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Soil nitrous oxide emissions in long-term cover crops-based rotations under subtropical climate

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ABSTRACT

It has been shown that cover crops can enhance soil nitrous oxide (N_2O) emissions, but the magnitude of increase depends on the quantity and quality of the crop residues. Therefore, this study aimed to evaluate the effect of long-term (19 and 21 years) no-till maize crop rotations including grass [black oat (*Avena strigosa* Schreb)] and legume cover crops [vetch (*Vigna sativa* L.), cowpea (*Vigna unguiculata* L. Walp), pigeon pea (*Cajanus cajan* L. Millsp.) and lablab (*Dolichos lablab*)] on annual soil N_2O emissions in a subtropical Acrisol in Southern Brazil. Greater soil N_2O emissions were observed in the first 45 days after the cover crop residue management in all crop rotations, varying from -20.2 ± 1.9 to 163.9 ± 24.3 μg N m^{-2} h^{-1}. Legume-based crop rotations had the largest cumulative emissions in this period, which were directly related to the quantity of N ($r^2 = 0.60$, $p = 0.13$) and inversely related to the lignin:N ratio ($r^2 = 0.89$, $p = 0.01$) of the cover crop residues. After this period, the mean fluxes were smaller and were closely related to the total soil N stocks ($r^2 = 0.96$, $p = 0.002$). The annual soil N_2O emission represented 0.39–0.75% of the total N added by the legume cover crops. Management-controlled soil variables such as mineral N (NO_3^- and NH_4^+) and dissolved organic C influenced more the N_2O fluxes than environmental-related variables as water-filled pore space and air and soil temperature. Consequently, the synchronization between N mineralization and N uptake by plants seems to be the main challenge to reduce N_2O emissions while maintaining the environmental and agronomic services provided by legume cover crops in agricultural systems.

1. Introduction

Nitrous oxide (N_2O) is a major greenhouse gas (GHG). Although emissions of N_2O are numerically smaller than those for the other GHGs, they are a major contributor (about 15%) to the current increase in global warming (Isermann, 1994), mostly because the global warming potential (GWP) of N_2O is about 296 times higher than that from carbon dioxide (CO_2). Arable soils are responsible for about 57% of the annual N_2O emissions in the world (Mosier et al., 1998). In Brazil, agriculture contributes about 94% to the total N_2O emissions (EMBRAPA, 2006). According to estimations based on the emission factors currently assumed by the Intergovernmental Panel on Climate Change (IPCC), 478 Gg N_2O are annually emitted from arable soils in Brazil.

In Southern Brazil, approximately 43% of total N_2O emissions (107 Gg) come from agricultural soils and constitute the greatest single source of N_2O to the atmosphere (EMBRAPA, 2006). However, most GHG studies have been conducted in the North Amazonia region (Neill et al., 2005; Carmo et al., 2007), while only few studies have attempted to evaluate the influence of different soil management practices on N_2O emissions and to identify the main soil and environmental driving factors determining N_2O emissions in subtropical agricultural systems of Southern Brazil (Pavei, 2005; Giacomini et al., 2006; Jantalia et al., 2008). In Southern Brazil, 8 Mha are cultivated with annual crops and the use of cover crops-based cropping systems has substantially increased in the last years as a consequence of the adoption of conservation practices, mainly no-tillage (Mielniczuk et al., 2003).

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Often, short-term peaks in N_2O emissions have been observed after crop residues are returned to the soil (Baggs et al., 2000; Millar et al., 2004). The magnitude of the emissions, however, is dependent on the chemical composition (Millar and Baggs, 2004; Garcia-Ruiz and Baggs, 2007), and the quantity of plant residues added to the soil (Aulakh et al., 2001). The contents of N and lignin in the plant residues are important variables determining the N mineralization kinetics in the soil (Constantinides and Fownes, 1994) and thus can also affect soil N_2O emissions. Soil N_2O emissions tend to be greater when the added crop residues have a low C:N ratio (Huang et al., 2004), as well as a low lignin:N ratio (Millar and Baggs, 2004). In this context, the addition of legume cover crop residues—residues characterized by a high N concentration and a low C:N ratio—to the soil is expected to increase N_2O emission in comparison to emissions observed in grass-based cropping systems (Baggs et al., 2001). Garcia-Ruiz and Baggs (2007) have reported N_2O emissions up to three times higher in a soil with a legume residue input than in a non-amended soil. However, the magnitude of response to legume residue addition is expected to be dependent on environmental and soil conditions (Rochette et al., 2004). Namely soil N_2O emissions are affected by water content, soil temperature, and soil compaction (Ball et al., 1999) due to their impact on oxygen supply and substrate availability (labile organic C and mineral N) (Beauchamp, 1997). The complexity of interactions among these driving factors controlling soil N_2O emissions has been largely reported (Kaiser et al., 1998; Baggs et al., 2003). However, few studies have assessed these interactions under subtropical climatic conditions of Southern Brazil (Jantalia et al., 2008).

