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Soil nitrous oxide emissions as affected by long-term tillage, cropping systems and nitrogen fertilization in Southern Brazil

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ABSTRACT

Soil nitrous oxide (N_2O) emissions are affected by management practices, but little information is available on the interactive effects of tillage, cropping systems and N sources in tropical and subtropical soils. In an 18-yr old experiment located in a subtropical Acrisol of Southern Brazil we conducted a sequence of two trials. The 1-year trial (October 2003–2004) was set to evaluate the long-term effects of tillage [CT: conventional; and NT: no-tillage] and cropping systems [O/M: black oat (Avena strigosa Schreb.)/maize (*Zea mays* L.); and V/M: vetch (*Vicia sativa* L.)/maize] on soil N_2O emissions, either in the post-management period (45 days after desiccation and knife-rolling of winter cover crops) or in the whole year. The second and short-term trial (October–November 2004) was carried out to compare the impact of N sources [urea (mineral) and legume-residue of vetch (biologically fixed), both at 180 kg N ha^{-1}] on soil N_2O emissions during 53 days after cover-crop management. Air sampling was carried out by static chambers and N_2O analysis by gas chromatography. In the 45-day post-management period of the 1-year trial, soil N_2O emissions were practically not affected by tillage systems, but increased 4 times due to vetch residues (average of 0.40 ± 0.08 kg N ha^{-1} in V/M versus 0.10 ± 0.05 kg N ha^{-1} in O/M) and related with soil contents of NO_3^--N, NH_4^+-N, and dissolved organic C (DOC). Over the whole year, soil N_2O emissions under CT were similar for grass- and legume-based cropping systems and averaged 0.43 ± 0.17 kg N ha^{-1}, while NT exacerbated N_2O emissions in the legume-based cropping system (0.80 ± 0.07 kg N ha^{-1} in V/M versus -0.07 ± 0.06 kg N ha^{-1} in O/M). Maize yield was not affected by tillage, but increased from 2.32 Mg ha^{-1} in O/M to 4.44 Mg ha^{-1} in V/M. Yield-scaled N_2O emissions varied from −33 g N_2O-N Mg^{-1} grain in NT O/M to 179 g N_2O-N Mg^{-1} grain in NT V/M, and were intermediate in CT soil (106 and 156 g N_2O-N Mg^{-1}grain in V/M and O/M cropping systems, respectively). In the short-term trial, the N_2O emitted in excess relative to the control treatment (O/M without N fertilizer) was at least 3 times greater with urea-N (0.44% of applied N) than with legume-residue-Nsource (0.13% of applied N). Yield-scaled N_2O emission after vetch residues management (67 g N Mg^{-1} grain) was half of that after urea-N application (152 g N Mg^{-1} grain). Partially supplying the maize N requirements with winter legume cover-crops may be a feasible strategy to mitigate soil N_2O emissions in the subtropical conservation agriculture.

1. Introduction

Agriculture contributes up to 80% and 96% of anthropogenic nitrous oxide (N_2O) emissions at global scale (Smith et al., 2008) and in Brazil (Brasil, 2010), respectively. In Southern Brazil, crop residue decomposition and fertilizer-N application makes the agriculture (43% of total N_2O emissions) the greatest individual source of N_2O (Brasil, 2006). Nevertheless, few studies have so far identified feasible alternatives to N_2O mitigation in subtropical

Abbreviations: NT, no-tillage; CT, conventional tillage; O, oat; V, vetch; M, maize; DOC, dissolved organic C; WFPS, water filled porosity space.

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croplands of Southern Brazil (Giacomini et al., 2006; Jantalia et al., 2008; Gomes et al., 2009), despite the region accounting for more than 40% of the Brazilian grain production (Conab, 2011).

The major soil processes related to N_2O production are nitrification and denitrification, which are controlled mainly by substrate (NH_4^+, NO_3^- and labile carbon) and O_2 availability (Lee et al., 2006; Beheydt et al., 2008). Tillage systems, cropping systems and N fertilization affect all these soil variables and thus can deeply affect soil N_2O emissions (Rochette et al., 2004; Jantalia et al., 2008; Jarecki et al., 2009; Frimpong and Baggs, 2010; Hoben et al., 2011).

Legume-based cropping systems (Bavin et al., 2009; Jarecki et al., 2009; Gomes et al., 2009) and mineral N fertilization (Hoben et al., 2011; Serrano-Silva et al., 2014) usually increase soil N_2O emissions due NO_3^- and NH_4^+ increments, but few studies compared the impact of biologically-fixed N against mineral N on N_2O emissions (Delgado et al., 2010; Frimpong and Baggs, 2010). As a reference value, in average 0.9–1.0% of the applied N as mineral or organic source is emitted as N_2O in agricultural soils (IPCC, 2006; Stehfest and Bouwman, 2006).

Tillage systems affect both substrate and O_2 availability, and their effects on N_2O emissions may be separated into short- and long-term effects (Six et al., 2004; Oorts et al., 2007). In the short-term, plowing and disking accelerate N mineralization because incorporates crop residues into the plow layer, while in no-tilled soil residues are kept on surface and decompose at lower rates (Giacomini et al., 2007). Residues of narrow C:N ratio rapidly increase NH_4^+ and NO_3^- contents in soil, and boost short-lived N_2O fluxes in tilled than in no-tilled soils (Jantalia et al., 2008; Dick et al., 2008; Almaraz et al., 2009). In contrast, higher soil N_2O emissions during the short-period after adopting no-tillage has been attributed to soil compaction (Six et al., 2004; Tan et al., 2009; Regina and Alakukku, 2010), higher water content (Baggs et al., 2003), lower O_2 diffusion, as well as to anoxic conditions resulting from high O_2 consumption in biological oxidation of labile C added on soil surface (Baggs et al., 2006; Liu et al., 2007). Increases of N_2O emissions after no-tillage adoption depend on soil characteristics and were observed mainly in clayey (Tan et al., 2009; Mutegi et al., 2010) and poorly-drained soils (Rochette, 2008; MacDonald et al., 2011).

