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A 3-year record of N_2O and CH_4 emissions from a sandy loam paddy during rice seasons as affected by different nitrogen application rates

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ABSTRACT

Greenhouse gas fluxes from rice paddies under nitrogen fertilization merit serious attention because nitrogen fertilizer is increasingly used for the intensification of rice cultivation. A 3-year field study was conducted to measure methane (CH_4) and nitrous oxide (N_2O) fluxes simultaneously in a sandy loam paddy field under three nitrogen application rates (0, 150 and 250 kg N ha^{-1}) in the Yangtze River Delta from 2005 through 2007. The rice paddies were under a typical Chinese water regime, characterized by intermittent irrigation with midseason drainage. The results revealed a trade-off between CH_4 and N_2O emissions as influenced by the application of urea-based fertilizers, i.e., the nitrogen fertilization reduced CH_4 emissions from rice paddies but increased N_2O emissions. The seasonal CH_4 emissions averaged 155.9 kg C ha^{-1} in the absence of nitrogen amendment. Compared to no nitrogen addition, the seasonal CH_4 emissions were decreased by 27% and 53% in the fertilized plots at rates of 150 and 250 kg N ha^{-1}, respectively. It was most likely that the sandy loam texture combined with the addition of urea-based fertilizers stimulated growth and activity of methane oxidizers. In contrast, nitrogen addition increased N_2O emissions 2.5 times for an application rate of 150 kg N ha^{-1} and 6.0 times at 250 kg N ha^{-1}, compared to no nitrogen addition (0.38 kg N ha^{-1}). The direct emission factor of fertilizer N for N_2O was estimated to be 0.39–1.22% for rice fields, with a mean value of 0.77%. The overall emissions of CH_4 and N_2O, expressed as carbon dioxide equivalents were affected by the nitrogen addition rate, with the minimum emissions occurring at 250 kg N ha^{-1}. This result indicated that the commonly applied nitrogen rate in this region might be an effective option for mitigating the combined impacts of rice production. Our results also demonstrate the presence of large interannual variations in the CH_4 and N_2O fluxes. It is probable that these variations resulted from differences in the amount and distribution of precipitation.

1. Introduction

Both nitrous oxide (N_2O) and methane (CH_4) are recognized as potent greenhouse gases, with 298 and 25 times higher global warming potential than carbon dioxide (CO_2), respectively, over a time horizon of 100 years (IPCC, 2007). Furthermore, CH_4 affects the chemistry and oxidation capacity of the atmosphere, and N_2O participates in the destruction of the stratospheric ozone layer that shields the earth's surface from harmful ultraviolet radiation (IPCC, 2007). Globally, anthropogenic sources of CH_4 and N_2O are dominated by agriculture, and agricultural CH_4 and N_2O emissions have increased by approximately 17% from 1990 through 2005 (Forster et al., 2007). In agricultural soils, the production and uptake of N_2O and CH_4 occurs in association with soil microbial activities (Conrad, 1996, 2002), so that the fluxes of N_2O and CH_4 are affected by soil factors such as temperature, inorganic N content (NH_4^+ and NO_3^-) and water content (Zheng et al., 2000; Zou et al., 2005). As a result of the unique nature of rice production in agricultural systems, i.e., typically flooded soils and relatively high N inputs, rice paddy fields have been identified as a major source of increasing atmospheric CH_4, accounting for approximately 5–19% of the annual global CH_4 emissions to the atmosphere (IPCC, 2007). Although most N_2O emissions are produced in upland fields, several studies on N_2O emissions from rice fields in the Philippines (e.g., Bronson et al., 1997), Japan (e.g., Yagi et al., 1996; Nishimura et al., 2004), China (e.g., Cai et al., 1997; Zou et al., 2005; Yao et al., 2010) and other countries (Akiyama et al., 2005) have shown that substantial N_2O emissions result from the midseason drainage and dry-wet episodes in rice fields. Predictions based on population growth rates in countries where rice is the main food crop indicate that rice production must increase 60% in the next few decades to meet the expected food demand from the growing population (Cassman et al., 1998). It is probable that this increasing production will

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Table 1
Field experimental treatments and management practices during the rice-growing seasons of 2005, 2006 and 2007.

