield) and significantly decreased under CTRR, NTNRR and NTWRR (0.59 ± 0.10, 0.67 ± 0.05 and 0.58 ± 0.09 kg CO_2-eq ha^{-1} kg^{-1} yield, respectively), indicating that the summer rice-winter rapeseed rotation system, irrespective of tillage management, rather than the summer rice-winter fallow system, had achieved the objective of higher yields with less greenhouse gas emissions. These results demonstrate that the no-tillage wide-ridge with a rice and rapeseed rotation (NTWRR) is the most efficient management in terms of decreasing CH_4 and N_2O emissions in Southwest China.

1. Introduction

Methane (CH_4) and nitrous oxide (N_2O) are the second and third largest greenhouse gases (GHG) contributing to global climate change next to carbon dioxide, respectively (IPCC, 2013). Globally CH_4 concentrations have risen from 722 ± 25 ppb in 1750 to 1803 ± 2 ppb in 2011 predominantly due to changes in anthropogenic-related CH_4 while agricultural soils have been identified as a major GHG source (IPCC, 2013). For instance, paddy soils emit a total of 33 to 40 Tg CH_4 yr^{-1} and 90% of them come from tropical Asia or 50% from China and India (Yan et al., 2009). Global N_2O concentration was 324.2 ppb in 2011 with a 20% increase as its level in 1750 (Prather et al., 2012). Anthropogenic N_2O emissions, mostly from agricultural and soil sources and fossil-fuel activities, account for 30% to 45% of the current global total N_2O emissions (Fowler et al., 2009).

Studies have showed inconsistent results of CH_4 and N_2O emissions under different tillage and/or cropping systems. For example, a meta-analysis showed that no-tillage (NT) could mitigate CH_4 emission from rice fields as compared to the conventional tillage (CT) in China (Feng et al., 2013). Similarly, no-tillage markedly decreased CH_4 emissions from double-rice cropping systems in the central and southeast China (Ahmad et al.,

* Corresponding author.
E-mail addresses: jiangcs@126.com, jiang.changsheng@yahoo.com (C. Jiang).

http://dx.doi.org/10.1016/j.agee.2016.09.026
0167-8809/

2009; Li et al., 2011). Reduction in tillage frequency had led to significant reductions in CH_4 emissions during the rice season in an Indian rice-wheat system (Pandey et al., 2012). In contrast, the adoption of an NT system significantly increased CH_4 emissions during both the wheat season and the following rice season (Zhang et al., 2015). As for N_2O, significant emissions between NT and CT could be decreased (Li et al., 1996; Pandey et al., 2012), increased (Yao et al., 2013; Zhang et al., 2011b) or similar (Ahmad et al., 2009; Feng et al., 2013; Zhang et al., 2015). Meanwhile, the impacts of cropping systems on concurrent CH_4 and N_2O emissions have been documented. For instance, a 2-year field experiment in Southwest China showed that the global warming potential (GWP) of CH_4 and N_2O was largely decreased in rice-wheat or rapeseed rotation systems that were transformed from permanently flooded rice fields (Jiang et al., 2006). Significantly greater or lower greenhouse gas intensity (GHGI) of Chinese major rice systems during the rice season ranked in the order: double rice > rice-upland crop rotation > single rice plantation based on rice yields and CH_4 and N_2O emissions (Feng et al., 2013). Nevertheless, GHG emissions during no-rice growing seasons are needed for a life-cycling assessment of GHG emissions under different cropping systems.

At present studies of tillage effects on GHG exchange between land surface and atmosphere mainly focused on comparatively short-term (<10 years), with only a few long-term (>10 years), field experiments (Omonode et al., 2007; Baker et al., 2007). For instance, compared to CT, newly converted NT systems increased GWP in both humid and dry climate regimes, while 10-year or 20-year longer-term NT significantly decreased GWP in humid climates or in dry areas, though with a high variation. Meanwhile, a meta-analysis has showed a strong time dependency in the GHG mitigation potential under NT (Six et al., 2004). Therefore, long-term tillage effects on field CH_4 and N_2O emissions are still needed.

