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RESEARCH ARTICLE

The effects of nitrogen fertilizer application on methane and nitrous oxide emission/uptake in Chinese croplands

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Abstract

The application of nitrogen (N) fertilizer to increase crop yields has a significant influence on soil methane (CH_4) and nitrous oxide (N_2O) emission/uptake. A meta-analysis was carried out on the effect of N application on (i) CH_4 emissions in rice paddies, (ii) CH_4 uptake in upland fields and (iii) N_2O emissions. The responses of CH_4 emissions to N application in rice paddies were highly variable and overall no effects were found. CH_4 emissions were stimulated at low N application rates (<100 kg N ha^{-1}) but inhibited at high N rates (>200 kg N ha^{-1}) as compared to no N fertilizer (control). The response of CH_4 uptake to N application in upland fields was 15% lower than control, with a mean CH_4 uptake factor of –0.001 kg CH_4-C kg^{-1} N. The mean N_2O emission factors were 1.00 and 0.94% for maize (*Zea mays*) and wheat (*Triticum aestivum*), respectively, but significantly lower for the rice (*Oryza sativa*) (0.51%). Compared with controls, N addition overall increased global warming potential of CH_4 and N_2O emissions by 78%. Our result revealed that response of CH_4 emission to N input might depend on the CH_4 concentration in rice paddy. The critical factors that affected CH_4 uptake and N_2O emission were N fertilizer application rate and the controls of CH_4 uptake and N_2O emission. The influences of application times, cropping systems and measurement frequency should all be considered when assessing CH_4 and N_2O emissions/uptake induced by N fertilizer.

Keywords: nitrogen fertilizer, methane, nitrous oxide, global warming potential, emission factor

1. Introduction

Agricultural land management activity is an important source of greenhouse gases (GHGs). In 2000, such activities were estimated to account for most of the global anthropogenic emissions of CH_4 (52%) and N_2O (84%) (USEPA 2006; Smith *et al.* 2008). Common agricultural practices such as irrigation (Bouwman and Boumans 2002), tillage (Venterea *et al.* 2011) or inputs of organic materials and N (Hao *et al.* 2001; Nayak *et al.* 2007) can substantially influence CH_4 and N_2O emissions from cropland soils. Of these factors, N fertilizer application is the most important practice associated with direct or indirect N_2O emissions (Nayak *et al.* 2007; Allen *et al.* 2010; Venterea *et al.* 2011). The CH_4 exchange between croplands and the atmosphere is also influenced by N fertilizer application (Cai *et al.* 1997). N fertilizer applications have varying effects on CH_4 emissions. In some cases CH_4 emissions are stimulated (Liu and Greaver 2009; Shang *et al.* 2011).

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In other cases they are inhibited (Venterea *et al.* 2005) and in certain situations there are no significant effects (Mosier *et al.* 2006). A recent meta-analysis conducted on rice paddy fields concluded that smaller amounts of N fertilizer application stimulated CH_4 emission, while larger amounts inhibited it (Banger *et al.* 2012; Linquist *et al.* 2012). The opposite result was reported by Aronson and Helliker (2010) for crops in non-wetland soils. N fertilizer can be nitrified or denitrified in soil and released as N_2O. Many field measurements of N_2O emissions induced by N fertilizer have been performed and the influencing factors (e.g., crop type and fertilizer rate/timing) have been analyzed (Venterea *et al.* 2005; Phillips *et al.* 2009; Linquist *et al.* 2012). However, how these CH_4 and N_2O emissions measurements occurred in China were not clear.

China requires at least 120 million ha of cropland to produce cereal grain to support its more than 1.3 billion people. Croplands contributed 18% of the national CH_4 emissions and 53% of the national N_2O emissions in 2005 (SSIBCCC 2013). The application of N fertilizer is an important practice and acts as the basic stimulator of high crop yields in China (Guo *et al.* 2010). Currently, the N fertilizer addition in China is 30.8 million tonnes in 2013, and N fertilizer inputs have surpassed 200 kg N ha^{-1} in many farming areas (NBSPRC 2014). Nevertheless, the N use efficiency in China (30%) is lower than the world's average level (40–50%) (Huang and Tang 2010). Therefore, it is necessary to analyze the mitigation potential of N fertilizer-induced GHGs emission/uptake.