Code	Water regime[b]	Nitrogen application rate[a] ($kg\,N\,ha^{-1}$)			Transplanting/Harvest date
		Basal fertilization	1st topdressing	2nd topdressing	
N_0	F-D-F-M	0	0	0	June 13/October 22
N_{150}	F-D-F-M	CF[c](70) + Urea(20)	0	Urea(60)	June 13/October 22
N_{250}	F-D-F-M	CF[c](70) + Urea(20)	Urea(60)	Urea(100)	June 13/October 22

[a] The experimental fertilization regime was consistent with local farming practices, i.e., the N fertilizers were either surface-applied (basal fertilization) at rice transplanting or provided by top dressings (first and second top dressing) at early- and late-tillering. N_0, N_{150} and N_{250} denote nitrogen application rates of 0, 150 and 250 $kg\,N\,ha^{-1}$, respectively.
[b] F, flooding; D, midseason drainage; M, moist but non-waterlogged by intermittent irrigation.
[c] Compound fertilizer is a mixture of $NH_4H_2PO_4$ and KCl, with $N:P_2O_5:K_2O$ = 15%:15%:15%.

result in increased CH_4 and N_2O emissions. Accordingly, it is urgent to establish technologies and management practices for mitigating CH_4 and N_2O emissions from paddy fields while sustaining or increasing rice production.

China is the most important rice-producing country in the world. Rough rice production in China contributes approximately 30% to the world total (http://www.irri.org/science/ricestat). The rice-planting area represents approximately 20% of the world total and occupies 23% of all cultivated land in China (Frolking et al., 2002). As a consequence, rice cultivation has been viewed as an important contributor to the global budgets of CH_4 and N_2O. Rough estimates of total annual CH_4 and N_2O emissions from Chinese rice paddy fields range from 7.7 to 8.0 $Tg\,CH_4\,yr^{-1}$ and from 88.0 to 98.1 $Gg\,N\,yr^{-1}$, respectively (Yan et al., 2003a; Zheng et al., 2004). Reductions in CH_4 and N_2O emissions from rice fields in China are urgently advised, with a total reduction of greenhouse gas emissions targeted at 40–45% per unit of gross domestic product (GDP) by 2020 (Anon., 2010). Because applications of N fertilizers in rice cultivation have been commonly adopted to improve N availability and thus achieve high grain yields, the use of N fertilizer may become an important factor regulating CH_4 and N_2O emissions. For example, nitrogen input has increased from 87.5 $kg\,N\,ha^{-1}$ in the 1950s to 224.6 $kg\,N\,ha^{-1}$ in the 1990s, accompanied by an increase in direct N_2O emissions from 9.6 to 32.3 Gg N in Chinese paddy rice production from the 1950s through the 1990s (Zou et al., 2009). The N_2O emitted from agricultural soils as a result of nitrification and denitrification processes arises predominantly from N fertilizers applied to the fields (Mosier et al., 1998; Akiyama and Tsuruta, 2003). Zheng et al. (2004) estimated that approximately 75% of the annual total N_2O released was a result of direct emissions from anthropogenic reactive nitrogen input to the croplands of China. Therefore, the quantity of fertilizer N applied can serve as an important index for estimating N_2O emissions from agricultural fields (IPCC, 2006). In fact, some researchers have attempted to quantify fertilizer-induced N_2O emissions and background N_2O emissions from rice fields at the regional and global scales; however, these estimates vary widely (Yan et al., 2003b; Zheng et al., 2004; Akiyama et al., 2005; Zou et al., 2007). Similarly, soil disturbance by such N fertilization practices can also change the CH_4 fluxes in rice fields (e.g., Dan et al., 2001; Cai et al., 2007; Xie et al., 2010). For example, some studies suggested that N fertilizer application decreased CH_4 emissions (e.g., Lindau et al., 1990; Cai et al., 1997; Ma et al., 2007), whereas others reported that CH_4 emissions increased with N fertilizer amendment (e.g., Singh et al., 1996; Schimel, 2000; Zheng et al., 2006) or found no difference in CH_4 emissions between N-fertilized and unfertilized rice fields (Bronson et al., 1997; Cai et al., 2007). In view of the abovementioned studies, the large variability in the effects of N fertilization on N_2O and CH_4 emissions from rice fields indicates that the soil N availability interacts with other site-specific factors to control the production of CH_4 and N_2O. Therefore, further investigations on CH_4 and N_2O emissions from rice fields are recommended. In addition, simultaneous measurements of CH_4 and N_2O emissions from the same rice paddy field will provide useful information for estimating the combined climatic impact of CH_4 and N_2O.

