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Spatial variation of nitrous oxide emission between interrow soil and interrow plus row soil in a long-term maize cultivated sandy loam soil

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ABSTRACT

There is a high spatial variation in N_2O emission from agricultural fields and N_2O emissions from fields cultivated with stalk-crops was generally measured in the interrow area. The aim of this study was to evaluate the difference in seasonal N_2O emissions between interrow soil and interrow + row soil, and to understand the effect of different fertilizers on N_2O emissions in a maize-cultivated sandy loam soil in the North China Plain. The experiment included five treatments: organic manure (OM), half-organic manure N plus half fertilizer N (HOM), fertilizer NPK (NPK), fertilizer NK (NK) and control (CK). Cumulative N_2O emission from interrow + row soil during the maize growth season was 0.84–1.22 kg N ha^{-1} with an average of 0.98 kg N ha^{-1} in the N-fertilized treatments, significantly higher than the 0.30–0.49 kg N ha^{-1} from interrow soil. However, no significant difference was observed in the CK treatment. The measurement in interrow soil underestimated N_2O emissions by 44–67%. This difference mainly occurred at the two peak emission periods following fertilizer application probably due to discrepancy in soil denitrification potential. Manure application more efficiently increased difference in N_2O emission between interrow soil and interrow + row soil than inorganic N fertilizer application. The higher NO_3^- concentration did not induce larger N_2O emission from interrow soil in the NK treatment than in the NPK treatment, but did from interrow + row soil, resulting in greater difference in N_2O emission between interrow soil and interrow + row soil. It is suggested that measuring N_2O emission solely from interrow soil could underestimate seasonal N_2O emissions, and partly mask the effect of N fertilizer application rates on N_2O emission in a maize-cultivated soil in the North China Plain.

1. Introduction

Nitrous oxide (N_2O) is an important atmospheric trace gas, with 298 times the global warming potential of carbon dioxide (CO_2) on a mass basis over a 100-year time scale (Forster et al., 2007). Agriculture is considered to be a major source of atmospheric N_2O, contributing 35% to global N_2O emissions (Kroeze et al., 1999), and 60% of global anthropogenic N_2O emissions (Smith et al., 2007). From 1990 to 2005, global N_2O emissions from agricultural ecosystems have increased by approximately 17% (Smith et al., 2007), and are predicted to rise by a further 35–60% by 2030 mainly due to increased nitrogen (N) fertilizer use and animal manure production (FAO, 2003). In China, annual consumption of N fertilizer increased from 9.34 Tg N in 1980 to 23.03 Tg N in 2008 (http://www.stats.gov.cn/), which accounted for 23% of the world's consumption (FAO, 2008). Furthermore, N fertilizer use in China is expected to increase so as to meet food demand for a rapidly burgeoning population (FAO, 2010). Increasing N fertilizer application to the field is likely to stimulate N_2O emission from China's agricultural ecosystems (Bouwman et al., 2002; Stehfest and Bouwman, 2006).

Several studies have estimated N_2O emission and fertilizer N-induced N_2O emission from agricultural soils in China over the last two decades. Chen et al. (2008) reported that N_2O emission during the wheat growth season from paddy field varied from 2.60 to 9.28 kg N ha^{-1}, with the emission factor of N fertilizer ranging from 1.33 to 2.97%. An annual N_2O emission of 2.6 kg N ha^{-1} and an emission factor of 0.95% were monitored from an irrigated cotton field in North China when 66.3 kg N ha^{-1} of urea was applied (Liu et al., 2010). Meng et al. (2005) found that annual N_2O emission from a sandy loam soil with the maize–wheat rotation in the North China Plain was 0.77 kg N ha^{-1}, and the emission factor of N fertilizer was estimated to be 0.21% with urea fertilizer applied at 150 kg N ha^{-1} for each crop. Based on the summary of data available in the literature, Xing (1998) suggested that the emission factor of N fertilizer as N_2O was 0.6% from upland crops in China. However, Zou et al. (2010) recently used their own empirical model to estimate that annual fertilizer N-induced N_2O emission from Chinese croplands increased from 115.7 Gg N in the 1980s to 210.5 Gg N in the 1990s, and the emission

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factor was on average up to 1.02% over the period 1980–2000. Although great efforts have been made to quantify China's agricultural N_2O emissions, much uncertainty still exists on the estimate of fertilizer N-induced N_2O emission from agricultural soils (Xing, 1998; Zheng et al., 2004; Zou et al., 2010).

