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Short communication

Nitrous oxide emissions from rape field as affected by nitrogen fertilizer management: A case study in Central China

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ABSTRACT

Agricultural soils are one of the major sources of atmospheric nitrous oxide (N_2O) emission. Red soil, one of the typical agricultural soils in sub-tropical China, plays an important role in the global N_2O flux emissions. To determine its N mineralization potential, a field study was conducted to assess the effect of application of nitrogen (N) fertilizer in a rape field under red soil at the experimental station of Heshengqiao at Xianning, Hubei, China. To estimate N-induced N_2O flux, we examined N_2O flux during the growth stages of the rape field including four treatments: fertilizer PK (N0), fertilizer NPK (60 kg N ha^{-1}) (N1), fertilizer NPK (120 kg N ha^{-1}) (N2), fertilizer NPK (240 kg N ha^{-1}) (N3). There were distinct variations in soil N_2O fluxes (from 0.16 to 0.90 kg N ha^{-1}), with higher values being observed during the spring and autumn while low values were observed during winter season. Among different treatments, N fertilization significantly increased the N_2O fluxes, with highest fluxes from N3 while lowest values being observed from N0 treatment. This suggested increased microbial activity in response to increased N fertilizer application. It was interesting to note that fertilizer-induced emissions decreased as the applied fertilizer amount was increased. During the whole growing season, N_2O flux did not correlate with soil temperature, but it significantly correlated to other environmental variables; water-filled pore space (WFPS), soil NO_3^-−N and NH_4^+−N contents, which suggests the need for efficient water use and low inorganic nitrogen fertilizer management practices.

1. Introduction

Nitrous oxide (N_2O) is an important long-living greenhouse gas after carbon dioxide and methane (Liu et al., 2010), with 296 times greater global warming potential than carbon dioxide. Agricultural activities, N fertilizer application, burning of agricultural residues, animal manure composting, have greatly altered the global nitrogen cycle and produced a great deal of nitrous oxide through crop cultivation (Dong et al., 2007). N_2O emissions grew by about 50%, due mainly to increased use of fertilizers and the growth of agriculture (IPCC et al., 2007). Fertilized agricultural fields are important sources of atmosphere N_2O (Bouwman et al., 2002). Zheng et al. (2004) estimated that about 75% of the annual total N_2O released was due to direct emission from anthropogenic reactive nitrogen input into croplands of China.

Nitrogen fertilizer management practices and soil and climatic factors control N_2O emissions from agricultural soils (Dalal et al., 2003). In previous studies, the link between the addition of fertilizer nitrogen and increased emission of N_2O has been well established (e.g. Lin et al., 2010). In most agricultural soils, N_2O is emitted biologically via nitrification and denitrification, while the activity of these microbial processes is strongly affected by natural conditions and nitrogen fertilizer management (Ludwig et al., 2001). The cultivation of rape with its high fertilizer nitrogen requirements creates potentially favorable conditions for nitrifying and denitrifying microbes that could result in high N_2O emission (Xiong et al., 2002). China is one of the major rape production regions in the world, and winter rape cropping system which is the major type in local upland crops cover a large area in central China. Although, N_2O emission has been extensively studied under different agroecosystems of China (Zheng et al., 2000; Zou et al., 2005; Liu et al., 2010), however, relatively less data exist on sub-tropical areas of central China. There is also scarcity of data about N_2O budgets from rape fields in central China. Thus, measurements of N_2O emission from rape fields are needed.

This study was carried out to improve the database for N_2O fluxes from subtropics of central China. The main objectives of our study were to (1) evaluate the influence of application of inorganic fertilizer

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on soil N_2O emission from intensively cultivated cropland soil, and to (2) understand the effects of soil temperature, moisture, and inorganic nitrogen on N_2O emission from conventional rape field.

2. Methods and materials

2.1. Site description

The experimental site is situated at the experimental station of Heshengqiao, Xianning city, Hubei province, Central China. It is located at 29°38′N latitude and 139°35′E longitude with an altitude of about 117 m above sea level. This region has a typical sub-tropical monsoon climate with an annual mean temperature of 16.8 °C and an annual average rainfall of 1577 mm. Red soil of this area can be classified as Ultisols in the Soil Taxonomy System of the USA and Acrisols and Ferralsols in the FAO legend (FAO/UNESCO, 1974). Soil is clayey, kaolinitic thermic Typic Plinthudults with over 2 m deep profile derived from quaternary red clay, subjected to severe erosion. The field has been continuously cultivated with rice-rape rotation since 1996. During the growing seasons, an annual average rate of inorganic N, P, K (270, 59, 187 kg ha^{-1}, respectively) was applied to the field. In addition to the application of N, P, and K, lime material was occasionally practiced. The field was conventionally tilled twice a year. The main soil properties (0–20 cm depth) of this study site are described in Table 1.