Permanently flooded rice or paddy fields are a special kind of rice fields in China and widely distributed in mountainous areas of Southwest China where the cropping system is a single middle rice (*Oryza sativa* L.) plantation (May to August) and in fallow with floodwater layer after rice harvesting (September to April). The area of such rice fields ranges from 2.7 to 4.0 Mha (Jiang et al., 2006). A few studies have reported that such flooded rice fields are one of the largest CH_4 emission sources in the world during the rice season in particular, and even in the fallow season (Chen et al., 1993; Khalil et al., 1998; Wei et al., 2000; Cai et al., 2003; Jiang et al., 2006). However, few studies have focused on N_2O emissions from these permanently flooded rice fields. Meanwhile, with the well-developed irrigation system, more and more these single rice planation fields have been converted to a yearly double cropping system: summer rice and winter upland crop, particularly the rice-rapeseed rotation in Southwest China. Furthermore, since 1990 an innovative approach—ridge cultivation with no-tillage has been increasingly adopted in Southwest China (Xie, 2002). Briefly, the paddy fields are changed from plain to ridge and store water in the ditches between the two ridges, rice and winter upland crops are planted on the ridges instead of a single rice crop a year. This innovative approach can improve soil permeability and heat condition, prevent paddy fields from over reduced redox potential owing to permanently flooded, increase grain yields and protect soil against erosion (Xie, 2002). As a result, the total CH_4 and N_2O emissions could be altered due to the changes in soil physico-chemical and biological properties. However, information is limited on how such a ridge double cultivation system could affect the flux and pattern of CH_4 and N_2O emissions, particularly under long-term ridge rice-winter crop rotation with no-tillage. In a 20-year long-term ridge cultivation paddy field in subtropical southwest China, the objectives of this study were therefore to address effects of four cultivation systems on their differences in (1) CH_4 and N_2O emissions between the conventional tillage with a single rice plantation plus or minus rapeseed (*Brassica napus* L.), and two (narrow and wide) ridge rice-rapeseed rotations with no-tillage, and (2) their GWP by relating such differences in CH_4 and N_2O emissions to crop yields under such tillage and cropping systems. The generated results could provide important implications for GHG mitigation in paddy soils globally.

2. Materials and methods

2.1. Study site and experimental design

The field site locates in the campus farm of Southwest University, Beibei, (30°26′N, 106°26′E, ~230 m above the sea level), Chongqing, Southwest China. Four tillage-cropping treatments with four replicates each over there have been established since 1990 in a randomized split-plot design. Each plot is in a 20 m × 5 m size with a 0.5 m border between plots. The four treatments are: (1) conventional tillage with a single rice plantation and floodwater fallow (CTRF); (2) conventional tillage with a rotation of rice and rapeseed (CTRR); (3) no-tillage “narrow” or (4) “wide” ridge with a rotation of rice and rapeseed (NTNRR or NTWRR). The NTNRR consists of a two 30 cm wide and 35 cm deep ditches on each side to form a 35 cm wide ridge, where rice is cultivated on both two sides of the ridge with a 0–3 cm water level below the ridge top during the rice growing season. After rice harvesting, rapeseed is cultivated in both sides of the ridge in the same way as rice when a 10–15 cm water level is kept in ditches. The NTWRR consists of two 35 cm wide and 35 cm deep ditches to form an 85 cm wide ridge, and the rice and rapeseed rotation plantation is the same, except four planting rows on the top of the ridge. Flooding was initiated one week before rice transplanting and maintained until two weeks before rice harvesting. The waterlogging depth was maintained at 0–3 cm below the ridge top in NTNRR and NTWRR, 8 cm in CTRF and CTRR during the rice growing season. Water level was still maintained 8 cm in CTRF, 20–25 cm below the ridge top in NTNRR and NTWRR, and completely drained in CTRR during the no-rice season. An irrigation-drainage system was used to maintain the waterlogging depth.

The soil is a Hydragric Anthrosol (FAO soil classification) and has developed from Jurassic purple shale and sandstone. The surface soil (0–20 cm) properties in 1990 were as follows: 1.2 g cm^{-3} bulk density, 42% clay (<0.005 mm), pH 6.5, 16.2 g total organic carbon kg^{-1}, 1.82 g N kg^{-1} and 128.5 mg alkali-soluble N kg^{-1}, 0.86 g P kg^{-1} and 9.2 mg available P kg^{-1}, and 24.1 g K kg^{-1} and 82.3 mg available K kg^{-1}.

The CH_4 and N_2O fluxes were measured in this site from October 2009 to October 2010. The seasonal variations of mean daily precipitation and daily air temperature during this observation period were presented in Fig. 1. The site region has an annual 990.4 mm precipitation (about 60% of which fell in the rice growing season), an annual daily 18.6 °C (ranging from 5.5 to 34.7 °C), an annual 1276.7 h sunshine hours and 334 non-frost days.

The rapeseed (*Brassica napus* ‘W You 25′) were sowed on 30 October 2009 and harvested on 27 April 2010 and the rice (*Oryza sativa* ‘Q You 6′) were transplanted on 10 May 2010 and harvested on 15 August 2010. Chemical fertilizers have been applied to all plots at an equal rate each year since 1990 (see Cai et al., 2003), i.e. 273 kg urea ha^{-1}, 500 kg superphosphate ha^{-1}, and 150 kg KCl ha^{-1} for the rice growing season while 333 kg urea ha^{-1}, 1126 kg superphosphate ha^{-1}, and 187 kg KCl ha^{-1} for the rapeseed growing season. Superphosphate was applied as basal fertilization, urea and KCl were applied as basal fertilization and topdressing. No exogenous organic manure was applied to the plots except for 1996, when human manure was applied to each plot at a rate of 20 t ha^{-1} before rice transplanting. After rice harvesting, rice stubbles about 30 cm above ground still stood in the CTRF field