Chemosphere 89 (2012) 884–892

Contents lists available at SciVerse ScienceDirect

Chemosphere

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

# Seasonal variations of $CH_4$ and $N_2O$ emissions in response to water management of paddy fields located in Southeast China

Huijing Hou [a], Shizhang Peng [a,*], Junzeng Xu [a], Shihong Yang [a], Zhi Mao [b,c]

[a] State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Hohai University, Nanjing 210098, China
[b] College of Water Resources and Hydroelectric Engineering, Wuhan University, Wuhan 430072, China
[c] State Key Laboratory of Water Resources and Hydropower Engineering Science, Wuhan University, Wuhan 430072, China

## HIGHLIGHTS

- ▶ We investigated $CH_4$ and $N_2O$ emissions from paddy fields under controlled irrigation.
- ▶ Controlled irrigation significantly decreased $CH_4$ emission from paddy fields.
- ▶ Controlled irrigation significantly increased $N_2O$ emission from paddy fields.
- ▶ Dry–wet alternations caused the variations of $CH_4$ and $N_2O$ emission from paddy fields.
- ▶ Controlled irrigation mitigated carbon dioxide equivalents from paddy fields.

## ARTICLE INFO

*Article history:*
Received 19 September 2011
Received in revised form 12 March 2012
Accepted 30 April 2012
Available online 5 June 2012

*Keywords:*
Water management
Controlled irrigation
Paddy field
Methane
Nitrous oxide
Soil drying

## ABSTRACT

Water management is one of the most important practices that affect methane ($CH_4$) and nitrous oxide ($N_2O$) emissions from paddy fields. A field experiment was designed to study the effects of controlled irrigation (CI) on $CH_4$ and $N_2O$ emissions from paddy fields, with traditional irrigation (TI) as the control. The effects of CI on $CH_4$ and $N_2O$ emissions from paddy fields were very clear. The peaks of $CH_4$ emissions from the CI paddies were observed 1–2 d after the water layer disappeared. Afterward, the emissions reduced rapidly and remained low until the soil was re-flooded. A slight increase of $CH_4$ emission was observed in a short period after re-flooding. $N_2O$ emissions peaks from CI paddies were all observed 8–10 d after the fertilization at the WFPS ranging from 78.1% to 85.3%. Soil drying caused substantial $N_2O$ emissions, whereas no substantial $N_2O$ emissions were observed when the soil was re-wetted after the dry phase. Compared with TI, the cumulative $CH_4$ emissions from the CI fields were reduced by 81.8% on the average, whereas the cumulative $N_2O$ emissions were increased by 135.4% on the average. The integrative global warming potential of $CH_4$ and $N_2O$ on a 100-year horizon decreased by 27.3% in the CI paddy fields, whereas no significant difference in the rice yield was observed between the CI and TI fields. These results suggest that CI can effectively mitigate the integrative greenhouse effect caused by $CH_4$ and $N_2O$ emissions from paddy fields while ensuring the rice yield.



## 1. Introduction

Global warming induced by increasing greenhouse gas concentrations in the atmosphere is a matter of great environmental concern. Methane ($CH_4$) and nitrous oxide ($N_2O$) are important long-living greenhouse gases, which have attracted considerable attention during the last decades because of their contribution to global warming. The global warming potential (GWP) of $CH_4$ and $N_2O$ is 25 and 298 times that of carbon dioxide ($CO_2$), respectively, on a 100-year horizon (IPCC, 2007). The agroecosystem plays a significant role in the global budget of greenhouse gases (OECD, 2001). Of global anthropogenic emissions in 2005, agriculture accounts for about 50% of $CH_4$ and 60% of $N_2O$ (IPCC, 2007). Agricultural $CH_4$ and $N_2O$ emissions have increased by nearly 17% from 1990 to 2005 (IPCC, 2007), and agricultural $N_2O$ emissions are projected to increase by 35–60% up to 2030 due to increased chemical and manure N inputs (FAO, 2003). Atmospheric $CH_4$ from rice fields would further increase with the increasing rice harvested area in years to come (Cai et al., 2007).

