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Effect of ammonium-based, non-sulfate fertilizers on CH_4 emissions from a paddy field with a typical Chinese water management regime

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ABSTRACT

The effects of ammonium-based, non-sulfate fertilizers, such as urea and/or ammonium phosphate ($NH_4H_2PO_4$), on methane (CH_4) emissions from paddy rice fields deserve attention, as they are being used increasingly for rice cultivation. A four-year field campaign was conducted in the Yangtze River Delta from 2004 to 2007 to assess the effects of different application rates of urea plus $NH_4H_2PO_4$ on the CH_4 emissions from a paddy rice field. The experimental field was under a typical Chinese water regime that follows a flooding-midseason drainage-reflooding-moist irrigation mode. Over the course of four years, the mean cumulative CH_4 emissions during the rice seasons were 221, 136 and 112 kg C ha^{-1} for nitrogen addition rates of 0, 150 and 250 kg N ha^{-1}, respectively. Compared to the treatment without nitrogen amendments, the 150 kg N ha^{-1} decreased the CH_4 emissions by 6–59% ($P < 0.01$ in one year, but not statistically significant in the others). When the addition rate was further increased to 250 kg N ha^{-1}, the CH_4 emissions were significantly reduced by 35–53% ($P < 0.01$) compared to the no-nitrogen treatment. Thus, an addition rate of 250 kg N ha^{-1}, which has been commonly adopted in the delta region in the past two decades, can be regarded as an effective management measure as regards increasing rice yields while reducing CH_4 emissions. Considering that doses of ammonium-based, non-sulfate fertilizers higher than 250 kg N ha^{-1} currently are, and most likely will continue to be, commonly applied for paddy rice cultivation in the Yangtze River Delta and other parts of China, the inhibitory effects on CH_4 emissions from rice production are expected to be pronounced at the regional scale. However, further studies are required to provide more concrete evidence about this issue. Moreover, further research is needed to determine whether N management measures are also effective in view of net greenhouse gas fluxes (including CH_4, nitrous oxide, ammonia emissions, nitrate leaching and N loss from denitrification).

1. Introduction

Methane (CH_4) is an abundant organic trace gas in the atmosphere (mixing ratio ~1.8 μL L^{-1}), contributing to global warming and affecting chemical changes in the troposphere and stratosphere (Keppler et al., 2006). Rice fields have been identified as a major source of increasing atmospheric CH_4 (IPCC, 2001; Conrad, 2002; Scheer et al., 2008), accounting for approximately 5–19% of the total global CH_4 emissions to the atmosphere (IPCC, 2007). Rice production must increase 60% in the next few decades to meet required food demand from the world's population growth (Cassman et al., 1998). According to the international rice research institute (IRRI) statistics, world rice harvested area increased by approximately 35.8%, from 115.5 Mha in 1961 to 156.6 Mha in 2007 (http://www.irri.org/science/ricestat). This intensified rice production will most likely result in increased CH_4 emissions. Accordingly, detailed knowledge about the sources and sinks of CH_4 in rice paddies, as well as more information on environmental factors regulating CH_4 fluxes from rice paddies, are imperative for designing possible mitigation strategies.

China is the most important rice producing country in the world. Its planting area accounts for about 23% of the world rice harvested area and 36% of rice grain production (http://www.irri.org/science/ricestat). As a consequence, it has been considered as an important contributor to the global CH_4 budget. Because CH_4 can be produced only in strictly anaerobic conditions with a low soil redox potential, water management has been recognized as one of the most important practices that affect CH_4 emissions in paddy fields. Hence, the relationship between the water regime and CH_4

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emissions has been investigated in many previous studies (e.g., Zou et al., 2005), and optimum water management practices have been proposed to reduce CH_4 emissions. In China, the most typical water management of paddy fields involves an episode of midseason aeration for 7–10 days, instead of continuous flooding to improve rice growth and increase yields (e.g., Cai et al., 1997). Furthermore, the effects of drainage and/or intermittent irrigation on CH_4 emissions from paddy fields have been widely reported (e.g., Wassmann et al., 2000; Nishimura et al., 2004; Zou et al., 2005).

Applications of N fertilizers in rice cultivation have been commonly adopted to improve N availability and achieve high grain yields; this may become an important controlling factor in CH_4 emissions. Moreover, the already high N applications to paddy fields will have to increase, because this is the most important limiting factor in rice productivity (Cassman et al., 1998). This may directly or indirectly affect all of the important processes involved in the CH_4 budget of rice paddies, i.e., the production, oxidation and transport of CH_4. However, studies investigating N fertilizer effects on these processes have yielded contradictory results. For example, after fertilization with urea or $(NH_4)_2SO_4$, lower CH_4 emissions were detected and attributed to the direct inhibition of methanogenesis (e.g., Lindau et al., 1990; Cai et al., 1997, 2000; Ma et al., 2007). However, higher CH_4 emissions were also observed from paddy fields after applications of ammonium-based, non-sulfate fertilizers (e.g., urea, $(NH_4)_2HPO_4$), which may increase plant growth and carbon supply, and thus provide more methanogenic substrates and enhance the efficiency of CH_4 transport to the atmosphere (e.g., Singh et al., 1996; Schimel, 2000; Zheng et al., 2006). Meanwhile, Dan et al. (2001) and Cai et al. (2007) reported no difference in CH_4 emissions between N fertilized and unfertilized rice paddies. Above all, these conflicting findings regarding CH_4 emissions as affected by N fertilizer underscore the need for more research, especially for non-sulfate, non-nitrate N fertilizers, because CH_4 production is generally inhibited by sulfate, as described by previous studies (e.g., Schütz et al., 1989; Minami, 1995; Scheid et al., 2003), and also because nitrate-based fertilizers are not recommended for use in paddy rice production in order to avoid intensive N loss from denitrification. In addition, the effects of N application on CH_4 emissions from paddy fields must be investigated not only over short-term (days and weeks), but also long-term (multi-season or year) time frames (Cai et al., 2007). An adequate characterization of the interannual variability will improve regional and national CH_4 budgets.

