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Comparison of greenhouse gas emissions from rice paddy fields under different nitrogen fertilization loads in Chongming Island, Eastern China

Xianxian Zhang [a,b,c], Shan Yin [a,b,c,*], Yinsheng Li [a,b], Honglei Zhuang [a,b,c], Changsheng Li [a,b,d], Chunjiang Liu [a,b,c]

[a] School of Agriculture and Biology, Shanghai Jiao Tong University, Dongchuan Rd. 800, Shanghai 200240, China
[b] Research Centre for Low Carbon Agriculture, Shanghai Jiao Tong University, Dongchuan Rd. 800, Shanghai 200240, China
[c] Key Laboratory for Urban Agriculture (South), Ministry of Agriculture, PR China, Dongchuan Rd. 800, Shanghai 200240, China
[d] Institute for the Study of Earth, Oceans, and Space, University of New Hampshire, Morse Hall, College Road, NH 03824-3525, USA

HIGHLIGHTS

- In Chongming Island, Shanghai, GHG emissions were measured under different nitrogen fertilizer rates from the paddy.
- Low nitrogen fertilizer application reduced CH_4 and N_2O emissions.
- The study showed that 210 kg N/ha was the suitable fertilizer application rate.

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ABSTRACT

Rice is one of the major crops of southern China and Southeast Asia. Rice paddies are one of the largest agricultural greenhouse gas (GHG) sources in this region because of the application of large quantities of nitrogen (N) fertilizers to the plants. In particular, the production of methane (CH_4) is a concern. Investigating a reasonable amount of fertilizers to apply to plants is essential to maintaining high yields while reducing GHG emissions. In this study, three levels of fertilizer application [high (300 kg N/ha), moderate (210 kg N/ha), and low (150 kg N/ha)] were designed to examine the effects of variation in N fertilizer application rate on carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions from the paddy fields in Chongming Island, Shanghai, China. The high level (300 kg N/ha) represented the typical practice adopted by the local farmers in the area. Maximum amounts of CH_4 and N_2O fluxes were observed upon high-level fertilizer application in the plots. Cumulative N_2O emissions of 23.09, 40.10, and 71.08 mg N_2O/m^2 were observed over the growing season in 2011 under the low-, moderate-, and high-level applications plots, respectively. The field data also indicated that soil temperatures at 5 and 10 cm soil depths significantly affected soil respiration; the relationship between *Rs* and soil temperature in this study could be described by an exponential model. Our study showed that reducing the high rate of fertilizer application is a feasible way of attenuating the global-warming potential while maintaining the optimum yield for the studied paddy fields.

1. Introduction

Global warming is caused by the emission of greenhouse gases (GHG), such as methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2), etc. Within 100 years, the global warming potentials of CH_4 and N_2O are expected to become 21 and 310 times that of CO_2 (IPCC, 1995), respectively. Today, GHG levels continue to increase not only because the anthropogenic emissions, but also because the longer lifetime which caused by the decreases in the amount and stability of atmospheric [$OH^·$] (Montzka et al., 2011). The energy consumption, industrial pollution, poor agriculture and deforestation management practices of humans have directly and indirectly increased the atmospheric concentrations of several GHGs, especially those of CO_2, CH_4, and N_2O (Houghton et al., 1996). Thus, mitigating the agricultural emissions of these GHGs by altering human activities is a very important endeavor.

On global scale, agricultural activities accounted for an estimated 5.1–6.1 Gt CO_2-eq/yr of emissions in 2005 (10%–12% of the total anthropogenic GHG emissions) and a nearly 17% increase in CH_4 and N_2O

* Corresponding author at: School of Agriculture and Biology, and Research Center for Low Carbon Agriculture, Shanghai Jiao Tong University, Dongchuan Rd. 800, Shanghai 200240, China. Tel./fax: +86 21 34204780.
E-mail address: yinshan@sjtu.edu.cn (S. Yin).

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emissions from 1990 to 2005 (IPCC, 2007). The GHG inventory for agriculture was 819 Mt CO_2-eq and accounted for 11% of the total GHGs in China. Emission from rice paddy and agricultural land uses was 374 Mt CO_2-eq, accounting for 45.7%. (P.R.-China, 2013).

Rice, an important food in many parts of the world, is a semi-aquatic species and mostly grows under flooded low-land conditions in paddies (Kögel-Knabner et al., 2010). Induced by periodic short-term flooded cycles over long periods of time, paddy fields have special soil characteristics, such as soil redox potential, different bacterial communities, anaerobic status, etc. (Kögel-Knabner et al., 2010; Lüdemann et al., 2000; Yao et al., 1999). The soil environment of redox gradients, microbes, and limited O_2 microhabitats significantly affects the biogeochemical processes [carbon cycle and nitrogen (N) dynamics] that occur in flooded paddy fields. Recent research on rice paddy fields has mostly focused on water management, microbial communities and GHG emissions (Fuller and Qin, 2009; Hama et al., 2011; Hou et al., 2012; Ke and Lu, 2012; Tago et al., 2011; Tyagi et al., 2010; van Groenigen et al., 2011). Rice producers employ multiple cropping management practices, e.g., tillage and fertilizers. The effects of tillage and fertilizer on the carbon stock of soil have recently been reported (Ahmad et al., 2009; Baggs et al., 2003; Huang et al., 2006; Morell et al., 2011; W. Zhang et al., 2007).

Modification of farming management practices such as tillage, fertilization, straw residue, and water management, is an effective way of mitigating GHG emissions. Direct-seeding mulch-based cropping (DMC) systems present a tillage method that has noticeably increased in application over the last decades.

