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Nitrous oxide emission after the addition of organic residues on soil surface

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ABSTRACT

The addition of organic amendments with a low Carbon:Nitrogen (C:N) ratio to restore degraded soils may increase the emission of greenhouse gases and affect the storage of these elements in the topsoil. Our objectives were to evaluate the effect of the addition to the surface of organic amendments to a non-tilled and non-cultivated soil, compared with the addition of cover crop residues, with respect to: (i) N_2O emissions and their relationships with soil variables, (ii) C and N content in the topsoil. We conducted an experiment during two consecutive years in Paraná, Argentina (−31° 50.9′ S; −60°32.3′ W). Treatments included the addition of organic amendments (composted poultry litter and poultry manure) and cover crops residues [wheat (*Triticum aestivum* L.) and white sweet clover (*Melilotus albus* Medik.)]. Soil variables that are most commonly reported as critical for N_2O emissions, i.e. soil nitrates ($N\text{-}NO_3$) and water filled pore space (WFPS), showed more differences among treatments in Year 1 than in Year 2, which was associated with a higher frequency and amount of rainfall. N_2O flux ranged between 0.12–50 $\mu g\ N\ m^{-2} d^{-1}$ (Year 1) and 0.62-13.7 $\mu g\ N\ m^{-2} d^{-1}$ (Year 2). N_2O flux was significantly associated with WFPS in both Years ($P < 0.004$ in Year 1 and $P < 0.002$ in Year 2) and with $N\text{-}NO_3$ ($P < 0.045$) in Year 2. Although the N_2O emissions were extremely low, the highest values were recorded in poultry manure treatment, whereas, the lower values were recorded in crop residues and in the control treatment. Overall, our results suggest that the addition of organic amendments in our region, with a massive adoption of no-till, that were broadcasted before (i.e. 30–45 days) the sowing of summer crops, are associated with low N_2O emissions and potential improvements in soil quality. In addition, the experimental approach allowed us to more clearly identify the drivers of N_2O emissions and to better understand the soil processes that are involved in this particular situation, without the presence of a living vegetal cover.

1. Introduction

Increasing global demand for food, fibre and biofuels (Godfray and Garnett, 2014; Godfray et al., 2010; Popp et al., 2014) has led to an important change in the use of agricultural lands, which may affect soil quality, thus reducing their productivity and their ability to provide key ecosystems services (FAO, 2011; Popp et al., 2014). As a consequence, there is a growing need to develop agricultural systems having a more efficient use of resources and a lower impact on soil health and environment. Future agricultural systems should be able to maintain or even increase productivity while protecting biological diversity and reducing greenhouse gas (GHG) emissions (Tilman et al., 2011).

However, that desirable goal is far from being reached in most South American agroecosystems, in which the land use change has been characterised by a trend toward soybean monoculture (Wingeyer et al., 2015), with dramatic consequences in terms of soil degradation. In fact, an important decrease in soil carbon (C) stocks has been documented when the cropping systems largely rely on soybean as the sole crop of the year (Novelli et al., 2017, 2011; Studdert and Echeverria, 2000). Soil degradation in these agroecosystems has been associated with the action of intense erosion processes (Viglizzo et al., 2011; Wingeyer et al., 2015). These erosion processes are related with the low amount of crop residues remaining on the soil surface which are inherent in simple rotations (i.e. soybean monoculture) in comparison with more complex rotations (Novelli et al., 2017).

The most important functions of soils for environmental health are associated with the content of soil organic carbon (SOC) (Lal, 2005, 2004; Six et al., 2004). Degraded soils, which have lost an important amount of SOC, usually have reduced intrinsic capability to provide essential ecosystem services such as nutrient cycling, chemical detoxification (Kirk et al., 2004) and water filtration. Therefore, soil restoration appears as a critical issue in order to achieve more productive and sustainable agroecosystems. The addition of crop residues or organic amendments (Lal, 2010) may have an important impact on

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restoring some of the lost ecosystems services in degraded soils.

Soil restoration using organic amendments has been successful, not only to increase the SOC stock, but it has also favoured the improvement of other physical, chemical and biological properties of soil (e.g. Ros et al., 2003; Tejada et al., 2006) however these studies have been carried out by mixing the amendment with the soil using tillage operations. These practices are not compatible with the wide use of the no-till system in South America, having the main premise of maintaining a crop residue mulch on soil surface (Alvarez et al., 2011). Although the effects of no-till on crop production and soil health have been widely reported (e.g. Díaz-Zorita et al., 2002; Fabrizzi et al., 2005; Fernández Canigia et al., 2000), a considerable time-period is required before these effects become evident (Lal, 2010).

The impact of the addition of organic amendments on surface, with respect to the potential for environmental pollution, has led to growing concerns in areas where residues of intensive poultry farms are frequently added to soil. Although the composting of poultry litter and manure may reduce their pollutant load (Tyson and Cabrera, 1993), the impact of these composted amendments on the emission of GHG remains unknown when the residues are broadcasted on the soil surface. Moreover, since the high mineral N availability as N-NO_3, the low tension of atmospheric Oxygen (O_2) and the temperature are the main driver factors of nitrous oxide (N_2O) emission (Beauchamp, 1997; Alvarez et al., 2012; Cosentino et al., 2013), no-till systems may be more prone to high emission than conventional tillage systems, due to higher water infiltration and lower soil evaporation which reduce soil aeration (Fabrizzi et al., 2005; Rochette, 2008).