Estimates of soil N_2O emissions in response to N fertilizer additions can vary depending on the proximity of the measurement to the agricultural crop (Ding et al., 2007; Kusa et al., 2006; Wolf et al., 2010). Pang et al. (2009) found that annual average N_2O emission rates decreased with increasing distance from trees in an apple orchard on the semiarid loess plateau in China. A similar decrease was observed in a wheat-cultivated soil, where mean annual N_2O emission rate from interrow soil was approximately half the value measured in row soil over the 3-year measuring period (Kessavalou et al., 1998). In a Spanish irrigated sandy loam soil amended with urea, Lopez-Fernandez et al. (2007) also found that cumulative N_2O emission from maize-unplanted plot was significantly lower than from maize-planted plot. By contrast, cumulative N_2O emission from interrow soil was greater than from row soil during the potato growth period (Ruser et al., 1998). Based on the aforementioned studies, it is still not clear where to measure soil N_2O emissions in relation to the crop so as to accurately estimate N_2O emissions and associated emission factors.

Nitrous oxide emission from arable soil cultivated with stalk crops such as maize was generally monitored in interrow soil rather than in interrow + row soil due to difficulty in locating the chamber around plants (Beheydt et al., 2008; Dong et al., 2001; Sehy et al., 2003; van Groenigen et al., 2004). However, some researchers suggested that the chamber containing both maize row and interrow area could better estimate N_2O emissions in the field (Halvorson et al., 2008; Mosier et al., 2006). Nevertheless, to the best of our knowledge, no study has investigated the differences in N_2O emission between interrow soil and interrow + row soil in Chinese agricultural fields. Maize is one of the most widely grown grain crops in China with 22.84 million ha in area, of which 7.47 million ha are located in the North China Plain (www.chinamaize.com.cn). The objective of our study was (1) to evaluate the difference in N_2O emission between interrow soil and interrow + row soil cropped to maize, and (2) to understand the effect of long-term (1989–2007) application of inorganic N fertilizers and organic manures on N_2O emissions during the maize growth season.

2. Materials and methods

2.1. Study site and experimental design

The field study was conducted during a maize growth season (June–September, 2007) on a site with long-term fertilizer experiment (see below for details) at the Fengqiu State Key Agro-ecological Experimental Station, Henan Province, China (35°00′N, 114°24′E). The 30-year mean annual temperature for the site was 13.9 °C, ranging from 13.0 to 15.3 °C, and the highest mean monthly value was 27.2 °C in July. The average precipitation was 615 mm, of which two-thirds fell between June and September. Soil was derived from alluvial sediments of the Yellow River and classified as Aquic Inceptisol with a sandy loam texture according to U.S. soil taxonomy (Meng et al., 2005; Table 1).

The randomized block design established in September 1989 consisted of seven fertilizer treatments with four replicate plots ($9.5 \times 5\ m^2$) per treatment. Winter wheat (*Triticum aestivum* L.) and summer maize (*Zea mays* L.) have been grown in rotation since the long-term study commenced. Five treatments were chosen for monitoring N_2O emission in the present study: organic manure (OM), half-organic manure N plus half-fertilizer N (HOM), fertilizer NPK (NPK), fertilizer NK (NK), and control without fertilizer (CK). Inorganic fertilizer N, P and K were applied in the form of urea (150 kg N ha^{-1} per crop), calcium superphosphate (75 kg P_2O_5 ha^{-1} per crop) and potassium sulfate (150 kg K_2O ha^{-1} per crop), respectively. The OM treatment was designed to provide the same amounts of N, P and K application as those provided by the NPK treatment. Organic manure was a composted mixture of wheat straw, oil cake and cotton cake in a ratio of 100:40:45. This proportion was calculated (based on the component C and N concentrations) with the aim of applying a total amount of organic C and N in manures (per hectare per season) equal to that in harvested wheat straw (per hectare per season). This assumed all wheat straw is returned to the soil and organic N being equivalent to 150 kg N ha^{-1}. The oil cakes and cotton cakes were the machine-dried residues of oil-harvested rapeseeds and cottonseeds, sourced from a local commercial cooking oil company. All these materials were machine ground into ~5 mm length, mixed completely with limited water and composted for nearly two months. The amounts of phosphorus and potassium they contained were generally less than the prescribed doses, so the manures were supplemented with calcium superphosphate (~25 kg P_2O_5 ha^{-1}) and potassium sulfate (~85 kg K_2O ha^{-1}) before application. The applied amounts of composted organic manure, containing 54.4 mg N g^{-1} and 422 mg organic C g^{-1}, were equivalent to 2758 and 1379 kg ha^{-1} in the OM and HOM treatments, respectively (on an oven-dried basis).