Rice is the staple food of nearly 50% of the world's population. Paddy fields are considered to be a significant source of anthropogenic $CH_4$ and $N_2O$ (Hadi et al., 2010). Rice planting areas account for about 20% of the world total and 23% of all cultivated land in China (Frolking et al., 2002). Hence, studies on $CH_4$ and $N_2O$

* Corresponding author. Tel./fax: +86 25 83786711.
*E-mail addresses:* shizhang_peng@163.com, szpeng@hhu.edu.cn (S. Peng).

0045-6535/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.chemosphere.2012.04.066

emissions from China's paddy fields are of national and global significance for both ozone depletion and climate change issues.

Water management has been recognized as one of the most important practices that affect $CH_4$ and $N_2O$ emissions from paddy fields (Zou et al., 2005a; Jiao et al., 2006; Xiong et al., 2007; Hadi et al., 2010; Liu et al., 2010). Traditional irrigation (TI) of rice fields requires the consumption of large amounts of water. The development of efficient irrigation water management practices such as water-saving irrigation (WSI) may change $CH_4$ and $N_2O$ emissions from paddy soils. In China, WSI practices have become one of the basic national policies given the decreasing water availability for agriculture and the increasing demand for rice (Li, 2001). Various WSI management modes are currently practiced in the paddy fields of Southeast China, including intermittent irrigation, controlled irrigation (CI), flooding-midseason drainage-frequent water logging with intermittent irrigation (FDF), and flooding-midseason drainage-reflooding-moist intermittent irrigation without water logging (FDFM) (Mao, 2002; Zou et al., 2007; Peng et al., 2011a). The influence of water management on $CH_4$ and $N_2O$ emission from paddy fields under continuous flooding, intermittent irrigation, FDF and FDFM has been well documented in literature (Zheng et al., 2004; Zou et al., 2005a; Johnson-Beebout et al., 2009; Hadi et al., 2010; Liu et al., 2010). Continuously flooded rice fields have a high potential for $CH_4$ emissions. However, $N_2O$ emissions are negligible. The water managements of intermittent irrigation, FDF and FDFM have been proven to mitigate $CH_4$ emissions compared with continuous flooding. However, a trade-off relationship between $CH_4$ and $N_2O$ emissions resulting from midseason drainage and wetting–drying alternations has been well documented in paddy studies. Field measurements reveal that midseason drainage and wetting–drying alternations in paddy fields mitigate $CH_4$ emissions, but trigger substantial $N_2O$ emission, in contrast with continuous flooding (Zou et al., 2009; Liu et al., 2010; Tyagi et al., 2010). $N_2O$ emissions during intermittent irrigation periods depend greatly on whether or not water logging is present in paddy fields (Zou et al., 2005a). However, few studies have examined the effects of CI on $CH_4$ and $N_2O$ emissions from paddy fields. Whether the trade-off relationship between $CH_4$ and $N_2O$ emissions is also present in CI paddy fields is worthy of further study.

In China, CI is one of the major WSI practices, initially proposed by Li and Peng (1991) and further developed by Peng (1992). During the rice growing season, the soil in CI paddy fields remains dry 60–80% of the time, and no standing water is found after the re-greening of rice seedlings (Peng et al., 2011a,b), similar to that observed in the water management strategy used in the System of Rice Intensification (Chapagain and Yamaji, 2010; Miyazato et al., 2010; Sato et al., 2011). CI has been proven effective in saving water without causing yield reduction (Yu and Zhang, 2002) and has been widely applied in several provinces in China, such as Jiangsu, Ningxia, and Heilongjiang. The soil properties (such as soil moisture, soil oxygen status, soil redox potential and soil temperature) and microbial activity in CI paddy fields are very different from those in TI rice fields. These transformations consequently induce changes in $CH_4$ and $N_2O$ emissions. To our knowledge, however, few studies have been dedicated to quantifying $CH_4$ and $N_2O$ emissions from CI paddy fields. Hence, it is important to study $CH_4$ and $N_2O$ emissions from paddy fields under the CI.

