Science of the Total Environment 565 (2016) 420–426

Contents lists available at ScienceDirect

Science of the Total Environment

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

Exploring a suitable nitrogen fertilizer rate to reduce greenhouse gas emissions and ensure rice yields in paddy fields

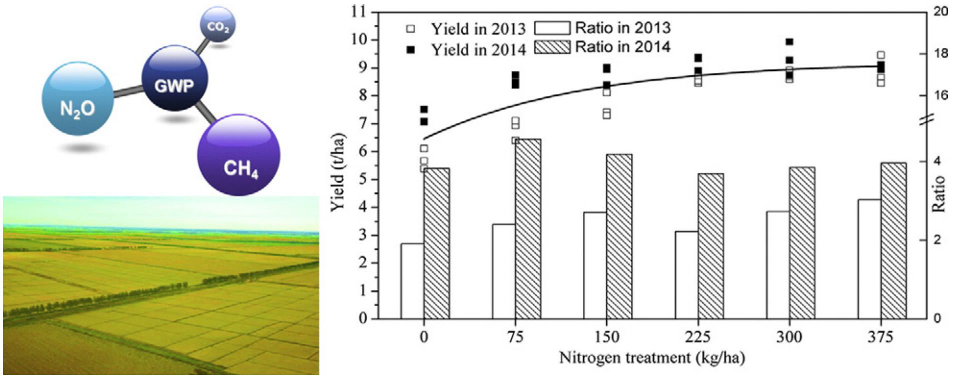
Yiming Zhong, Xiaopeng Wang, Jingping Yang *, Xing Zhao, Xinyi Ye

Institute of Environmental Science and Technology, College of Environmental and Resource Sciences, Zhejiang University, Hangzhou 310058, China

HIGHLIGHTS

- Exploiting co-benefits of rice yield and reduction of greenhouse gas emission.
- Global warming potential and rice yield increased with nitrogen fertilizer rate up.
- Emission peaks of CH_4, CO_2 and N_2O appeared at vegetative and reproductive phase.
- 225 kg N/ha rate benefits both rice yields and GWP reduction.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 16 January 2016
Received in revised form 15 April 2016
Accepted 23 April 2016
Available online 12 May 2016

Editor: Ajit Sarmah

Keywords:
Greenhouse gas
Paddy field
Nitrogen fertilizer
Global warming potential

ABSTRACT

The application rate of nitrogen fertilizer was believed to dramatically influence greenhouse gas (GHG) emissions from paddy fields. Thus, providing a suitable nitrogen fertilization rate to ensure rice yields, reducing GHG emissions and exploring emission behavior are important issues for field management. In this paper, a two year experiment with six rates (0, 75, 150, 225, 300, 375 kg N/ha) of nitrogen fertilizer application was designed to examine GHG emissions by measuring carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) flux and their cumulative global warming potential (GWP) from paddy fields in Hangzhou, Zhejiang in 2013 and 2014. The results indicated that the GWP and rice yields increased with an increasing application rate of nitrogen fertilizer. Emission peaks of CH_4 mainly appeared at the vegetative phase, and emission peaks of CO_2, and N_2O mainly appeared at reproductive phase of rice growth. The CO_2 flux was significantly correlated with soil temperature, while the CH_4 flux was influenced by logging water remaining period and N_2O flux was significantly associated with nitrogen application rates. This study showed that 225 kg N/ha was a suitable nitrogen fertilizer rate to minimize GHG emissions with low yield-scaled emissions of 3.69 (in 2013) and 2.23 (in 2014) kg CO_2-eq/kg rice yield as well as to ensure rice yields remained at a relatively high level of 8.89 t/ha in paddy fields.

1. Introduction

Anthropogenic GHG emissions in 2010 reached 49 ± 4.5 Gt CO_2-eq/y. Though the portion of emissions from Agriculture, Forestry, and Other Land Use (AFOLU) decreased to 24% of the total, the amount of emissions still increased (IPCC, 2014). The concentrations of CO_2, CH_4 and N_2O in

---

* Corresponding author.
E-mail address: jpyang@zju.edu.cn (J. Yang).

http://dx.doi.org/10.1016/j.scitotenv.2016.04.167

2011 were 391 ppm, 1803 ppb, and 324 ppb respectively, exceeding pre-industrial levels by approximately 40%, 150%, and 20% (IPCC, 2013). It is reported by the Second National Communication of China that GHG emissions caused by agricultural activities were 819 Mt CO_2-eq/y and accounted for 10.97% of China's total GHG emissions. Furthermore, emissions from paddy fields with single-cropping rice accounted for 46.38% of total agricultural GHG emissions (China, 2013). With increasing food demand, GHG emissions from agriculture production become an important source and have to be substantially reduced to minimize the risk of climate change (Godfray et al., 2011).

Due to the periodic flooded cycles, the soil environment in paddy fields has unique characteristics, such as the alternation of aerobic and anaerobic conditions. Paddy fields are considered to be a main source of methane and nitrous oxide emissions (Hadi et al., 2010; Harris et al., 1985). CO_2 and CH_4 are the end products of anaerobic carbon mineralization (Kirk, 2004). CH_4 is produced by methanogens in an environment which the oxygen (O_2) and sulfate (SO_4^{2-}) are limited. N_2O is produced by ammonia-oxidizing bacteria (AOB) and archaea (AOA) via nitrification and denitrification processes in the soil (Kögel-Knabner et al., 2010; Santoro et al., 2011).

