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Assessing impacts of alternative fertilizer management practices on both nitrogen loading and greenhouse gas emissions in rice cultivation

Zheng Zhao [a], Yubo Yue [a], Zhimin Sha [a], Changsheng Li [b], Jia Deng [b], Hanlin Zhang [c], Maofang Gao [d], Linkui Cao [a, *]

[a] School of Agriculture and Biology, Shanghai Jiao Tong University, Shanghai 200240, China
[b] Institute for the Study of Earth, Ocean and Space, University of New Hampshire, Durham, NH 03824, USA
[c] Eco-environmental Protection Institute of Shanghai Academy of Agricultural Science, Shanghai 201403, China
[d] Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, China

HIGHLIGHTS

- N loss and GHG emissions were measured from a paddy field in Shanghai.
- N loss associated to different precipitation patterns.
- GHG emissions related to different fertilizer and water management.
- Application of urea increased N losses and N_2O emissions.
- Application of organic manure enhanced CH_4 emissions and net GWP.

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ABSTRACT

Nitrogen (N) losses and greenhouse gas (GHG) emissions from paddy rice fields contaminate water bodies and atmospheric environment. A 2-year (2012–2013) field experiment was conducted at a typical paddy rice field in a rural suburb of Shanghai, China. N losses and GHG emissions from the paddy field with alternative fertilizer management practices were simultaneously measured. Four treatments were tested in the experiment: applications of only chemical synthetic fertilizer urea (CT), only organic manure (OT), a combination of the two types of fertilizers (MT) and a control (CK). Results from the field study indicated that CT produced the highest seasonal N loading rate (18.79 kg N/ha) and N_2O emissions (1.81 kg N_2O/ha) but with the lowest seasonal CH_4 emissions (69.09 kg CH_4/ha). With organic manure applied, MT and OT respectively reduced N loading by 21.86% and 30.41%, reduced N_2O emissions by 28.34% and 69.41%, but increased CH_4 emissions by 137% and 310% in comparison with CT. However, the net impact of CH_4 and N_2O emissions on global warming was enhanced when organic manure was applied. In addition, CT and MT produced the optimal rice yield during the experimental period, while OT treatment led to a yield reduction by 9.29% compared with CT. In conclusion, the impacts of alternative fertilizer management practices on ecosystem services ought to be assessed specifically due to the great variations across rice yields, N loss and GHG emissions.

1. Introduction

Paddy rice is one of the most important staple crops in the world and widely cultivated in Asia. Chinese rice planting area accounts for approximately 20% of global total and produces nearly 30% of world's total rice production quantity, that has made China as the largest rice producer in the world (Frolking et al., 2002). In order to meet the increasing food demand of the rapidly growing population in China, the country's rice production has been substantially improved in the past decades. The high application rates of synthetic nitrogen (N) fertilizer have contributed to the substantial increase in the rice production in China (Peng et al., 2009). The

* Corresponding author. School of Agriculture and Biology, Shanghai Jiao Tong University, 800 Dongchuan Rd., Shanghai 200240, China.
E-mail address: clk@sjtu.edu.cn (L. Cao).

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application rates of N fertilizer in most Chinese rice cultivation areas have reached 300 kg/ha or higher (Lin et al., 2007), which are much higher than the suggested application rate (Chen et al., 2011; Xia and Yan, 2012). As a result, China has become the largest N fertilizer consumer in the world and use more than 30% of world's total consumption (FAO). However, the use efficiency of N fertilizer in Chinese rice cultivation was only ranged from 24.8% to 35.7%, much lower than the level of 50% in most developed countries (Dobermann and Cassman, 2002; Jin, 2012). Due to the high application rates as well as low use efficiency in N fertilizer use in China, a large portion of the fertilizer N is lost into the environment around agricultural lands (Zhao et al., 2009). The mechanisms causing the N losses include soil surface runoff, subsurface leaching and N gas emissions (Zhang et al., 2011; Zhu et al., 2013). This inevitably leads to a number of environmental issues, including eutrophication of surface water, nitrate contamination of ground water and global warming (Chen et al., 2010; Guo, 2007; Wuebbles, 2009). Although rice production plays an important role in the world food supply, its impacts on the local and global environments are not negligible.

N losses from paddy field contribute largely to agricultural non-point source pollution and water quality degradation in China (Wang et al., 2011). The fertilizer N is easily loss through surface runoff or subsurface leaching water flow when flooding irrigation is conducted in paddy field. In China, about 7% of fertilizer N is lost into water bodies via surface runoff and subsurface leaching that has caused the widely observed water contamination issues (Zhu and Sun, 2008). Previous investigation showed that 42% of the freshwater lakes in China were contaminated with N and other chemicals (Jin et al., 2005). For example, the water quality of Taihu Lake, the second largest lakes in China, has been classified to be eutrophicated or heavily eutrophicated (Ye et al., 2007). Similarly, nitrate contamination of groundwater is harmful to human health. In order to ensure the safety of drinking water, the Public Health Ministry of China set a nitrate limit of 20 mg/L for drinking water. However, investigations showed that most of the groundwater samples collected in China had nitrate concentrations higher than its safety standard (Qu and Fan, 2010). Therefore, effective measures are urgently needed to mitigate the N contamination of water bodies in China.

