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Dinitrogen and N_2O emissions in arable soils: Effect of tillage, N source and soil moisture ☆

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Abstract

A laboratory investigation was performed to compare the fluxes of dinitrogen (N_2), N_2O and carbon dioxide (CO_2) from no-till (NT) and conventional till (CT) soils under the same water, mineral nitrogen and temperature status. Intact soil cores (0–10 cm) were incubated for 2 weeks at 25 °C at either 75% or 60% water-filled pore space (WFPS) with ^{15}N-labeled fertilizers (100 mg N kg^{-1} soil). Gas and soil samples were collected at 1–4 day intervals during the incubation period. The N_2O and CO_2 fluxes were measured by a gas chromatography (GC) system while total N_2 and N_2O losses and their ^{15}N mole fractions in the soil mineral N pool were determined by a mass spectrometer. The daily accumulative fluxes of N_2 and N_2O were significantly affected by tillage, N source and soil moisture. We observed higher ($P<0.05$) fluxes of N_2+N_2O, N_2O and CO_2 from the NT soils than from the CT soils. Compared with the addition of nitrate (NO_3^-), the addition of ammonium (NH_4^+) enhanced the emissions of these N and C gases in the CT and NT soils, but the effect of NH_4^+ on the N_2 and/or N_2O fluxes was evident only at 60% WFPS, indicating that nitrification and subsequent denitrification contributed largely to the gaseous N losses and N_2O emission under the lower moisture condition. Total and fertilizer-induced emissions of N_2 and/or N_2O were higher ($P<0.05$) at 75% WFPS than with 60% WFPS, while CO_2 fluxes were not influenced by the two moisture levels. These laboratory results indicate that there is greater potential for N_2O loss from NT soils than CT soils. Avoiding wet soil conditions (>60% WFPS) and applying a NO_3^- form of N fertilizer would reduce potential N_2O emissions from arable soils.

Keywords: No-till; WFPS; ^{15}N-labeled fertilizer; Denitrification; Nitrification; Nitrous oxide emission

1. Introduction

Denitrification is a major microbial-based process that completes the nitrogen (N) cycle by returning N_2 to the atmosphere. Loss of N from agricultural soils by denitrification is an important pathway for fertilizer N loss (Aulakh et al., 1992). In a review of ^{15}N field N-balance studies, Hauck (1981) estimated that, on average, 30% of fertilizer ^{15}N was unaccounted for, as a result of dentrification. A product of the denitrification process, nitrous oxide (N_2O), is an important greenhouse gas (GHG), which is emitted from N-fertilized agricultural soils and its contribution to the anthropogenic greenhouse effect has been estimated at 5% (IPCC, 2001). N_2O is an obligatory intermediary product of denitrification (Crutzen, 1981). The N_2O molecule is also produced as a by-product of nitrification (Firestone and Davidson, 1989). Under specific soil conditions, coupled nitrification–denitrification may occur (Bateman and Baggs, 2005). This happens when nitrite or nitrate produced by nitrifiers is used by denitrifiers (Wrage et al., 2001).

According to a model of Davidson (1991), N_2O is primarily derived from nitrification at low and moderate soil moistures while denitrification becomes more important

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at soil moisture contents greater than 60% water-filled pore space (WFPS) due to a decreased O_2 supply. Bateman and Baggs (2005) also found that all of the N_2O emitted at 70% WFPS was produced during denitrification, but nitrification was the main process producing N_2O at 35–60% WFPS. However, the relative contributions of denitrification and nitrification to the emissions of N_2O are still not well documented (Arah, 1997; Bateman and Baggs, 2005; Stevens et al., 1997).

No-till (NT) conservation tillage is commonly practiced in order to reduce soil erosion and energy consumption in North America (Holland, 2004; Halvorson et al., 2006). Reducing the intensity of soil cultivation under NT lowers the emissions of CO_2, while C sequestration is raised via increasing soil organic matter. Thus global warming potential (GWP) and GHG flux intensity can be reduced if the cropping system management practices are altered (Mosier et al., 2006). In general, NT is found to be effective in mitigating N_2O or GHG emissions in dry and humid climate soils due to reduced surface disturbance (Kaharabata et al., 2003; Lemke et al., 2004; Mosier et al., 2006; Lee et al., 2006). However, some studies have shown NT to produce larger (Baggs et al., 2003; Liu et al., 2006; Six et al., 2004) or similar (Grandey et al., 2006; Liu et al., 2005) N_2O emissions compared with CT. Using the DAYCENT ecosystem model, Del Grosso et al. (2002) observed that during the first few years of NT, the soil N_2O emissions and thus the net GWP decreased. Over time, as the rate of increase in soil organic carbon (SOC) declined and N_2O emissions increased because of increased N availability, the net GWP increased relative to CT soils. This simulation suggests that the impact of NT on N_2O emission and net GWP decreases over time in a dry agroecosystem. But there are great uncertainties regarding the impact that NT has on nitrification and denitrification rates and N_2O emissions in irrigated and fertilized soils.