The application of nitrogen fertilizers in rice cultivation has been commonly adopted to improve the nitrogen availability, with high chemical fertilizer usage, China's nitrogen fertilizer consumption on arable land for permanent crops reached 296.8 kg N/ha, and the rate in paddy is approximately 180 kg N/ha, higher than the Asian average level of 128.1 kg N/ha (FAO, 2013; Ma et al., 2008). The FAO (Food and Agriculture Organization of the United Nations) predicted that the world nitrogen fertilizer demand will be approximately 1.19×10^8 t in 2018 at the annual growth of 1.4%, and China will contribute 18% to the increase. But the use of nitrogen fertilizer may be an important factor that regulates CH_4 and N_2O emissions (Yao et al., 2012). Previous study declined CH_4 emission was due to the combined effects of nitrogen fertilization on production, oxidation, and transportation. As most CH_4 is emitted through aerenchyma system of the rice plants, higher tiller numbers (due to an increase in N rate) provide pathway for CH_4. In contrast, with high N application the concentration of NH_4^+ increased, which can stimulate CH_4 oxidation and lead to a reduction in CH_4 emission (K et al., 1989; Liang et al., 2013). Nitrogen has been reported to play an important role in soil C storage. Addition of N increased net C stored in response to additions of straw and root growth, which provides abundant carbon resource for soil respiration releasing CO_2 (Snyder et al., 2009). N_2O can be generated by both nitrification and denitrification processes. As nitrogen fertilization is the main nitrogen source, nitrogen application rate is main factor influencing N_2O emission. A meta-analysis of 78 published studies suggested a general trend of exponentially increasing N_2O emissions as N inputs in excess of crop needs (Shcherbak et al., 2014). The N_2O response to nitrogen fertilization suggests that agricultural N_2O fluxes could be reduced with no or little yield penalty by reducing nitrogen fertilization inputs to the level that just satisfy crop needs (Mcswiney and Robertson, 2005). Meanwhile many crop management practices, such as tillage, the timing of fertilization and resource of nitrogen, can affect GHG emissions, directly by affecting the NO_3^- availability or by modifying the soil microclimate and the cycling of carbon and nitrogen (Snyder et al., 2009). The potential of increasing NO_3^- N in residual soil can be reduced by cutting nitrogen application rates to decrease N_2O emission, but this is not considered to be appropriate management because the lack of nitrogen could result in a decrease of soil organic carbon (SOC) and cause a decline in the long-term soil productivity, which would reduce crop yields.

Numerous studies have shown that the appropriate use of N fertilizer increases biomass production, and appropriate management practices may lower the risk of increased GHG emissions. An optimum N fertilizer application rate of 225–270 kg N/ha was suggested to achieve good rice productivity in the Taihu Lake region (Deng et al., 2012; Wang, 2003). However, we suspect the recommended N fertilizer application rates may be still too high. This study aims to measure and estimate GHG emission potential and emission behavior during the rice growth stage under different nitrogen fertilization rates, to reduce GHG emissions and maintain rice yields at a relatively high level in paddy fields in Hangzhou, China.

2. Materials and methods

2.1. Experimental site and design

Field experiments were conducted from June to November 2013 on the experimental farm at Site 1 and from June to November 2014 at Site 2 of the Hangzhou Academy of Agriculture, Hangzhou, Zhejiang China (Table 1). The region has a subtropical monsoon climate with mean annual precipitation of 1454 mm and a mean air temperature of 17.8 °C. Rice cultivar "Hang 43" was planted in a paddy field plot under six nitrogen rates 0 (CK), 75, 150, 225, 300, and 375 kg N/ha by using a randomized block design with three replicates. Each plot size was 3.6 m × 5 m and separated by a high ridge with a plastic film cover to prevent the movement of water and fertilizers between plots.

Rice seedlings with five or six fully expanded leaves were transplanted on June 18. Hill spacing was 0.23 m × 0.13 m, with two seedlings per hill, resulting in a plant density of 67.6 plants/m^2. Superphosphate (225 kg/ha) and potassium chloride (75 kg/ha) were incorporated into each plot on the day of transplantation; an additional 75 kg/ha of potassium chloride was applied as a top-dressing after transplantation 40 days to prevent K deficiency. Plants received nitrogen in the form of urea, with each N application rate applied in three doses based on the rice growth stages as follows: June 16 (first fertilization, 50%), July 22 (second fertilization, 30%), and August 23 (third fertilization, 20%).

2.2. Measurement of GHG emissions and GWP

After rice transplantation and nitrogen fertilization, the opaque plastic static chamber was used weekly to collect the gas from paddy field at 9:00 am from the first fertilization until harvest. An additional sample collection was added during the fertilization week. The static chamber, with a size of 50 cm × 50 cm × 90 cm, was placed over nine hills of rice plants to collect gas. Each sampling was conducted in 10 min intervals for a total of 40 min. Syringes were used to transfer gas from the chamber to 100 mL gas-sampling bag made of aluminum foil. The N_2O concentration was measured with a gas chromatograph equipped with an electron capture detector (GC-ECD) operating at 350 °C, while CO_2 was reduced to CH_4 by methaniser with H_2 at 350 °C, and CH_4 concentrations were measured by flame ionization detector (GC-FID) operating at 250 °C. Both chromatograph contained a stainless-steel HayeSep Q 80–100 mesh column (outer diameter 3.17 mm), maintained at 60 °C. The increase of GHG concentration in the static chamber was calculated by linear regression. GHG flux was calculated from the increase of GHG concentration using Eq. (1) (Davidson et al., 1998; Zhang et al., 2014).

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

Table 1
The main properties of paddy soil.

Year	Site location	Soil type	pH	Organic-C (g/kg soil)	Total-N (g/kg soil)
2013	30.26°N, 120.12°E	Loam clay	5.87	35.50	2.75
2014	30.13°N, 120.16°E	Loam clay	5.57	12.16	2.05