Methane (CH_4) and nitrous oxide (N_2O) are two important GHGs with 25 and 298 times higher global warming potential than carbon dioxide (CO_2) in a time horizon of 100 years, respectively. The concentrations of CH_4 and N_2O in the atmosphere have increased by 148% and 18% since the pre-industrial era (Solomon, 2007). Agricultural soils are a significant anthropogenic source of GHG and contributing approximately 20% of global GHG emissions (Lokupitiya and Paustian, 2006). In the next two decades, the agricultural CH_4 and N_2O emissions would increase by 60% due to the increasing applications of synthetic N fertilizer (Li et al., 2006). Rice paddy fields have been identified as a major source of agricultural CH_4 and N_2O emissions (Das et al., 2011). In China, the CH_4 and N_2O emissions from paddy field were estimated to range from 7.4 to 8.0 Tg CH_4/year and from 88.0 to 98.1 Gg N_2O–N/year, respectively (Yan et al., 2009; Zou et al., 2009). Mitigation of CH_4 and N_2O emissions from paddy fields is considered as an urgent task for the world GHG reduction. Accordingly, a mitigation target was set by China to reduce CH_4 and N_2O emissions from paddy field by 40–45% per unit of GDP by 2020 (Metz et al., 2007). In order to achieve this goal, studies on the effective measures to regulate CH_4 and N_2O emissions from Chinese paddy fields are of national significance.

In the past decades, many researches have focused on the N losses and GHG emissions from paddy field under various agricultural management practices, including fertilizer management, water regime, tillage method and diverse of soil amendments application (Ahmad et al., 2009; Shen et al., 2014; Yang et al., 2013; Zou et al., 2005). Fertilizer management, both in terms of types and quantities, has proved an effective way to regulate N losses and GHG emissions from paddy fields (Peng et al., 2011; Wang et al., 2013a). However, most of the previous researches evaluated the effect of fertilizer management practices on N losses or GHG emissions separately. It has been being lack of the studies that assess the effects of fertilizer management practices on both N losses and GHG emissions. The study reported in the paper was to meet the gap.

2. Materials and methods

2.1. Experimental site

A 2-year experiment (2012–2013) was conducted in a typical rice paddy field at the Irrigation Technology Extension Station of Qingpu District, Shanghai, China (31°12′N, 121°08′E). The experimental site was located in the upper reaches of Huangpu River watershed, which is one of the water-resource protection areas in Shanghai. The local climate is subtropical humid monsoon, with a daily average air temperature of 16.7 °C and an annual average precipitation of 1087.3 mm. The experimental conditions are showed in Fig. 1. Twelve plots (2 × 3 m) with lysimeter systems permanently installed were employed for the field study. The lysimeter systems were constructed in 1998 with a basement. The collection pipes were buried into soil and connected with an automatically collection and recording system which set up in basement. The system will collect water samples and record water discharge volume automatically when surface runoff or subsurface leaching occurred (Fig. 2). The soil in the plots is Pup-Orthic Entisol and classified as Anthrosols based on the Chinese Soil Taxonomy. The physical and chemical characteristics of the topsoil (0–20 cm) are showed in Table 1. Rice-wheat rotation is the typical cropping system in this area and has been planted in the experimental plots with the locally routine management practices.

2.2. Experimental design and management

Rice seedlings were transplanted to the experimental plots in June and harvested in November after maturity. In order to investigate the effects of alternative fertilizer management practices on N losses and GHG emissions from paddy field, four treatments were established in a randomized block design with 3 replicates. The alternative management practices included (1) sole chemical synthetic fertilizer (urea) application treatment (CT), (2) sole organic manure application treatment (OT), (3) a mixture treatment with 80% urea and 20% organic manure on the N basis (MT), and (4) the control treatment receiving neither synthetic fertilizer nor manure (CK). The manure utilized in the experiment was made from poultry waste, containing 16.6 g of N, 15.1 g of P, 11.9 g of K and 519.7 g of organic matter per kilogram. The three fertilization plots treated with total N at a same rate of 300 kg N/ha, which was in line with the local farmers' practices. In addition, calcium superphosphate (90 kg P_20_5/ha) and potassium chloride (60 kg K_2O/ha) was applied in the CT plots to ensure the rice growth not limited by other nutrients. In consideration of the sufficient nutrients from the organic manure, no additional P or K fertilizer was applied in the OT plots, but 8.3 kg K_2O/ha was added into the MT plots to meet the application rate of 60 kg K_2O/ha. Urea was applied in three split times with 60%, 20% and 20% of the urea at basal fertilizer stage, jointing stage and heading stage, respectively. Manure, P and K fertilizer was applied as basal fertilizer once before rice transplanting (Table 2). All the experimental plots remained