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Nitrogen oxide emissions affected by organic fertilization in a non-irrigated Mediterranean barley field

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ABSTRACT

Contradictory findings can be found in the literature regarding the effects of applying organic instead of mineral fertilizers on the associated emissions of nitrous oxide (N_2O) and nitric oxide (NO). The main aim of this experiment was to study the effect on these emissions of applying mineral or organic fertilizers to a non-irrigated crop under Mediterranean conditions. A secondary aim was to determine whether application of the fertilizer had a residual effect on the N_2O and NO pulses observed after the first rainfall events in autumn, and the magnitude of these fluxes. A field experiment was carried out with a barley crop (*Hordeum vulgare* L. cv Bornova). Untreated pig slurry (UPS), digested pig slurry (DPS), municipal solid waste (MSW) and composted crop residues mixed with sewage sludge (CCR + S) were applied to the soil. The resulting emissions were compared with those from a mineral fertilizer, urea (U), and a control treatment (C), in which no nitrogen was applied. Very low NO and N_2O fluxes were measured during the entire experimental period in all treatments. The accumulated N_2O emissions from the organic and inorganic fertilizers ranged from 266 to 345 g N_2O-N ha^{-1} and did not show significant differences. Three of the four organic fertilizers had the positive effect of reducing NO emissions (28.82–44.48 g NO-N ha^{-1}) compared with inorganic fertilizer (61.86 g NO-N ha^{-1}). Nitrous oxide pulses were observed in autumn. Negative N_2O fluxes were measured on several occasions. The emission factor relating N_2O emissions to the N applied as fertilizer, ranged from 0.06 to 0.17% for MSW and DPS, respectively, which is much lower than the default factor proposed by the IPCC. The emission factor which relates N_2O emissions to crop production ranged from 241 to 361 mg N_2O-N kg^{-1} for DPS and U, respectively, suggesting that DPS should be promoted in order to reduce N_2O emissions.

1. Introduction

Agricultural soils are one of the main anthropogenic sources of nitrous oxide (N_2O) (IPCC, 2007), which is a powerful greenhouse gas (GHG), and nitric oxide (NO), which catalyses the photochemical formation of tropospheric ozone (Crutzen, 1979). These nitrogen (N) oxides are predominantly produced by microbial processes, as by-products of nitrification and products of denitrification (Firestone and Davidson, 1989). In agricultural systems, organic and mineral fertilizers are known to be key contributors to N_2O and NO emissions from soils (Mosier et al., 1998). Fluxes depend on the amount and chemical composition of fertilizers (Baggs et al., 2002; Vallejo et al., 2006), both of which affect denitrification and nitrification. However, the effect of each fertilizer is also controlled by other conditions of the agrosystem (soil, crop, water-filled pore space (WFPS), temperature, etc.), and it is not possible to establish a general behaviour.

The application of organic amendments to annual crops generally increases denitrification and N_2O emissions (Mogge et al., 1999; Jones et al., 2005, 2007; Vallejo et al., 2006; Dambreville et al., 2008; Miller et al., 2008). However, contradictory effects on N oxides have been reported when comparing organic and mineral fertilizers in arable soils. For example, in a maize crop in the Netherlands, Van Groenigen et al. (2004) found a higher emission factor of N_2O for manure than for mineral N fertilizer. This effect was attributed to more anoxic conditions produced by the stimulation of denitrification and to the supply of readily available C, a substrate for denitrification (Beauchamp et al., 1989). On the other hand, other studies such as those of Meijide et al. (2007), also in a maize crop, or of Ball et al. (2004), in a silage crop, demonstrated that manure reduced N_2O fluxes compared with a source of mineral N. In these latter cases, the authors justified this by saying that conditions were favourable for denitrification, such as under irrigation (Meijide et al., 2007), or in systems with high rainfall (Ball et al., 2004). The application of a labile C source reduced the N_2O:N_2 ratio of the gases emitted by denitrification processes, thereby decreasing the N_2O losses. There is, however, a lack of knowledge concerning the comparative

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effects of applying organic or mineral fertilizers in non-irrigated semiarid systems. Our hypothesis was that applying a source of C along with N fertilizers would have a small effect in systems where denitrification is not the main process responsible for N_2O and NO emissions.

Mediterranean climate is characterized warm and dry conditions in summer and moderate precipitation in winter ($<300\ \mathrm{mm\ year}^{-1}$). The pattern of N oxides emissions in this system is not well known and probably different to that observed in semiarid grassland by Mosier et al. (1998) or in semiarid agricultural soils by Bronson and Mosier (1993), Malhi et al. (2006) and Malhi and Lemke (2007), because in those studies, most of the rainfall occurred in summer. The upper part of the soil is usually dry during a significant part of the year in non-irrigated Mediterranean systems. When a dry soil is rewetted rapid emission pulses of N_2O are generally produced, as observed by various authors in different soils (Davidson et al., 1993; Jørgensen et al., 1998; Kessavalou et al., 1998; Beare et al., 2009). Pulses of NO have also been measured after rewetting, as observed by Dick et al. (2001) in African soils. These pulses are produced because a significant proportion of microorganisms can die during the drying (Van Gestel et al., 1991) and rewetting (Kieft et al., 1987) of soil. The C and N present in dead microbial cells could be released to the soil and cause part of the flush of N (Marumoto et al., 1977). After rewetting, bacteria and fungi resistant to wetting and drying could use these labile compounds, producing pulses of N oxides in the process. The importance of these pulses in Mediterranean agrosystems is, however, not known. Additionally, we hypothesised that the emissions produced as a consequence of autumn rainfall could be influenced by the residual effect of treatments previously applied to the soil during the crop period. This is because C and N from the fertilizer could remain in the soil and affect the nitrification and denitrification processes. It was, therefore, of interest to study N_2O and NO emissions during both the period after fertilizer application and after the first rainfall events following the dry period in order to better understand the mechanisms responsible for these emissions and the magnitude of the fluxes during both periods.