Reports on the impact of tillage systems on N_2O emissions are, however, contradictory. For instance, Liu et al. (2007) have reported higher fluxes of N_2O in no-till than in conventional tillage, whereas the opposite was reported by Perdomo et al. (2009). Others researchers have found no differences in the flux of N_2O emissions between tillage systems (Metay et al., 2007; van Kessel et al., 2013).

The quantification of the N_2O emissions associated to a soil restoration practice, such as organic amendment addition, is a key issue for the design of sustainable agricultural systems, due to the increasing need to reduce N_2O emissions from agriculture (Henault et al., 2012). Likewise, reduction of N emission from soil may increase the N-use efficiency of the agroecosystems, which is another benchmark to improve the whole system efficiency and sustainability. In our region, with a massive adoption of no-till, organic residues on surface are broadcasted far ahead, usually 30–45 days, before sowing of the next crop. However, most studies on N_2O emissions have been carried out in the presence of a living vegetal cover, which could affect N_2O emissions, due to changes in the soil environment (mainly N and C substrate availability) that are promoted by plant water and N uptake. Thus, an experimental approach without living vegetal cover may allow more clear identification of the drivers of N_2O emissions and to better understand the soil processes that are involved.

Our objectives were to evaluate the impact of the addition of organic amendments and vegetal residues to the soil surface, with no vegetal living cover on it: (i) N_2O emissions and its relationships with soil moisture and inorganic N, (ii) soil C and N content in topsoil after two consecutive years of addition.

2. Materials and methods

2.1. Experiments

We conducted an experiment during two consecutive years, from September 2014 to January 2015 (Year 1, encompassing 157 days) and from October 2015 to January 2016 (Year 2, encompassing 97 days), in a field of the experimental station of INTA Paraná (−31° 50.9′ S; −60° 32.3′ W), Entre Rios province (Argentina). The soil was classified as an Aquic Argiudoll (Plan Mapa de Suelos, 1998; Soil Survey Staff, 2010) under no-till since 1998.

The treatments included the addition of different residues on soil surface: two cover crop residues and two organic amendments. Crops residues were wheat (*Triticum aestivum* L.) and white sweet clover (*Melilotus albus* Medik) from cover crops cultivated elsewhere whereas organic amendments were composted poultry litter and poultry manure. A control treatment without residue addition was also included. The area of each plot was 2 m^2. We used a randomised complete block design with four replicates.

The experiment was kept free of crops and weeds over the two-year period because no crops were planted and weeds were removed using manual and chemical control methods. The location of the plot was the same over the two-year period, i.e. the treatments were consecutively replicated on the same plot.

The organic amendments were previously composted in order to reduce their pollutant load whereas crop residues were cut, oven-dried and stored until addition. Organic amendments were composted until their stabilization, according to the method proposed by Petric and Mustafić (2015), i.e. using an air flow rate of 0.43 l min kg^{-1} and mean air temperature of 28 °C for poultry litter and poultry manure. The residues were added on 24 September 2014 (Year 1) and on 1 October 2015 (Year 2).

2.2. Residues characterization

Total nitrogen (N) and total carbon of the residues were determined by dry combustion using a LECO TRU SPEC autoanalyzer (Leco Corp., St. Joseph, MI, USA) (Table 1). The rate of residue addition was 5 t C ha^{-1}, therefore the total amount of dry matter of the added residues ranged from 12 to 12.5 t ha^{-1} for crops residues, from 20.2 to 20.8 t ha^{-1} for poultry manure, whereas the amount of added poultry litter was 10.7 t ha^{-1} in both years.

2.3. Measurements

Periodically, between 09 and 12 a.m. (Cosentino et al., 2012), we measured the emission of N_2O using the static chamber methodology (Conen and Smith, 1998). The chambers were designed according to the minimum established requirements for the protocol as proposed by Parkin et al. (2003). The chambers, with an area of 0.04 m^2, were carefully installed until they reached 0.05 m soil depth after residue addition. Air samples from the chamber were taken at time 0 for the starting values of the atmospheric concentration of N_2O and after 20 and 40 min following chamber closure. Samples were stored in vials until analysis in a cool, dry place.

The concentration of N_2O in the air samples was determined by gas chromatography using a gas chromatograph GC 7890 A with autosampler 7697 A (Agilent Network GC System, AECD, Santa Clara, CA, USA).

Coinciding with each air sampling date, soil samples were collected at 0.05 m depth in order to evaluate soil moisture and N-NO_3 concentration. Three or four samples were taken from the area surrounding the chamber, and mixed to form one composite sample per plot. Soil moisture was determined using the gravimetric method, i.e. weighing the sample immediately after sampling and after 48 h of being oven-

Table 1
Nitrogen concentration (N), carbon concentration (C) and the C:N ratio of the added residues.

	N (%)		C (%)		C:N ratio	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Poultry manure	2.2	2.2	24.8	24.0	10.8	11.3
Poultry litter	2.5	2.5	47.0	47.0	18.8	18.8
White sweet clover	1.7	3.3	39.2	42.2	22.6	12.8
Wheat	1.0	1.5	42.7	40.2	42.7	27.0