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The influence of straw returning on N_2O emissions from a maize-wheat field in the North China Plain

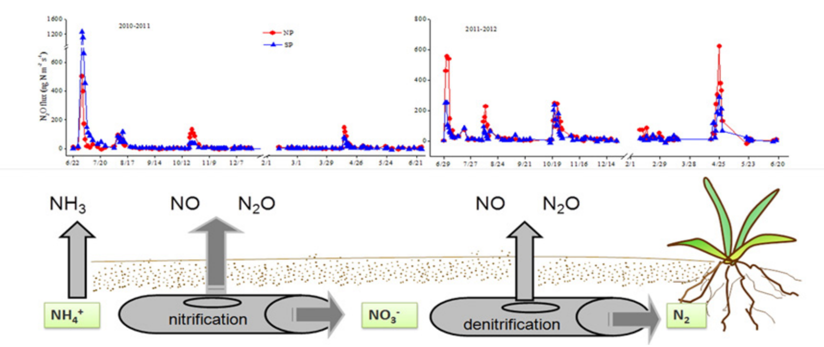
Yizhen Zhou [a,c], Yuanyuan Zhang [a,c], Di Tian [a,c], Yujing Mu [a,b,c,*]

[a] Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China
[b] Center for Excellence in Regional Atmospheric Environment, Institute of Urban Environment, Chinese Academy of Sciences, Xiamen 361021, China
[c] University of Chinese Academy of Sciences, Beijing 100049, China

HIGHLIGHTS

- Crop straw returning has become a prevailing cultivation practice in the NCP.
- Straw returning reduced N_2O emission under high soil moisture during the maize season.
- Straw returning reduced N_2O emission during wheat seasons were attributed to anoxic condition induced by rotting the maize straw.

GRAPHICAL ABSTRACT



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ABSTRACT

Crop straw returning has become a prevailing cultivation practice in the vast area of the North China Plain (NCP), while few investigations about its influence on nitrous oxide (N_2O) emission have been conducted. In this study, N_2O emissions from an agricultural field in the NCP with and without straw returning were comparably investigated by using static chambers in two consecutive maize-wheat growing seasons from June 2010 to June 2012. Compared with the NP treatment (compound nitrogen fertilizer only), the cumulative N_2O emission from the SP treatment (compound nitrogen fertilizer plus straw) increased about 150% during the maize season in 2010, but decreased by about 35% during the maize season in 2011. The inconsistent influence of straw returning on N_2O emission from the maize field was ascribed to the evidently different soil moisture between the two years, which was further confirmed by laboratory simulation experiments. About 40% reduction of N_2O emission from the SP treatment during the two winter wheat seasons, which was mainly attributed to anoxic condition induced by rotting the maize straw.

1. Introduction

Nitrous oxide (N_2O) is one of important greenhouse gases and participates in the depletion of stratospheric ozone (Crutzen, 1970). Currently, the mixing ratio of N_2O in troposphere is about 328 ppbv, and still increases at a rate of about 0.3% yr^{-1} which is mainly attributed to the emissions from agricultural soil (IPCC, 2013). The application of nitrogen (N) fertilizer in agricultural fields for increasing crop yield

* Corresponding author.
E-mail address: yjmu@rcees.ac.cn (Y. Mu).

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also provides the substrate for soil microbes to promote nitrification and denitrification processes, resulting in remarkable increment of N_2O emissions (Robertson and Groffman, 2015; Snyser et al., 2009; Wrage et al., 2001). Additionally, N_2O emissions from agricultural fields are also strongly affected by cultivation manners, e.g., tillage (Saggar, 2010; Yanai et al., 2011), irrigation (Trost et al., 2013), straw returning (Millar et al., 2004; Singh et al., 2008; Toma and Hatano, 2007) and fertilization manner (Sarkodie-Addo et al., 2003). Therefore, the change of cultivation manners should be considered for estimating N_2O emissions from agricultural fields.

The cultivation manners for the agricultural fields in China have evidently changed in recent years, especially in the North China Plain (NCP). Instead of using crop straw for cooking, crop straw returning in the NCP has become a prevailing agricultural practice for improving soil fertility and reducing air pollution induced by crop straw burning (Gao et al., 2011). However, only few studies reported the influence of straw returning on N_2O emission from the agricultural fields in the NCP and their conclusions are inconsistent. For example, Liu et al. (2011), Zhang et al. (2011, 2012) and Hu et al. (2013) pointed out that the addition of wheat straw increased N_2O emission in maize seasons, whereas the results from Pan et al. (2004) and Pei et al. (2012) showed that the addition of maize straw evidently reduced N_2O emission during the winter-wheat season. The inconsistent conclusions about the influence of crop straw returning on N_2O emissions from agricultural fields in the regions other than the NCP are also reported: some results indicated enhanced N_2O emission (e.g. Baggs et al., 2003; Cheng et al., 2012; Hu et al., 2013; Liu et al., 2011; Muhammad et al., 2011; Singh et al., 2008; Yao et al., 2010; Yang et al., 2014), whereas the others implied reduced N_2O emission (e.g. Aulakh et al., 2001; Fu et al., 2012; Hao et al., 2001; Ma et al., 2007; Shen et al., 2014; Yamulki, 2006; Zou et al., 2005). Because N_2O emissions from the vast agricultural fields in the NCP is one of the most important sources for global atmospheric N_2O (Ding et al., 2007; Zhang et al., 2012), the influence for the currently prevailing agricultural practice of straw returning on N_2O emissions should be considered.