For this study, we conducted a meta-analysis based on paired measurements of CH_4 and N_2O emission/uptake in fields treated with N fertilizer and in control fields. The study aimed to (1) determine (i) CH_4 emissions in rice cropping systems, (ii) CH_4 uptake in upland crops and (iii) N_2O emissions in response to inputs of N fertilizer; (2) investigate how certain other factors (e.g., application amounts and times, cropping system) influenced the effect of N fertilizer on CH_4 and N_2O emission/uptake.

2. Results

2.1. Response of CH_4 emission to N addition in Chinese rice paddy fields

Across all 64 comparisons of rice paddy fields, N inputs in the range of 52.5–300 kg N ha^{-1} per season did not change CH_4 emissions compared with controls (Table 1 and Fig. 1). However, the effects of N inputs on CH_4 emission varied significantly with different N application rates/times, cropping systems and frequency of measurements (Table 2). With the increasing rates of N fertilizer applied, CH_4 emission went from stimulatory (50–100 kg N ha^{-1} increment of 34%) to inhibitory (200–250 kg N ha^{-1} decrement of 14%) (Fig. 1). Splitting application with 1–2 times inhibited CH_4 emissions by 10%, but 3–4 applications stimulated CH_4 emissions by 12%. The N fertilizer applications stimulated CH_4 emission by a significant 21% in the rice-rice cropping systems, but suppressed it in single rice or wheat-rice systems. CH_4 emissions for the gas sample measurements of twice per

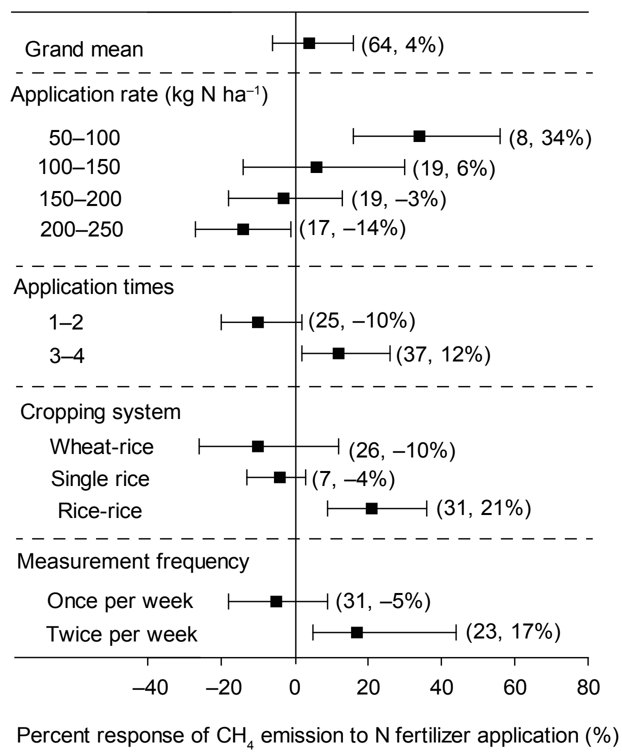

Fig. 1 The response of methane emission to N fertilizer application in Chinese rice paddies. Small squares and bar represent the mean and range at 95% confidence intervals of percent response to N fertilizer application as compared to no fertilizer. The values in parentheses represent independent sample size and percent response to N fertilizer application. The same as in Figs. 2, 3 and 5.

Table 1 The data of CH_4 (kg CH_4-C ha^{-1}) and N_2O (kg N_2O-N ha^{-1}) emission/uptake value in N fertilizer application and no fertilizer (control) treatments

Item	N fertilizer rate (kg N ha^{-1})	Emission/ Uptake factor	*n*	N fertilizer application			Control		
				Mean±SD	Min.	Max.	Mean±SD	Min.	Max.
CH_4 emission	52.5–300	–0.007	64	143±99	23	470	145±95	14	369
CH_4 uptake	62–300	–0.0011	43	0.75±0.30	0.13	1.32	0.95±0.64	0.19	3.80
N_2O emission	52.5–300	0.0079	162	2.13±2.06	0.21	7.74	0.65±0.72	0.10	2.84