This study aimed to evaluate the long-term (>19 years) effect of no-till cover crop based rotations on the annual soil N_2O emissions from a subtropical Acrisol in Southern Brazil, as well as to identify environmental and soil factors controlling soil N_2O emissions in these systems.

2. Material and methods

2.1. Local climate and soil characteristics

Soil N_2O emissions were evaluated in two long-term field experiments (19 and 21 years) established at the Agronomic Experimental Station of the Federal University of Rio Grande do Sul, located in Eldorado do Sul county (30°06′S, 51°41′W; about 45 m altitude), in Rio Grande do Sul State, Southern Brazil. The local climate is subtropical humid (Cfa type according to Köppen classification), with a mean annual temperature of 19.4 °C and a mean annual rainfall of 1440 mm. The soil is classified as an Alumic Acrisol by the FAO classification system and as a Typic Paleudult by the USA classification system. Soil particle size distribution is 540 g sand kg^{-1} soil, 240 g silt kg^{-1} soil, and 220 g clay kg^{-1} soil, with the clay fraction dominated by kaolinite (720 g kg^{-1}) and iron oxides (109 g kg^{-1} of Fe_2O_3).

2.2. Long-term experiments

Two experiments were adjacently established in 1983 and 1985, both in a randomized block design and with three replicates. At that time, the soil showed visible signs of physical degradation (e.g. like rill erosion, low water infiltration, and compaction) caused by conventional ploughing and disking implemented for the previous two decades. The crop rotations (winter/summer crop) selected for this study were pigeon pea (*Cajanus cajan* L. Millsp) + maize (*Zea mays* L.) (P + M), lablab (*Dolichos lablab*) + - maize (L + M), and black oat (*Avena strigosa* Schreb) + vetch (*Vigna sativa* L.)/maize + cowpea (*Vigna unguiculata* L. Walp) (O + V/M + C) from the oldest experiment (21 years), and black oat/maize (O/M) and vetch/maize (V/M) from the 19-year-old experiment. Vetch is a subtropical legume, while pigeon pea, lablab, and cowpea are tropical legume species. All crop rotations have been managed under no-till and there was no N fertilizer applied since the establishment of the experiments.

After the management of winter and summer cover crops by glyphosate-based herbicide and roller-cutter in October 30, 2003, a 2 m × 2 m area was delimited in one plot of each treatment, where two aluminum-made bases for gas sampling were placed. Shoot residues of the cover crops were uniformly distributed across the surface of the soil, at amounts equivalent to 5 and 4 Mg ha^{-1} of dry matter (DM) for the single oat and vetch, respectively, and a mix of 4:2.5 Mg DM ha^{-1} (oat:vetch) for the O + V/M + C crop rotation (Table 1). For pigeon pea, cowpea and lablab, historical shoot biomass production of 12.6, 3.2 and 7.7 Mg DM ha^{-1}, respectively, were assumed. In the 2 m × 2 m area, spontaneous weeds were managed with glyphosate when necessary. In April 2005, after the maize grain harvest, shoot residues of maize were uniformly distributed across the soil surface in amounts equivalent to the DM input measured in each respective treatment (Table 1).

2.3. Air sampling and N_2O analysis

The sampling for soil N_2O emission analysis was performed for about a year, with weekly sampling in the post-management period that corresponded to the first 45 days after cover crop management (seven sampling events in this period). In the following period, sampling had intervals from 15 to 60 days (seven sampling events). The sampling schedule is shown in Fig. 1.

Air samples were manually taken from closed flux chambers (0.25 m diameter × 0.2 m height) per treatment composed of a PVC-cylinder with the top border hermetically closed. At the time of the gas measurements this chamber was fitted on to an aluminum base (0.0346 m^2) inserted 5 cm into the soil. The aluminum base was equipped at the top with a circular water channel (diameter of 0.21 and 0.28 m of inner and outer ring, respectively, and height of 0.05 m) to ensure a good seal between the base and the PVC chamber. The aluminum bases were only

Table 1
Dry matter (DM) and N content of plant biomass from winter and summer cover crops plus maize added annually to a subtropical Acrisol under no-till crop rotations in Southern Brazil.

Crop rotation[a]	Winter		Summer			
	Cover crops		Cover crops		Maize	
	DM (Mg ha^{-1})	N (kg ha^{-1})	DM (Mg ha^{-1})	N (kg ha^{-1})	DM (Mg ha^{-1})	N (kg ha^{-1})
O/M	5.0	61	–	–	6.2	37.3
V/M	4.0	115	–	–	8.4	29.8
O + V/M + C	6.5	121	3.2	76	8.5	34.7
P + M[b]	–	–	12.6	327	7.0	40.6
L + M[b]	–	–	7.7	128	8.0	39.5

[a] O, oat; V, vetch; C, cowpea; P, pigeon pea; L, lab-lab; M, maize.
[b] Dry matter and N and C additions estimated from historical data of the experiment.