In this study, N_2O fluxes from a summer maize-winter wheat field with and without straw returning treatments were comparably investigated for two consecutive years, and both negative and positive influences of straw returning on N_2O emissions were also found. The inconsistent influence of straw returning on N_2O emission was mainly ascribed to the different soil moistures, which was well confirmed by laboratory simulation experiments.

2. Materials and methods

2.1. Experimental site

The experimental site is located in Wangdu Country (38°68′N, 115°25′E), Hebei Province, China. The soil of the agricultural field is classified as aquic inceptisol with a sandy loam texture, soil pH (in a 1: 2.5 soil-to-water ratio) of 8.8, soil organic C of 8.7 g/kg and total N of 1.0 g/kg. The annual mean temperature was about 12.9 °C and the annual precipitation is about 519 mm. Summer maize-winter wheat is the dominant cropping system in the field.

2.2. Field experiments

The field had been divided into three treatments (each treatment with an area of 6.4×6.3 m^2) since 2008: One was the control treatment (designated as CK) without fertilization or straw returning; the second was applied with compound nitrogen fertilizer (designated as NP); the third was treated with straw returning plus compound nitrogen fertilizer (designated as SP). Each treatment was isolated by a 1.2 m broad zone to prevent nutrient transfer between treatments, and three opaque static chambers were set for measurements of N_2O emissions in each treatment. Maize was sown on 30 June 2010 and 30 June 2011 respectively, and harvested on 14 October 2010 and 17 October 2011. During each summer-maize season, compound fertilizer (107 kg N/ha, $N:P_2O_5:K_2O = 26\%:6\%:8\%$) was broadcast to the NP and SP treatments as basal fertilizer after seeding, and air-dried wheat straw (4.7 t/ha, $N = 0.48\%$) was simultaneously applied to the soil surface of the SP treatment. Compound fertilizer (69 kg N/ha, N: K = 25%:5%) was broadcast to the NP and SP treatments as topdressing on 6 August 2010 and 8 August 2011, respectively. Wheat was sown after tillage on 17 October 2010 and 19 October 2011, and harvested on 28 June 2011 and 15 June 2012. During the winter-wheat season, compound fertilizer (60 kg N/ha, $N:P_2O_5:K_2O = 18\%:18\%:18\%$ in 2010 and $N:P_2O_5:K_2O = 12\%:18\%:15\%$ in 2011) was broadcast to the NP and SP treatments as basal fertilizer, and air-dried maize straw (11.5 t/ha, $N = 0.6\%$) was simultaneously applied to the SP treatment, and then was tilled into the soil depth of 10 cm before sowing wheat. Urea (105 kg N/ha, $N = 46.4\%$) and compound fertilizer (N:S = 20%:22%) were broadcast to the NP and SP treatments as topdressing on 14 April 2011 and 18 April 2012, respectively. Flooding irrigation was carried out immediately after each fertilization. Additional irrigations were conducted on 21 November 2010 and 22 May 2011, and 18 November 2011 and 21 May 2012 for the wheat during two winter wheat seasons.

Three opaque static chambers were set for measurements of N_2O emissions (Zhang et al. 2011). The chambers (length × width × height: $60 \times 60 \times 90$ cm^3) were placed on the corresponding pedestals which were inserted into soil about 8-cm depth. Four air samples from each chamber were collected into polyethylene coated aluminum bags (0.2 L, Delin, Dalian, China) by a mini-pump (NMP 830 KNDC, Germany) at 10-min intervals after the chamber being enclosed (5, 15, 25 and 35 min). The daily fluxes were measured between 9:30 a.m. and 10:30 a.m. (Local time). Soil temperature at 5 cm depth was simultaneously recorded on each sampling occasion and rainfall data was obtained from http://weather.org/weatherorg_records_and_averages.htm. The top part of the maize plant above the chamber was cut off when its height exceeded 80 cm. The measurements in 2010–2012: N_2O fluxes were measured every day within duration of >10 days after fertilization, then continuous sampling once or twice weekly during other periods of crops' growing seasons.

2.3. Simulation experiments

The soil samples collected from the agricultural field were placed into twelve plastic cylinders (ID of 20 cm and 26 cm in height) for laboratory simulation at room temperature (~25 °C) and each cylinder was filled with about a depth of 10 cm soil (~2500 g soil). The air-dried maize straw cut into segments of about 3 cm were broadcasted on the soil surfaces of six cylinders (36 g for each cylinder, which was equal to 11.5 t/ha). Based on the initial water content in the soil samples, the soil WFPS values in the twelve cylinders were firstly adjusted to be about 40% by adding distilled water for three days' incubation, and then compound fertilizer ($N:P_2O_5:K_2O = 20\%:20\%:5\%$, 1.7 g for each cylinder, which was equal to 107 kg N/ha) was evenly broadcasted on the soil surfaces of the twelve cylinders. The twelve cylinders were equally divided into two groups, and each group included three cylinders with only application of compound fertilizer (designated as treatment N1) and three cylinders with application of both the compound fertilizer and the maize straw (designated as treatment N2). The WFPS values of the soil samples were immediately adjusted to be 60% in one group and 90% in the other group just after the fertilization.

Four air samples from each cylinder were collected by a glass syringe (100 mL) at 10-min intervals (5, 15, 25 and 35 min) after it being enclosed with a cap. The measurements lasted 9 days from 23 to 31 January in 2015.