The experiment reported in this study was carried out in the Taihu Lake region, in Southeast China, where about 75% of the arable land is used for rice growth. It is one of the most densely populated areas of China cultivated with the most typical paddy rice–winter wheat rotation system in China. The experiment was performed in this region to study the effects of CI on $CH_4$ and $N_2O$ emissions from paddy fields in Southeast China.

## 2. Materials and methods

### 2.1. Experimental site description

The experiment was conducted from June to October 2009 and from June to October 2010 in drainage lysimeters at the Kunshan Irrigation and Drainage Experiment Station in the Taihu Lake region, Jiangsu Province, China (31°15′N, 120°57′E). This region has a subtropical monsoon climate with an average annual temperature of 15.5 °C and a mean annual precipitation of 1097.1 mm. Soil in the experimental site is classified as dark-yellow hydromorphic paddy soil, which represents the typical soil type in this region. The soil texture in the plowed layer is clay, with organic matter amounting to 21.88 g $kg^{-1}$, total nitrogen (N) content of 1.03 g $kg^{-1}$, total phosphorus content of 1.35 g $kg^{-1}$, total potassium content of 20.86 g $kg^{-1}$ and pH of 7.4.

### 2.2. Experimental design

The experiment involved two irrigation treatments, CI and TI. Each irrigation treatment was designed with three replications, and these replicates were established in a randomized block design in six plots with an area of 5 $m^2$ each (2 × 2.5 m). These experiment plots were numbered as CI1, CI2, CI3, TI1, TI2, and TI3. The administering of soil moisture in each experiment plot was a continuous dynamic process. In the CI paddy fields, the irrigation water layer was kept at 5–25 mm in the re-greening stage; irrigation was applied only to keep soil moist and standing water was avoided in other stages except during periods of pesticide and fertilizer applications. Table 1 presents the root zone soil water content criteria in different rice growth stages for CI. In the TI paddy fields, there was a 3–5 cm shallow water layer after transplanting except during the midseason drainage period and the yellow maturity stage of rice. Rainfall was deflected with a canopy to accurately control soil moisture.

Rice seedlings were transplanted to the paddy fields on June 23 and harvested on October 31, 2009. They were then transplanted to the paddy fields on June 26 and harvested on October 29, 2010. N fertilizer was applied in accordance to the local conventional fertilizer application methods (Table 2). The base fertilizer consisting of compound fertilizer and ammonium bicarbonate was applied two times to improve N utilization rate (Table 2).

### 2.3. Sampling and measurements

The static chamber technique was used for in situ measurement of gas emissions. The chamber was made of polyvinyl chloride (PVC) and divided into two separate layers of the same size (0.5 m × 0.5 m × 0.6 m). The top layer of the chamber with the sealed top was used when the rice plant height was below 60 cm, and the bottom layer of the chamber not sealed at both ends was used to increase the chamber height when the rice plant height was above 60 cm. The bases for the chambers, which were also made of PVC, were installed in all plots before rice transplantation, and remained there until rice harvesting. There was a 5 cm-deep groove on the top edge of the bottom layer and on the base of the chamber, to be filled with water to seal the rim of the chamber. Moreover, the chamber was equipped with a thermometer and an electric fan at the top for air mixing inside the chamber and was wrapped with a layer of sponge and aluminum foil to minimize air temperature changes inside the chamber during the period of sampling. A rubber tube was inserted into the chamber from one side, and was connected outside to three stopcocks used to draw air samples every 10 min with a 60 mL syringe, which were then transferred into an empty sealed airbag for analysis.