Agriculture, Ecosystems and Environment 164 (2013) 209–219

Contents lists available at SciVerse ScienceDirect

Agriculture, Ecosystems and Environment

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

Net global warming potential and greenhouse gas intensity of annual rice–wheat rotations with integrated soil–crop system management

Y.C. Ma[a], X.W. Kong[a], B. Yang[a], X.L. Zhang[a], X.Y. Yan[b], J.C. Yang[c], Z.Q. Xiong[a,*]

[a] *Jiangsu Key Laboratory of Low Carbon Agriculture and GHGs Mitigation, Nanjing Agricultural University, Nanjing 210095, China*
[b] *State Key Laboratory of Soil and Sustainable Agriculture, Institute of Soil Science, Chinese Academy of Sciences, Nanjing 210008, China*
[c] *Agricultural College of Yangzhou University, Yangzhou 225009, China*

ARTICLE INFO

Article history:
Received 8 May 2012
Received in revised form 18 October 2012
Accepted 11 November 2012
Available online 8 December 2012

Keywords:
Net ecosystem carbon budget
Soil carbon sequestration
Rice–wheat rotation
Nitrogen use efficiency
Greenhouse gas mitigation

ABSTRACT

The impact of management practices on the net global warming potential (GWP) and greenhouse gas intensity (GHGI) of rice cropping systems is not well documented. A field experiment was established in 2009 to gain insight into the net ecosystem carbon budget and the net GWP and GHGI on the crop seasonal scale over two cycles of rice–wheat rotations. With the local farmer's practices (FP) as the control, three integrated soil–crop system management (ISSM) practices at different nitrogen (N) application rates were established – ISSM-N1, ISSM-N2 and ISSM-N3 – for improvement of rice yield and agronomic nitrogen use efficiency (NUE). Compared with the FP, the rice yields significantly increased by 8.2%, 18% and 31%, while the agronomic NUE increased by 68%, 74% and 99% for ISSM-N1, ISSM-N2 and ISSM-N3, respectively. Within the three ISSM practices averaged over the two cycles, the soil organic carbon sequestration potentials, CH_4 and N_2O emissions were estimated to be 0.089–0.67 t C ha^{-1} yr^{-1}, 166–288 kg CH_4—C ha^{-1} yr^{-1} and 4.27–5.47 kg N_2O—N ha^{-1} yr^{-1}, respectively. Compared to the net GWPs (8.36 t CO_2eq ha^{-1} yr^{-1}) and GHGI (0.58 kg CO_2eq kg^{-1} grain) from the FP, the ISSM-N1 and ISSM-N2 reduced both the net GWPs and GHGIs to some extent, indicating that GHG mitigation can be simultaneously achieved with improved food production and NUE. Although it produced similar GHGIs, the ISSM-N3 increased the net GWPs by 16% compared to the FP, indicating that more research is required on ISSMs for mitigating GHGs to further increase the grain yield and NUE in rice agriculture.

1. Introduction

Rapid population growth and economic development have increased the need for food production around the world (Barrett, 2010). Chinese agriculture has intensified greatly since the early 1980s within a limited land area with large inputs of chemical fertilizers (Ju et al., 2009; Makino, 2011). Because a high proportion of applied nitrogen (N) is lost to the environment (Erisman et al., 2008), large inputs of N fertilizer and low N use efficiency are causing serious environmental problems in the intensive agricultural regions of China (Ju et al., 2009).

With approximately 130 million hectares of rice paddies, China accounts for approximately 31% of the global rice production (Frolking et al., 2002). Summer rice-upland crop annual rotation is a dominant cropping system in the Taihu Lake region in the central Yangtze River Delta. In these rotations, basal N fertilizer was typically applied in a large amount (Zhao et al., 2009). At the conventional application rate of 550 kg N ha^{-1} yr^{-1} (250 kg N ha^{-1} for wheat and 300 kg N ha^{-1} for rice), the nitrogen use efficiency (NUE) was very low (31% for rice and 33% for wheat) (Huang and Tang, 2010). Thus, integrated soil–crop system management (ISSM) has been advocated and developed in China to increase crop productivity and NUE (Chen et al., 2011; Zhang et al., 2011).