A field experiment involving the application of different organic fertilizers (compost and liquid manures) and mineral N (urea) to a barley crop (*Hordeum vulgare* L. cv Bornova) grown in a non-irrigated soil under Mediterranean climatic conditions was carried out. The aims of this experiment were to: (1) evaluate the effect of fertilizer composition (mineral N, organic N, total organic C, soluble organic C) on NO and N_2O emissions and the processes responsible of the production of these gases and (2) study the magnitude of N_2O and NO pulses after the first rainfall events following the dry period and the processes and fertilizer effects controlling these pulses.

2. Materials and methods

2.1. Soil characteristics and experimental procedure

The field experiment was carried out at 'El Encín' Field Station (40°32′N, 3°17′W) in Alcalá de Henares, Madrid. The site is located in the Henares river basin. The soil is a Calcic Haploxerepts according to the USDA soil taxonomy system (Soil Survey Staff, 1992) and a Calcaric Cambisol according to the FAO taxonomy (FAO, 1998) with a clay loam texture in the upper (0–28 cm) horizon. Some of the physicochemical properties of the top soil layer (measured on 20 January 2006 by conventional methods) are: total organic C, $8.2 \pm 0.4\ \mathrm{g\ kg}^{-1}$; total N, $0.75 \pm 0.12\ \mathrm{g\ kg}^{-1}$; pH_{H_2O}, 7.9; bulk density, $1.41\ \mathrm{Mg\ m}^{-3}$; $CaCO_3$ $13.1 \pm 0.3\ \mathrm{g\ kg}^{-1}$; clay, 28%; silt, 17%; sand, 55%, soluble organic C (SOC), $30.6\ \mathrm{C\ mg\ C\ kg}^{-1}$; $NO_3{}^-$ 28 mg $NO_3{}^-$-N kg soil^{-1} and $NH_4{}^+$ 5.1 mg $NH_4{}^+$-N kg soil^{-1}. The 10-year mean annual averages for temperature and rainfall in this area are 13.2 °C and 430 mm.

Eighteen $30\ \mathrm{m}^2$ plots were selected and arranged in a randomized block design with three replicates per treatment in a field where no crop had been sown and no fertilizer had been applied in the previous 5 years. The treatments were: untreated pig slurry (UPS), anaerobically digested thin pig slurry fraction (DPS), composted organic waste (MSW), composted crop residues mixed with sludge (CCR + S), urea (U) and a control treatment without any nitrogen fertilizer (C). The physicochemical properties of the different fertilizers and the quantities of the different compounds incorporated into the soil with the different types of waste are summarised in Table 1.

Pig slurries were obtained from the treatment plant at Almazán (Soria, Spain). The slurry was separated into its liquid and solid fractions using a rotary sieve drum (0.9 mm mesh). The digested pig slurry was obtained by the anaerobic digestion of the liquid fraction in a $50\ \mathrm{m}^3$ continuous digester with a hydraulic retention time of 32 days and a fermentation temperature of 35–40 °C. The composted organic waste was a mixture of the organic fraction of municipal solid waste obtained from the Pinto municipal waste treatment plant (Madrid, Spain) and garden waste, combined in a ratio of 1:2. The CCR + S was obtained by composting a mixture of crop residues with sewage sludge obtained, from the waste water treatment plant of Villanueva de La Cañada, Madrid, in a 3:1 ratio.

All the organic treatments were taken to the experimental field between 2 and 4 weeks before the beginning of the experiment and the analysis of the composition of the fertilizers was carried out one week before the treatments were applied. They were applied on 23 January 2006 and were incorporated into the upper 0–5 cm of the soil profile using a rotocultivator. The fertilizers were applied at a rate of 125 kg available N ha^{-1}. For the solid treatments, the estimated percentage of organic N mineralised in the soil was around 40%, according to the method described in Sánchez et al.

Table 1
Composition of the fertilizers and amounts of the different compounds added with the fertilizers.

Property	UPS[a]		DPS[a]		MSW[a]		CCR + S[a]	
	Composition (g kg^{-1})	Added (g m^{-2})	Composition (g kg^{-1})	Added (g m^{-2})	Composition (g kg^{-1})	Added (g m^{-2})	Composition (g kg^{-1})	Added (g m^{-2})
Moisture	966	–	942	–	354	–	212	–
pH	7.1	–	7.6	–	7.6	–	6.8	–
Total N	86	12.5	82	12.5	19	12.5	22	12.5
$NH_4{}^+$	70	10.2	64	9.76	3.40	2.28	4.63	2.65
Total C	186.5	27.1	144.0	22.0	262.0	172.4	259.0	146.9
Soluble organic C	4.95	0.72	3.35	0.51	0.11	0.07	0.12	0.07
C/N	2.17	–	1.76	–	14.0	–	11.7	–

Calculated in dry weight.

[a] UPS—Untreated pig slurry; DPS—digested pig slurry; MSW—municipal solid waste composted with vegetable wastes; CCR + S—composted crop residues with sewage sludge.