The above contrasting effects of N fertilizer on CH_4 emissions from paddy fields indicate that the soil N availability interacts with other site-specific factors when controlling CH_4 production processes. In the present study, we conducted multi-year measurements (from 2004 to 2007) of CH_4 emissions from a paddy field with typical Chinese water management. The aims of this study are to characterize and quantify seasonal CH_4 emissions and better understand the effects of ammonium-based, non-sulfate fertilizers (i.e., urea plus ammonium phosphate) on CH_4 emissions. This information is expected to be helpful for developing appropriate mitigation management practices in paddy fields.

2. Materials and methods

2.1. Site description and experimental design

The field experiment was carried out in a paddy field (32°35′N, 119°42′E) in the Yangtze River Delta, in southeast China, where the typical cropping system is characterized by alternating harvests of paddy rice and winter wheat throughout the year. The investigated site is one of the oldest agricultural areas under the northern subtropical monsoon climate. The mean annual precipitation and mean air temperature at the site are about 924 mm and 15.9 °C, respectively. The soil is a sandy-loamy Shajiang Hapli-Stagnic Anthrosol (Cooperative Research Group on Chinese Soil Taxonomy, 2001) with 13.6% clay (<0.002 mm), 28.5% silt (0.002–0.02 mm), and 57.8% sand (0.02–2 mm). Other important soil properties are: 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}; and bulk density, 1.16 g cm^{-3}.

As shown in Table 1, the study was performed at three N fertilization levels: 0, 150 and 250 kg N ha^{-1} (hereafter referred to as N_0, N_{150} and N_{250}, respectively). In N_0, no N fertilizer was applied for just the experimental rice-growing season. For the fertilized treatments (i.e., N_{150} and N_{250}), ammonium-based, non-sulfate fertilizers (urea plus a compound fertilizer of $NH_4H_2PO_4$ and KCl) were either surface-applied (basal fertilization) or provided by a top dressing (second and third applications). We note that the N_{250} treatment, which has been commonly adopted in the past two decades, is a conventional agricultural practice for rice cultivation in this delta region. In each N fertilization treatment, three spatial replicates were randomly assigned in the experimental field. In each plot, rice (*Oryza sativa L., cv. japonica 99-15*) seedlings were manually planted at a density of 3 seedlings hill^{-1} and 24 hills m^{-2} on average in mid-June. A typical water regime of intermittent irrigation in a local region, as well as in other regions of China, was employed for all field plots. Specifically, flood irrigation of the field was initiated two or three days before transplanting and maintained for 30-40 days until a midseason drainage for one week. Thereafter, the rice paddies were intermittently flooded until the final drainage before rice harvesting.

2.2. Measurement of CH_4 flux

The flux of CH_4 was measured using a static opaque chamber and gas chromatography (GC) techniques as described by Wang and Wang (2003). Before fields were initially flooded, boardwalks to randomly selected experimental plots were installed from border levees to reduce soil disturbance during flux measurements. A stainless steel frame, which covers an area of 0.25 m^2 and six hills of rice, was permanently installed in the center of each experimental plot for the entire measurement period. Square chambers, 50 cm × 50 cm in bottom area and 50 or 100 cm high (depending on the plant height), with water seals, were temporarily mounted on the stainless steel frames. To measure the CH_4 flux, five gas samples were taken at 8-min intervals during a half-hour time period, using 60 ml plastic syringes. Within 4 h after sampling, the

Table 1
Field management of nitrogen fertilizer for rice cultivation from 2004 to 2007.

	N application rate (kg N ha^{-1})			Application date
	N_0	N_{150}	N_{250}	
Basal fertilizer	0	CF[a](70) + Urea(20)	CF[a](70) + Urea(20)	14 Jun 2004 15 Jun 2005 13 Jun 2006 21 Jun 2007
Tillering fertilizer	0	0	Urea (60)	21 Jun 2004 21 Jun 2005 20 Jun 2006 24 Jun 2007
Panicle initiation fertilizer	0	Urea (60)	Urea (100)	01 Aug 2004 01 Aug 2005 02 Aug 2006 03 Aug 2007

[a] Compound fertilizer is a mixture of $NH_4H_2PO_4$ and KCl, with $N:P_2O_5:K_2O$ = 15%:15%:15%. N_0, N_{150} and N_{250} denote nitrogen application rates of 0, 150 and 250 kg N ha^{-1}, respectively.