However, the overall impacts of different ISSM practices on net global warming potential (GWP) are unknown (Chen et al., 2011; Zhang et al., 2011). The balance among the net exchanges of CO_2, N_2O and CH_4 constitutes the net GWP (Mosier et al., 2006). The agricultural practices can be related to GWP by estimating net GWP per tone of crop yield and is referred as greenhouse gas intensity (GHGI) (Li et al., 2006; Mosier et al., 2006; Shang et al., 2010). Future sustainable agriculture should explore systems with low net GWP and GHGI at high crop productivity for food security. The overall impacts of different ISSM practices on net GWP and GHGI have not been assessed.

Paddy fields have a high capacity for soil carbon sequestration (Lu et al., 2009; Pan et al., 2004; Shang et al., 2010; Zheng et al.,

Abbreviations: F-D-F-M, flooding-midseason drainage-re-flooding-moist irrigation; FP, conventional farmer's practices; GWP, global warming potential; GHGs, greenhouse gases; GHGI, greenhouse gas intensity; GPP, gross primary production; ISSM, integrated soil–crop system management; NECB, net ecosystem carbon budget; NEP, net ecosystem production; NPP, net primary production; Re, ecosystem respiration; SOC, soil organic carbon.

* Corresponding author. Tel.: +86 25 84395148; fax: +86 25 84395210.
E-mail address: zqxiong@njau.edu.cn (Z.Q. Xiong).