2.2. Experimental design

In November 2006, an experiment from rape field was established to measure N_2O fluxes. The experimental design consisted of four treatments arranged in a randomized block design with three replications. Keeping in view of the conventional amount of fertilizer usage, treatments with different N fertilizer rate were selected. These four treatments were fertilizer PK (N0), fertilizer NPK (N1), fertilizer NPK (N2), fertilizer NPK (N3). Each plot was 50 m^2 in the field. The treatments description along with fertilizers applied is described in Table 2. Rape was transplanted on 14 November 2006 and harvested on 10 May-2007. For transplantation, 25 days old seedlings were transplanted at 20 × 20 cm spacing giving a population of 25 hills m^{-2}. The short-term seasonal N_2O flux from each plot was measured at different growth stages starting from transplantation till maturity. All the measurements were done in the morning from 09:00 to 11:00 a.m.

2.3. Measurement of soil N_2O flux and other environmental predictors

N_2O fluxes were measured using static closed chamber and gas chromatography techniques as described by Lin et al. (2010). The closed chamber was made from 8 mm thick stainless steel materials consisting of two parts, a square box (without a top and bottom, length × width × height = 50 cm × 50 cm × 10 cm) and a removable cover box (without bottom, length × width × height = 50 cm × 50 cm × 50 cm). The top edges were rubber-sealed in order to prevent from leakage when the top lid was put on it. The square box was inserted directly 5 cm into the soil, and the cover was placed on top during sampling and removed afterwards. The chambers were equipped with 2 cm vents (diameter 1 mm) for pressure equilibration. A white thermal insulation cover was added outside of the stainless steel cover to reduce the impact of direct radiative heating during sampling. Samples were taken with 100 ml plastic syringes attached to a three-way stopcock at 0, 10, 20, 30 min following chamber closure, respectively, and then injected into evacuated bags made of inert aluminum-coated plastic. N_2O concentrations in the samples were analyzed in the laboratory within 24 h following sampling using a gas chromatograph (HP 6890 Series, GC System, Hewlett Packard, USA). The gas chromatograph was equipped with an electron capture detector for N_2O analysis. N_2O flux was calculated based on the rate of change in N_2O concentration within the chamber, which was estimated as the slope of linear regression between concentration and time.

Table 1
Selected physico-chemical properties of the soils.

Properties	Values
Texture	Sandy loam
Bulk density (Mg m^{-3})	1.35
pH (1:2.5, soil:water)	5.05
Water holding capacity (g/100 g)	55.27
Total organic carbon (g kg^{-1})	24.82
Total N (g kg^{-1})	2.74
C/N ratio	9.06
Total P (g kg^{-1})	1.07
Total K (g kg^{-1})	1.82
Available N (mg kg^{-1})	315

2.4. Soil sampling and analysis

When N_2O flux was measured, fresh soil samples (0–20 cm) were collected from the field simultaneously, and then placed in plastic bags after manual removal of visible plant residues and roots. Ten sub-samples (0–20 cm) were collected from each sampling point and composited into one soil sample. Soil samples were analyzed for soil particle size distribution, water content, bulk density, total organic C, total N, pH, NH_4^+–N and NO_3^-–N as described by Iqbal et al., (2009). Each measurement was replicated three times.

2.5. Measurement of other environmental factors

Soil temperatures (at depth 0–5 cm) were measured using soil thermometers inserted to a depth of 5 cm inside the chambers. Soil moisture content (0–10 cm) was estimated by the relative water content as the percentage of water-filled pore space (WFPS). The water mass content of soil (g g^{-1}) was determined by gravimetry with oven drying at 105 °C for 24 h. Soil WFPS was calculated based on the equation: WFPS = (SWC × BD)/[1-(BD/PD)] where SWC is the soil water content (g g^{-1}), BD is the soil bulk density (g cm^{-3}), and PD is the soil particle density.

2.6. Statistical analysis

All the statistical analyses were performed by using the SPSS 11.0 package (SPSS, Chicago, IL, USA). Statistically significant differences were identified using analysis of variance (ANOVA); used Duncan's Multiple Range Test for determining significant mean differences; accepted the 0.05 probability as significant. Simple correlation coefficients between soil N_2O flux and soil temperature, WFPS, NH_4^+–N and NO_3^-–N contents were developed using the same statistical package.

3. Results

3.1. Seasonal variations of N_2O fluxes

In general, rape field served as a net N_2O source. However, at N0 treatment, negative fluxes were also observed during the winter season. N_2O fluxes for all treatments were significantly lower during winter than other seasons (Fig. S2). The maximum N_2O flux took place in November 2006 when soil temperature and moisture were relatively high (Fig. S1), while the same trend was found for