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Nitrous oxide emissions from irrigated and fertilized spring maize in semi-arid northern China

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ABSTRACT

As maize requires a high input of fertilizer nitrogen, it is likely to be an important source of nitrous oxide (N_2O). Detailed information on N_2O emissions over long time periods, and management practices that aim to reduce N_2O emissions from spring maize fields in China is lacking. Consequently we measured the emissions of N_2O from a spring maize field continuously from 2007 to 2009 at Yuci, Shanxi Province, China using newly developed automated chambers and explored strategies to reduce N_2O emissions. The results showed that the Optimal fertilizer treatment (120 kg N ha^{-1} y^{-1}) produced the same yield of grain as the Traditional fertilizer treatment (330 kg N ha^{-1} y^{-1}), and significantly reduced N_2O emissions by 48%. Topdressing with urea was the main source of N_2O, which on average accounted for 58% of the total N_2O emissions each year. Uptake of N_2O occurred during the late stage of maize growth when soil mineral N content was less than 46.4 mg N kg^{-1} soil. The N_2O emission factors were lower than the IPCC default value. Nitrous oxide emissions could also be reduced if farmers did not apply fertilizer N during periods of heavy rainfall and did not irrigate immediately after fertilization.

1. Introduction

Nitrous oxide (N_2O) contributes to rising atmospheric temperature with a global warming potential 296 times greater than CO_2 for a 100-year time horizon and participates in the destruction of the stratospheric ozone layer (IPCC, 2000, 2006). The atmospheric N_2O concentration has increased from about 273 ppb in 1750 to 319 ppb in 2005 (IPCC, 2007).

Approximately 57% of total global annual N_2O emissions emanate from soils, and 35% of these come from agricultural production (FAO/IFA, 2001). While N_2O is mainly produced in soil by the two microbially mediated processes, nitrification and denitrification (Granli and Bøckman, 1994) it may also be produced by other organisms. For example nitrate-respiring bacteria were found to produce N_2O by consuming NO_3^- through a process that is apparently not restricted by soil NH_4^+ content or oxygen level (Bleakley and Tiedje, 1982). The activity of these microbial processes is strongly affected by environmental conditions such as soil temperature and moisture (Smith et al., 2003; Adviento-Borbe et al., 2007), but fertilizer management can also have an effect (Wagner-Riddle et al., 2007; Song and Zhang, 2009; Ma et al., 2010) as application of fertilizer nitrogen usually results in enhanced emission of nitrous oxide (Skiba et al., 1994).

In China, the area sown to maize has increased from 19.6 million hectares in 1978 to 29.8 million hectares in 2008 (19.1% of the total cropped area; China Statistical Yearbook, 2009) and maize is the second most important cereal crop in China (FAO, 2010). Spring maize is mainly grown in Liaoning, Jilin, Heilongjiang, Inner Mongolia, Ningxia, Gansu, Shanxi, and Shaanxi provinces (Fig. 1). The sowing area of spring maize is almost 36% of the total maize area, and the yield accounts for 40% of the total maize yield (Xiao et al., 2010). In addition China's fertilizer nitrogen (N) use has increased rapidly from 544 Gg N in 1961 to 32.4 Tg N in 2007. Since 1979 China has been the world's biggest N fertilizer consumer, and since 2002 it has accounted for about 30% of the world's N fertilizer use (FAO, 2010; Fig. 2). Maize requires more fertilizer N than other crops (IFA, 2009), but the N use efficiency for maize world wide is only ~30% because much of the applied N is lost to the environment (Balasubramanian et al., 2004; Peoples et al., 2004). As large fertilizer N applications to croplands can result in very high N_2O emissions (Wagner-Riddle et al., 2007) maize may be an important source of atmospheric nitrous oxide.

The use of a static chamber (Hutchinson and Mosier, 1981), and the traditional manual measurement frequency of one flux deter-

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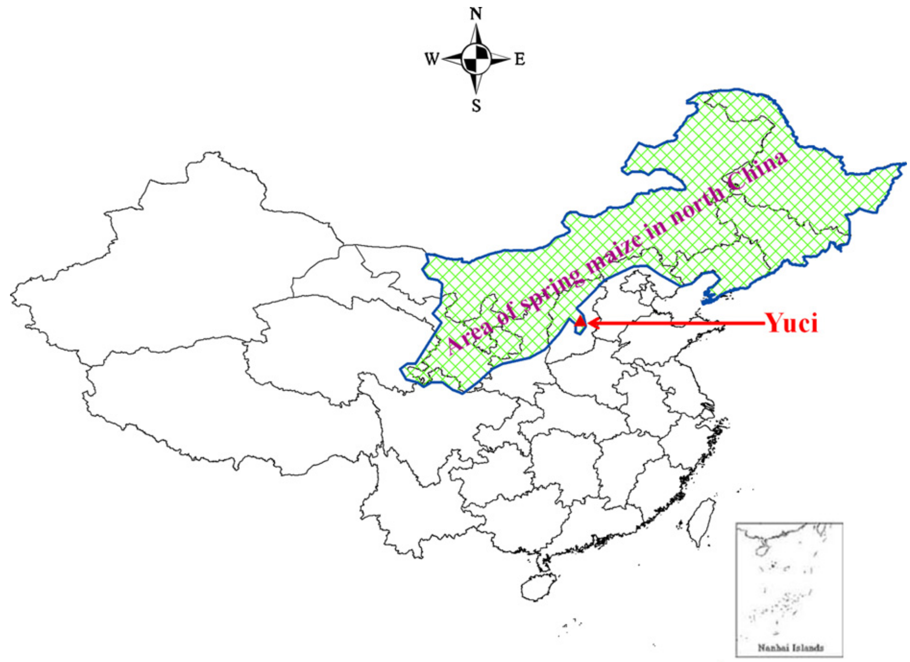

Fig. 1. Area where spring maize is grown in China and location of the experiment at Yuci.