0167-8809/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.agee.2012.11.003

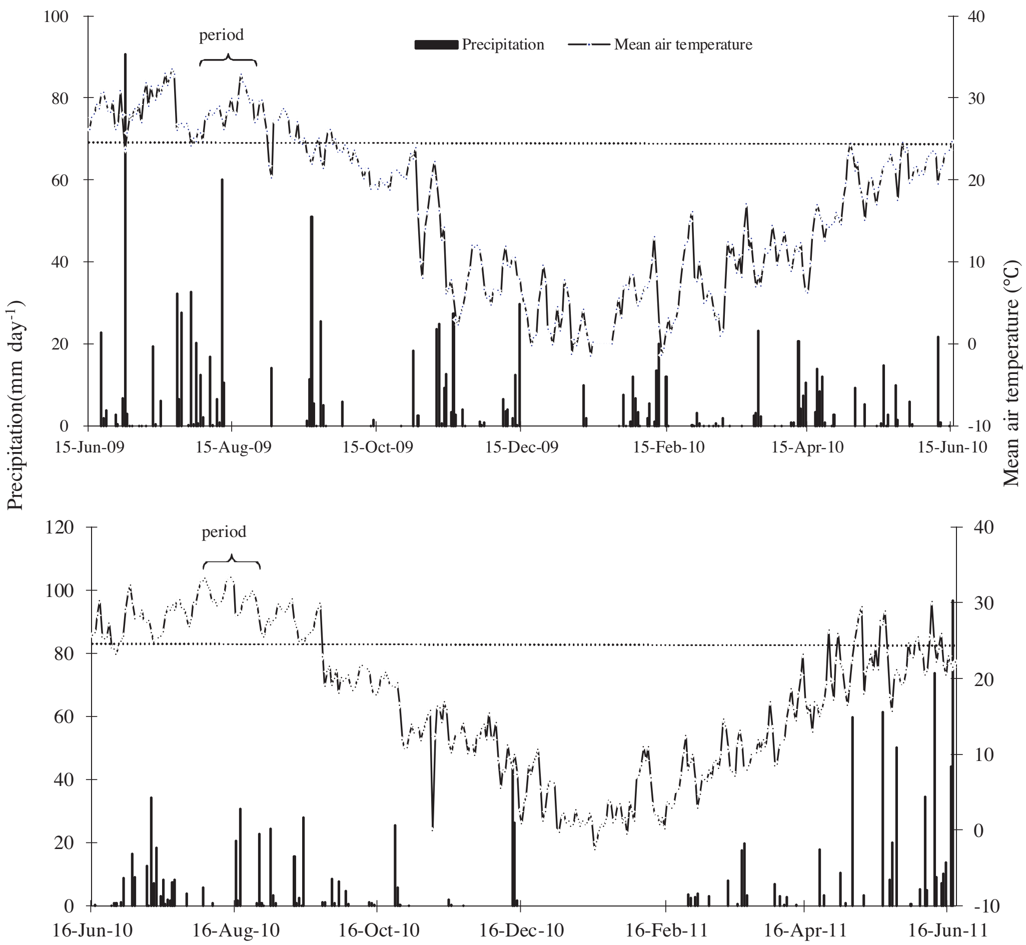

Fig. 1. Daily mean air temperature and precipitation during the two cycles of rice–wheat rotations in 2009 and 2010 in Changshu, China. The period indicated by the arrows refers from rice elongation to the heading stage.

2008). The soil carbon sequestration, i.e., net exchanges of CO_2, could be measured by soil organic carbon (SOC) changes over a subdecadal or decadal timescale (Pan et al., 2004; Shang et al., 2010); the method is not sensitive enough to detect seasonal or annual changes (Zheng et al., 2008). A chamber-based technique has been adopted by Burkart et al. (2007) and Zheng et al. (2008) for the daily net ecosystem CO_2 exchange. The net ecosystem carbon budget (NECB) can essentially provide a scientific basis for the development of carbon sequestration strategies (Chapin et al., 2006; Smith et al., 2010). A simplified chamber-based technique for deriving SOC change from NECB on the crop seasonal time scale was examined in our previous report on vegetable cropping systems (Jia et al., 2012). Here, we conducted intermittent chamber measurements for a typical rice–wheat annual rotation to assess SOC changes on the crop seasonal time scale for the different ISSMs.

Thus, our objectives were to investigate the impacts of different ISSM practices on (1) crop yield and NUE, (2) CH_4 and N_2O emissions, (3) SOC changes derived from the NECB, and (4) net GWP and GHGI in the first two cycles of rice–wheat annual rotations.

2. Materials and methods

2.1. Experimental sites

A field experiment was established at the Changshu agro-ecological experimental station (31°32′93″N, 120°41′88″E), Chinese Academy of Sciences, Jiangsu province. The main cropping system is flooded rice (*Oryza sativa* L.) and drained wheat on an annual rotation. The soil is classified as an *Anthrosol* developed from lacustrine sediment, having silt clay texture. The soil at 0–20 cm depth has a pH of 7.35, a total N content of 2.1 g N kg^{-1}, and an organic C content of 20.3 g C kg^{-1}. The daily mean air temperatures and precipitation during the experimental cropping seasons are collected from Changshu station, which is 100 m away from our experimental site shown in Fig. 1.

2.2. Field plot treatment and management

With local, conventional farmer's practices (FP) as the control and three integrated soil–crop system management (ISSM) practices at different nitrogen (N) application rates were established-ISSM-N1, ISSM-N2 and ISSM-N3, for improving rice yield and agronomic nitrogen use efficiency (NUE). A zero-N control (NN) was included to calculate the agronomic NUE and N_2O emission factors. In total, five field experimental treatments with four replicated field plots (6 m × 7 m) were established with a randomized block design in 2009. According to the local FP, the total N fertilizer application rate was 300 kg N ha^{-1} for the rice crop season and 180 kg N ha^{-1} for the wheat crop season as measured by farmer's application which usually used by conventional farmer's practice as usual. The ISSM strategies include N fertilizer splitting application and transplanting density as the main techniques improving rice yield and the NUE at the reduced N levels of the ISSM-N1 and ISSM-N2 with different yield targets. N was reduced by 25% and 10% for ISSM-N1 and ISSM-N2, respectively, and the corresponding total N application rate for the rice and wheat crop