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RESEARCH ARTICLE

Sugarcane Crop Residue Increases N_2O and CO_2 Emissions Under High Soil Moisture Conditions

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Abstract Sugarcane crop residues from green cane harvests may affect the greenhouse gas fluxes from the soils. Therefore, it is important to understand how changes in soil moisture covered with cane trash alter the N_2O and CO_2 emission. The aim of this study was to evaluate N_2O and CO_2 emission from repacked soil columns incubated with (16 Mg ha^{-1}) or without crop residues and N fertilizer (0 or 2.1 g N m^{-2}), and as a function of four soil moisture levels (25, 50, 75 and 100 % of water holding capacity). For gas samplings, the columns were closed with a lid and four gas samples were taken in 20 min. The N_2O fluxes increased linearly ($p < 0.01$) with increasing soil moisture regardless of the residue application on soil. However in the columns with trash the moisture effect, on N_2O emission rates, was two-fold greater. Every 10 % increase in moisture in relation to the holding capacity resulted in losses equivalent to 790 and 1,640 µg N m^{-2} for the 0 and 16 Mg ha^{-1} crop residue rates, respectively. In conditions of low moisture (25 and 50 %), the crop residue did not increase emissions compared to the bare soil. The CO_2 emission also was linearly stimulated with increasing soil moisture, regardless of crop residue application. However, the CO_2 emission rate was higher with the residue. Our study indicates that the effects of crop residue on greenhouse gas emissions are exacerbated in periods with high soil moisture.

Keywords Greenhouse gases · Methane · Soil respiration · N application · Soil columns

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Introduction

Soils are major sources of the greenhouse gases (GHG) carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) to the atmosphere triggering the global warming. These greenhouse gases differ in their ability to trap heat and in the time they reside in the atmosphere (IPCC 2007), presenting different global warming potentials. Furthermore, N_2O indirectly contributes to ozone layer depletion (Crutzen 1981).

Many factors affect the exchange of GHG between soil and atmosphere such as land use, temperature and precipitation, N input, residue amendment and soil properties (Aulakh et al. 2001; Schaufler et al. 2010). Among the drivers of gas exchange, the soil moisture has great impact on emission and gases uptake through its effect on microbiota activity (Smith et al. 2003). The water content is

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important for the substrate supply for soil microorganisms (Schindbacher et al. 2004; Meixner and Yang 2006) and also influences gas diffusivity (Smith et al. 2003). Usually in dry and well-aerated soils CH_4 and N_2O emissions are low; the latter is produced essentially through the nitrification (Russow et al. 2000). Increasing water saturation increases anaerobic microsites and promotes N_2O emission by denitrification. Some studies have reported maximum N_2O emission between 60 and 80 % of water filled pore space—WFPS (Denmead et al. 2010). On the other hand, Schaufler et al. (2010) postulated that for some soils highest N_2O emissions might be verified under wetter conditions, up to 95 %. For many soils 60 % WFPS means approximately field capacity (Schaufler et al. 2010). The condition of water saturation after a rain seems to be short or absent in the weathered Brazilian Oxisols, which may lead to low N_2O emissions (Jantália et al. 2008). Sposito (1989) stated that the reduction of soil redox potential until optimum levels to begin the denitrification and N_2O emission might take hours with the soil moisture near saturation. Several studies performed in-field have shown low or no agreement between soil moisture and the GHG fluxes, mainly for N_2O and CH_4 (Schindbacher et al. 2004), which hampers the understanding of this driver on GHG fluxes under non controlled conditions.

Another relevant driver of GHG emissions is the application of organic residues—sources of labile C for soil microorganisms. The rapid microbial biomass developing may promote anoxia, condition which favours the growth of microbes responsible for N_2O and CH_4 emission. With the increasing adoption in Brazil of sugarcane mechanized harvest, large amounts of trash crop ranging from 8 to 22 t dry matter/ha (Vitti et al. 2008; Thorburn et al. 2012) are kept on cane fields. Compared to cane burning, there are GHG and air quality benefits of keeping trash on soil surface and to use mechanical harvest (Figueiredo et al. 2011), but trash can also increases N_2O emission (Carmo et al. 2012). The interactions among soil moisture, soil mulch and N and C availability are complex. It has been very difficult to establish strong predictive relationships between daily fluxes and field-scale parameters such as soil moisture and soil N inorganic concentrations. In-field trials, such as those of Carmo et al. (2012) do not allow to distinguish what is the trash or soil moisture effect on increasing of N_2O fluxes because the trash cane also preserves higher soil moisture than bare soil. Therefore, laboratory studies can be of assistance.

Our goal was to evaluate the impact of cane trash under four soil moisture levels and two rates of N on GHG emissions (CO_2, CH_4 and N_2O) from packed soil columns for 60 days after a pre-incubation period.

Materials and Methods

Site Description, Soil and Trash Preparation

The trial was carried out at Agronomic Institute (IAC), Campinas, Brazil, between May and November, 2011. Soil material used in the investigation was gathered from a sugarcane field in Piracicaba, SP. Sugarcane has been grown in this area since 2000. The soil was a Clayey Eutrodox (Soil Survey Staff 2003) and had not been limed for at least 3 years. Samples were collected from the 0–20 cm layer, air dried and sieved (2 mm). Selected soil chemical and physical properties are displayed in Table 1. Maximum water holding capacity (WHC) of sieved soil was 0.41 g/g. Cane trash was gathered in the same field. In order to avoid trash with different stages of decomposition, we collected senesced sugarcane leaves (variety SP 81-3250), which were dried and had particle size standardised between 2 and 5 cm. Total trash dry matter nutrient composition was: 450.0, 2.0, 1.5, 0.2, 3.9 and 1.3 g/kg for C, N, K, P, Ca and Mg, respectively.

Experimental Set-up, Treatments and Gas Analysis

The experimental design was a triple factorial trial in a completely randomised design with three replicates. The factorial design included two trash levels (0 and 16 t/ha DM), four soil moisture treatments (equivalent to 25, 50, 75 and 100 % of maximum WHC) and two levels of mineral N (control—without N, and a dose equivalent to 21 kg N/ha—8.3 mg N/kg soil) as analytical grade ammonium sulfate. The low N rate was chosen to emphasize the trash and soil moisture effects.

Table 1 General soil properties of incubated soil before treatments application

Clay g/kg	Sand	C[δ]	N[δ]	pH[δδ] –	P mg/dm^3	K mmolc/dm^3	Ca	Mg	CEC[£]	BS[££] %
658.0	219.0	16.8	1.0	5.2	16.0	2.5	27.0	9.0	72.4	53.0

[δ] Determined with elemental analyserVario EL

[δδ] 0.01 mol/L $CaCl_2$ solution ratio 1:2.5

[£] Cation exchange capacity

[££] Base saturation percentage

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