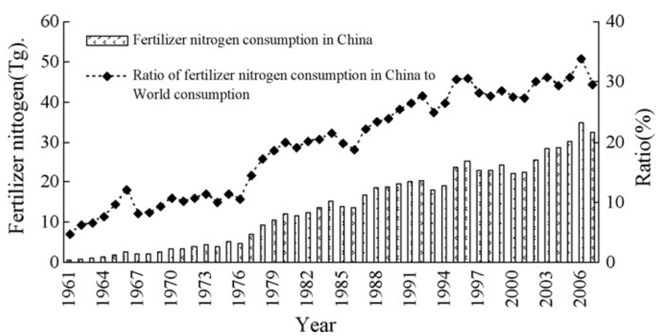

Fig. 2. Nitrogen fertilizer used in China during the period 1961–2007.

mination of a single gas per 3–10 days may miss the peak emissions because fertilizer-induced N_2O emissions are often short-lived (Zheng et al., 2000). Low frequency measurements have produced annual estimates which differed widely from those based on continuous measurements (Liu et al., 2010). In order to save manpower and improve estimates of the contribution of terrestrial ecosystems to the global N_2O budget, automated chamber sampling systems have been developed (Conrad et al., 1983; Loftfield et al., 1997; Zheng et al., 1998; Breuer et al., 2000), modified (Zheng et al., 1998) and applied to rice (Bronson et al., 1997; Zheng et al., 1998; Seiichi et al., 2005), forests (Butterbach-Bahl et al., 1997, 1998; Breuer et al., 2000), potato (Flessa et al., 2002), wheat (Seiichi et al., 2005; Barton et al., 2008), cotton (Liu et al., 2010), summer maize (Wan et al., 2005) and canola (Barton et al., 2010). Although numerous studies have investigated N_2O emissions from agricultural soils cropped to maize, very few have used the automated chamber system to measure N_2O emissions from irrigated and N fertilized spring maize crops.

The objectives of this study were: (i) to present a detailed description of a system for continuous automated monitoring of N_2O emissions, (ii) to compare the effects of fertilizer treatments on N_2O emissions, (iii) to identify the main environmental drivers of N_2O emissions from a spring maize field in northern China, and (iv) to devise feasible strategies to reduce N_2O emissions.

2. Materials and methods

2.1. Study site

The study site was at Yuci in north China (37°38′N, 112°51′E, elevation 789 m) (Fig. 1). Field experiments were conducted during the maize growing periods from May to September from 2005 to 2009, and the measurement of N_2O fluxes from the two treatments commenced from 2007. Maize is the main crop in this area. Yuci is classified as a semi-arid climatic region with an average annual rainfall of 430 mm, which mainly falls during the summer months (June, July and August), and with average annual air temperature of 9.3 °C (China Meteorological Data Sharing Service System, 2010). The soil at the site is classified as a meadow saline soil (National Soil Survey Office, 1998). The 0–20 cm topsoil has a bulk density of 1.33 g cm^{-3}, a pH of 8.4 (1 soil:2.5 water), and contains 19.9% clay, 16.9 g organic C kg^{-1}, 1.79 g N kg^{-1}, 1.58 g P_2O_5 kg^{-1}, and 90.6 mg available K kg^{-1}.

2.2. Treatments

The experiment was established to evaluate fertilizer-efficient management practices for achieving high maize yield and reduced N_2O emissions. A completely randomized design with three replicates was set up. Each plot had an area of 10 m × 6 m, separated by buffer zones 1 m wide, which were also planted with maize. There were two fertilizer treatments: (1) Traditional, with a basal dressing of nitrophosphate fertilizer (supplying 60 kg P_2O_5 ha^{-1} and 145 kg N ha^{-1}, of which 75% is NH_4^+-N), and a topdressing of urea (185 kg N ha^{-1}, 0.05 m deep in the row) at approximately 60 days after seeding, and (2) Optimal, recommended by the Soil and Fertilizer Research Institute of Shanxi Academy of Agricultural Sciences, with a basal dressing of superphosphate (100 kg P_2O_5 ha^{-1}) and potassium sulfate (100 kg K_2O ha^{-1}) and a topdressing of urea (120 kg N ha^{-1} 0.05 m deep in the row) on the same day as the Traditional treatment. The same land management practices were applied to both treatments (Table 1). Two flood irrigations were applied each year, one before tillage and one after top dressing, at the rate of 70 mm water for each event. Each year the basal fertiliz-