A previous study showed that DMC use in rainfed fields (rice, wheat, maize) in Latin America results in maximized productivity and stable or unstable carbon protection (Scopel et al., 2004). Carbon and N contents as well as denitrification activity in the soil increase significantly under DMC systems mainly because the microbial community and chemical processes in soil are closely correlated with soil tillage management (Baudoin et al., 2009). The DMC system may increase carbon stocks in soil and emissions (Chapuis-Lardy et al., 2009; Metay et al., 2007; Six et al., 2002).

Rice contributes about 43.7% of the total national grain production in China (irri.org, from International Rice Research Institute). Paddy-rice yields per hectare have greatly increased with the application of high levels of fertilizer, especially N fertilizers (ICAM, 2012; Peng et al., 2002b). Approximately, 30% of the N fertilizer produced worldwide is consumed by China with low fertilizer use efficiency (Peng et al., 2002a). Fertilization management significantly affects GHG emissions from paddy fields. According to Kahrl's estimation, N fertilizer reduction can lead to GHG emission reductions (Kahrl et al., 2010), and N_2O emission rate is also affected by fertilizer types. Appropriate N fertilizer application rates can help increase biomass production and decrease GHG emissions (Snyder et al., 2009). It was observed that seasonal N_2O emissions generally increase with fertilizer input during the rice-growing season (Zou et al., 2008).

Numerous countries have taken effective actions to reduce GHG emissions. Agricultural management practices contribute significantly to GHG emissions. China is a developing country with rapid economic growth in conjunction with increasing of GHG emissions. Few studies have addressed the nature of GHG emissions from DMC. This study aims to estimate the GHG emissions of DMC-paddy fields under different doses of applied N fertilizer in a typical rice field in Chongming Island, Shanghai, China and explore mitigation measures.

2. Materials and methods

2.1. Experimental site

The experiment was carried out in a paddy field of Dadong Village, Chongming Island, Shanghai, China (31.61°N, 121.62°E) from 2010 to 2011. Chongming Island, the third largest island in China, is located in the Yangtze River estuary. The fields used for the experiment had been cultivated with rice and broad bean (*Vicia faba* Linn.) rotation over the last 5 years and had been managed routinely according to local planting traditions. The soil organic carbon, total N content, and soil bulk density before planting were 15.65 g/kg, 1.28 g/kg, and 1.4 g/cm^3, respectively. The paddy fields were fertilized with 300 kg N/ha, a typical practice in Chongming Island. The rate was much higher than the crop demand for N. In East Asia, the estimated average N application rate is 155 kg N/ha (F. Zhang et al., 2007).

The rice paddy plots used in this experiment measured 5 m × 15 m with three replicates separated by plastic film and a high ridge. Each plot has three measurement points. Paddy was treated with a urea dosage of 150 (low), 210 (moderate), or 300 (high) kg N/ha. The rice seeds were directly planted and flooded after 2 weeks. The fertilization stages included (1) basal fertilizer application during the transplanting stage and (2) top dressing fertilizer application during the tillering stage (before flooding and 2 weeks after flooding, with 2/3 and 1/3 of the designated fertilizer treatment, respectively).

2.2. Observed data

2.2.1. CH_4 and N_2O emission flux

After planting and fertilization, the dark static chamber/GC method was used to detect the GHG flux between 9:00 am and 12:00 am every 2 weeks from June 9 to November 10 in 2011. The static chamber was a gas collector box made of PVC plastic plate with a standard size of 50 cm × 50 cm × 75 cm. Five hills of rice seedlings were covered in each chamber. Each sampling was subdivided five times in 10 min intervals. A fan was used to mix the gases in the chamber, which were then drawn off by a syringe and transferred into a 100 mL gas-sampling bag made of aluminum foil. CO_2, CH_4, and N_2O were simultaneously detected by a GC system configured by the Institute of Atmospheric Physics, Chinese Academy of Sciences (Wang et al., 2010; Zheng et al., 2008) in laboratory. The increase of GHG concentration in the static chamber was calculated by linear regression. Fluxes were calculated from the following formula (Davidson et al., 2002; Huang, 2003).

$$F = \frac{dC}{dt} \times \frac{mPV}{ART} = H \times \frac{dC}{dt} \times \frac{mP}{RT}. \tag{1}$$

Here, $\frac{dC}{dt}$ is acquired by the linear regression equation. The value m is the molecular weight of trace gas, P indicates the atmospheric pressure ($P = 1.013 \times 10^5$ Pa), R is the gas constant (R = 8.314 J/mol/K), and T is the air temperature in the chamber. V, H, and A are the volume, height, and area of the static chamber, respectively.

2.2.2. Soil CO_2 emission flux

The soil CO_2 flux was measured in 3 points per each plot from June 9 to December 23 in 2011 using the static chamber method. However, no rice seedlings were covered in these sampling chambers.

Soil respiration (Rs) in the paddy field was calculated, along with the GHG flux. An exponential model was fitted with the soil temperature to obtain the following formula.

$$Rs = \alpha e^{\beta T} \tag{2}$$

where α and β are two different constants and T is the soil temperature.

T was measured adjacent to each static chamber ring at the time of flux measurement. The temperature was measured at 5 and 10 cm below the surface of the paddy soil.

Q_{10} values (the coefficient for the exponential relationship between soil respiration and temperature) were calculated by equation 3. (Boone et al., 1998; Davidson et al., 2002; Lloyd and Taylor, 1994)

$$Q_{10} = e^{10\beta} \tag{3}$$