All organic manure (150 kg N ha^{-1} for OM, and 75 kg N ha^{-1} for HOM), phosphorus and potassium fertilizers were applied as basal fertilizers, whereas urea (150 kg N ha^{-1}) was split into two applications as basal (60 kg N ha^{-1}) and supplemental (90 kg N ha^{-1}) fertilizer for the NPK and NK treatments during the maize growth season. For the HOM treatment, urea was applied at a rate of 75 kg N ha^{-1} as supplemental fertilizer. The NK treatment received no phosphorus fertilizer and no fertilizer was applied in the CK treatment. Basal fertilizers were evenly broadcasted onto the soil surface by hand and immediately incorporated into the plowed soil by tillage on 5 June 2007. Supplemental fertilizer was top-dressed by hand following a rainfall event on 19 July 2007.

Maize was directly sown into each plot by hand on 5 June 2007 except for the gas measurement area. In this area, a cylindrical polyvinyl chloride (PVC) plastic tube (10 cm long, 10 cm outer diameter in the lower half and 10 cm inner diameter in the upper half), which was designed to exclude the maize plant and avoid the need to raise the height of the chamber, was inserted approximately 5 cm into the soil, and three maize seeds were sown into the tube. There was a

Table 1

Physical and chemical properties of the surface soils (0–20 cm) prior to inception of this study.

Treatment	pH	Organic C ($g\ C\ kg^{-1}$)	Total N ($g\ N\ kg^{-1}$)	Easily oxidized organic C ($mg\ C\ kg^{-1}$)	NH_4^+-N ($mg\ N\ kg^{-1}$)	NO_3^--N ($mg\ N\ kg^{-1}$)	Bulk density ($g\ cm^{-3}$)	
							Interrow	Row
CK	8.53 ± 0.05^c	4.43 ± 0.06^a	0.40 ± 0.02^a	3.45 ± 0.10^a	0.72 ± 0.06^a	5.15 ± 0.25^a	1.35 ± 0.02^A	1.45 ± 0.03^B
OM	8.25 ± 0.01^{ab}	9.91 ± 0.06^e	1.06 ± 0.03^d	8.29 ± 0.08^d	0.77 ± 0.22^a	16.60 ± 1.42^{bc}	1.29 ± 0.03^A	1.41 ± 0.06^B
HOM	8.21 ± 0.01^a	7.63 ± 0.07^d	0.93 ± 0.03^c	6.79 ± 0.23^c	0.99 ± 0.23^b	10.91 ± 0.72^b	1.31 ± 0.01^A	1.42 ± 0.03^B
NK	8.46 ± 0.02^c	4.71 ± 0.05^b	0.41 ± 0.02^a	3.50 ± 0.03^a	0.64 ± 0.06^a	20.30 ± 5.74^c	1.34 ± 0.05^A	1.45 ± 0.08^B
NPK	8.30 ± 0.01^b	5.61 ± 0.01^c	0.70 ± 0.03^b	5.05 ± 0.19^b	0.77 ± 0.04^a	17.60 ± 3.07^{bc}	1.32 ± 0.02^A	1.42 ± 0.07^B

Mean ± standard error (n = 4).

Bulk density was measured after maize harvest.

Different lowercase letters within the column indicate significant difference among treatments at $P < 0.05$. Different capital letters within the row indicate significant difference for the same treatment at $P < 0.05$.