In the present study, we conducted 3 years (from 2005 through 2007) of simultaneous measurements of the CH_4 and N_2O emissions from a sandy loam paddy field under a typical intermittent irrigation regime. The objectives of this study are to characterize and quantify CH_4 and N_2O emissions from the rice field under three levels of N fertilizer application and to assess the combined climatic effect of CH_4 and N_2O emissions as influenced by N fertilization. Such information is expected to be helpful in developing appropriate management practices for mitigating climatic impacts in paddy fields.

2. Materials and methods

2.1. Site description and field experiment

The experimental site is located at a paddy rice field (32°35′5″N, 119°42′0″E) in the Yangtze River Delta, where the cropping regime is dominated primarily by the annual rice paddy-winter wheat rotation. Rice has been cultivated in the delta for several thousand years, and this area is considered to be one of the most productive regions for rice production (Zheng et al., 2000). The region has a subtropical monsoon climate with a mean annual precipitation of 924 mm and a mean air temperature of 15.9 °C. The soil of the experimental field is classified as Shajiang Hapli-Stagnic Anthrosol (Cooperative Research Group on Chinese Soil Taxonomy, 2001) or Fluvisols with the classification of World Reference Base for Soil Resources 2006 (IUSS Working Group WRB, 2006, http://www.fao.org/ag/Agl/agll/wrb/doc/wrb2006final.pdf), which has a sandy-loamy texture. The plough layer of the experimental field is approximately 15 cm in depth. The important properties of the topsoil are as follows: bulk density, 1.16 $g\,cm^{-3}$; pH (H_2O) 8.0; total porosity, 54%; organic carbon content, 18.4 $g\,kg^{-1}$; total N content, 1.45 $g\,kg^{-1}$; total P content, 0.63 g P kg^{-1}; clay (<0.002 mm), 13.6%; silt (0.002–0.02 mm), 28.5%; and sand (0.02–2 mm), 57.8%.

The experimental design consisted of a completely randomized block with three replicates, with an area of 4 m × 5 m for each plot. As shown in Table 1, three N fertilization levels (0, 150 and 250 $kg\,N\,ha^{-1}$) were used in this study. Compound fertilizer ($N:P_2O_5:K_2O$ = 15%:15%:15%) and urea were applied at a rate of 150 (N_{150}) and 250 $kg\,N\,ha^{-1}$ (N_{250}) to the fertilized fields, respectively. These applications represented the low and common fertilization levels used in rice production in the delta region. No N fertilizer was applied to the N_0 treatment in the experimental rice-growing season. In accordance with the local conventional fertilizer application methods, compound fertilizer combined with urea was broadcasted as basal fertilization at the time of rice transplanting at a rate of 90 $kg\,N\,ha^{-1}$. Additional application of urea was also broadcasted in the form of top dressings at the early- and late-tillering stage of rice crop. For crop production, the typical agricultural management