In the long-term, the effect of tillage systems on soil N_2O emissions is possibly related to alterations in physical, chemical and biological characteristics of soils (Robertson et al., 2000; Six et al., 2004; Mosier et al., 2006). However, few studies have addressed the long-term effects of tillage on N_2O emissions in tropical and subtropical soils. Analyzing data from short- and long-term experiments in temperate soils, Six et al. (2004) projected smaller N_2O emissions in long-term no-tillage soils because improved soil aggregation and aeration status. In contrast, in modeled scenarios, the Daycent ecosystem model predicts that N_2O fluxes rise in no-tillage soils over time, because of increase of soil N availability in comparison to conventional tillage (Del Grosso et al., 2002). Thus, there is no consensus on the effect of tillage systems on soil N_2O emissions in long-term, and probably this effect may be variable among different soils and/or climates.

The N_2O emissions are usually accounted as mass per unit of area (m^{-2} or ha^{-1}), or as a percentage of the fertilizer application rates. However, emissions have been recently accounted per unit of crop yield (van Groenigen et al., 2010; Halvorson et al., 2010). Yield-scaled N_2O emissions are more appropriate to evaluate soil management systems, for it considers the efficiency in food, fiber or energy production (Reijnders and Huijbregts, 2011; Venterea et al., 2011). Few studies have quantified crop yield and N_2O emissions simultaneously, and most of them focused on mineral N sources evaluation, so that practically no data are available over the impact of legume or other organic N sources.

We hypothesized that the impact of soil management practices on soil N_2O emissions are mainly related to the influence on C and N cycling in soil, so that (i) lower N_2O emissions possibly occurs under no-tillage and (ii) despite the effect of N input by legume cover-crops at increasing N_2O emissions, yield-scaled emissions are lower for biologically-fixed N than for mineral N fertilizers. This study aimed to evaluate the long-term effects (18 years) of tillage, cropping systems and N fertilization on N_2O emissions from a subtropical Acrisol in Southern Brazil. We used simultaneous measurements of C and N cycling parameters, water content and temperature of soil to examine their role in controlling soil N_2O emissions.

2. Material and methods

2.1. Local climate and soil characteristics

The study was carried out in a long-term field experiment at the agronomic experimental station of the Federal University of Rio Grande do Sul near Eldorado do Sul Rio Grande do Sul State, Southern Brazil (30°06′S; 51°4′W, about 45 m altitude). The local climate is subtropical humid (Cfa type, according to Köppen classification), with annual mean temperature of 19.4 °C, mean monthly temperature varying from about 9 °C in the winter to 25 °C in the summer, and annual mean rainfall of 1440 mm. The soil was classified as an Alumic Acrisol by FAO Legend (IUSS, 2006) or Typic Paleudult by USDA soil taxonomy (USDA-NRS, 2010). The soil-particle size distribution was 540 g kg^{-1} sand, 240 g kg^{-1} silt, and 220 g kg^{-1} clay, with the clay fraction composed mainly of kaolinite (720 g kg^{-1}) and iron oxides (109 g kg^{-1} of Fe_2O_3).

2.2. Experimental area

The experiment, established in 1985, follows a randomized block design and it is comprised of three tillage systems (CT-conventional, reduced, and NT-no-tillage), three cropping systems [O/M-black oat (*Avena strigosa* Schreb.)/maize (*Z. mays* L.), V/M-vetch (*Vicia sativa* L.)/maize, and oat + vetch/maize + cowpea (*Vigna unguiculata* L.)], and two mineral N fertilization rates (0 and 180 kg ha^{-1}), with three field replicates (Zanatta et al., 2007). Black oat, vetch and cowpea were used as cover crops. When the experiment was initiated, the soil showed visible signs of physical degradation caused by conventional tillage that had been adopted previously, for almost two decades (Bayer et al., 2000; Zanatta et al., 2007).

We conducted two field trails. In the first, called the 1-year trial, we measured N_2O emissions during 344 days in the 2003/04 crop season (October 2003–2004) to evaluate the combined effect of tillage systems (CT and NT) and cropping systems (O/M and V/M), in plots which never received mineral N fertilizer. The soil of CT plots was plowed to 17–cm depth with a three-disk plow and then harrowed twice (10-cm depth) with a disk harrow. Tillage was carried out once a year, in spring, and in case of the current study-year, that happened four days before maize was sown. In NT plots, winter cover-crops were managed with glyphosate-based herbicide and knife-roller (October 30).

In the second trial, called the short-term trial, we measured N_2O emissions during 53 days in the 2004/05 crop season (October–November 2004) to evaluate the effect of two N sources: broadcasted urea-N (mineral) and legume-residue-N (biologically fixed). This trail was set only in NT plots, after winter cover-crop management (October 22) and one week before maize was sown. Three treatments were employed: (i) control, without N addition, in O/M plot; (ii) urea-N, with 180 kg N ha^{-1} applied when maize was at the V4 (60 kg N ha^{-1}) and V7 (120 kg N ha^{-1}) stages, in O/M plot; and (iii) legume-residue-N, with vetch (legume) biomass