In the present study, we selected the ^{15}N tracer method to quantify the effect of tillage, N source and moisture content on gaseous N losses and N_2O emissions from soils collected in a northern Colorado maize field. The main objectives of the present study were: (1) to determine how NT affects the fluxes of N_2O and N_2 compared with CT; (2) to determine the relative contributions of nitrification and denitrification to N_2O emissions in both NT- and CT-treated soils; and (3) to gain a critical insight as to how N_2O emissions might be reduced by integrating tillage, N source and soil water management.

2. Materials and methods

2.1. Soils

Soil samples were collected from two typical tillage systems (CT and NT) in a tillage by N rate experiment (Halvorson et al., 2006) that was initiated in 1999 at the Agricultural Research Development and Education Center (ARDEC) in northeastern Colorado near the city of Fort Collins (40°39′N, 104°59′W; 1530 m above mean sea level). The soil was a clay loam soil (fine-loamy, mixed, superactive, mesic Aridic Haplustalfs, according to US Soil Taxonomy) and its related properties are listed in Table 1. Corn had been continuously planted under the CT or NT treatments with no fertilizer N since 1999.

Table 1
Selected soil (0–10 cm) chemical and physical properties of the study site

Tillage	pH (0.01 M $CaCl_2$)	Bulk density ($g\,cm^{-3}$)	SOC[a] ($g\,kg^{-1}$)	TSN[b] ($g\,kg^{-1}$)	Sand ($g\,kg^{-1}$)	Clay ($g\,kg^{-1}$)
CT	7.77	1.38	11.9	1.15	402	334
NT	7.66	1.42	12.8	1.48	402	334

[a]SOC represents soil organic carbon.
[b]TSN represents total soil nitrogen.

2.2. Consecutive incubation

Intact soil cores (diameter 5.4 cm, height 10 cm) were collected from the 0 to 10 cm soil depth from the NT and CT plots in the Summer of 2004 (maize growing season) and immediately stored at 4 °C until start of the incubation study (the storage period was 5–7 days). The treatments applied to the soil cores included N fertilizer form and soil moisture content. N fertilizer was applied either as $^{15}NH_4^+$ (99 at% excess ^{15}N ammonium sulfate) or $^{15}NO_3^-$ (99 at% excess ^{15}N potassium nitrate). The incubation study was conducted at two soil moisture contents: 75% and 60% WFPS, respectively. There were four treatments represented as CT NH_4, CT NO_3, NT NH_4, and NT NO_3 at the two soil moisture levels. Glass canning jars (0.43 L), fitted with air-tight metal lids, were used as incubation vessels. There was a 1-cm diameter butyl rubber septum (thickness 1.5 cm) inserted into a hole that was punched in the center of the lid for gas sampling. Each incubation vessel contained one soil core. The headspace of each incubation vessel was 0.20 L. The $^{15}NH_4^+$ or $^{15}NO_3^-$ solution was homogeneously injected in to both the CT and NT soil profiles with three triangle injection points per soil core via a 10 cm length needle (as shown in Fig. 1). The resulting N concentration in either the CT or NT treatment was $100\,mg\,N\,kg^{-1}$ soil. The rate of N applied to each soil core was equivalent to $150\,kg\,N\,ha^{-1}$, a moderate rate when compared with local farming practices. The incubation vessels were sealed immediately after N addition. Each treatment was replicated 18 times to provide 6 dynamic sampling times (three replications each sampling) during the entire incubation period. Prior to the incubation, initial soil moisture contents were measured and expressed as WFPS according to the following Eq. (1):

$$\text{WFPS}, \% = \text{Soil water content}(\%) \times \rho_v/(1 - \rho_v/2.65). \quad (1)$$

In the equation, ρ_v represents soil bulk density ($g\,cm^{-3}$), while soil water content is calculated based on oven-dry