Influence of stubble quality and degree of soil-stubble contact on N_2O emission

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ABSTRACT

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The organic residue position and C/N ratio regulate decomposition rate and, therefore, nitrogen (N) release to the soil. The N_2O emission from soil is produced by nitrification and denitrification processes. These processes are affected by the mineral N concentration, water filled pore space (WFPS) and soil temperature. The N_2O emission from soils covered by corn and soybean residues has been little studied so far. The aim of the present study was to evaluate the C/N ratio of corn and soybean residues and their contact degree with the soil on soil N_2O emissions. A greenhouse experiment was conducted with a completely randomized design and N_2O emission was determined using closed chambers. The N_2O emissions were affected by the residue position and not by its origin (soybean = corn). Treatments with residue on the surface had the highest N_2O emissions at the beginning of the trial, while residue incorporation showed constant values of N_2O emission during the experiment. Soil N_2O emissions were explained by two controlling variables: the WFPS and the $N\text{-}NO_3^-$ soil concentration. The WFPS separated the emission values of N_2O into two groups (threshold value near 77% WFPS). When the WFPS exceeded the threshold value, the emissions of N_2O were partially explained by the concentration of $N\text{-}NO_3^-$ soil.

Keywords: greenhouse gas; soil matrix; crops

The decomposition rate of crop residues in a soil is controlled by the C/N ratio of the material, the contact between the soil matrix and the residues, and environmental factors, including temperature, water content and nutrient availability (Varela et al. 2014). Residues with less C/N ratio offer a less N-constrained environment for microorganism growth and reproduction than those with high C/N relation, as it decomposes and mineralizes faster (Gul and Whalen 2013).

Soil N_2O is generated by microbial nitrification and denitrification processes. These processes are regulated by N availability (mainly NO_3^-) and soil water content among other factors (Steenwerth and Belina 2008, Cosentino et al. 2013). Soil N availability depends on the decomposition rate of

the stubble. Therefore, soil-residue contact and stubble quality (C/N ratio) affect the dynamics (timing and magnitude) of N_2O emissions (Aulakh et al. 1991).

Stubble N_2O emission was studied in various crops (sugarcane, sorghum, cotton, rice and lettuce (Huang et al. 2004, Muhammad et al. 2010). Soybean and corn are the most important summer crops in the Argentine cropping region, so it was considered of great importance to study the effects of their residue decomposition on dynamic of N_2O soil emissions. The aim of the present study was to evaluate the effect of the C/N ratio of soybean and corn stubble and the degree of contact between crop residues and the soil matrix on soil N_2O emissions.

MATERIAL AND METHODS

A greenhouse experiment was conducted with a completely randomized design with factorial arrangement of three factors: factor A – sampling time (0, 10, 30, 90 and 150 days); factor B – stubble (corn stubble, soybean stubble, no stubble) and factor C – stubble position (incorporated in the soil and on the soil surface), each with four replicates. One-litre pots were filled with 1.1 kg top soil (0–20 cm) Typical Argiudol, O'Higgins Series. The surface texture of the soil is loamy, while the sub-surface is silty clay loam. Its main limitation is poor drainage (INTA 2017). The soil had an organic carbon content of 19.96 g/kg (standard error (SE) = 0.5), $N\text{-}NO_3^-$ content of 64.42 mg/kg (SE = 9.8) and a pH in water value of 5.69 (SE = 0.2).

Soil, together with the amount of stubble (stem, leaf and pod) representative of that found in the field were placed in each of the pots. For the maize stubble treatment, 8.04 g of stubble per pot was placed either on surface or incorporated. This stubble amount corresponded to 9000 kg/ha maize yield which represented the average yield reported in the sampled field. For the soybean stubble treatment, 5.8 g of stubble per pot was placed either on surface or incorporated, this amount corresponded to an average soybean yield of 3500 kg/ha as was reported previously in the field. Before stubble was placed into the pots, it was oven-dried at 60°C during 48 h, sieved (1 mm mesh), and finally homogenized.

N_2O was measured in 130 cm-high and 160 cm-diameter closed chambers. Pots were used as the base of the chamber, covered with a tightly sealed press-fitted plastic pot during sampling. Three samples per chamber were taken using a vacuum pump, 0, 20 and 40 min after sealing the chamber, and placed in 10 mL vials.

Within seven days of sampling, N_2O was measured in the laboratory with a GC 6890 Agilent Technologies Network gas chromatograph, fitted with a 63Ni electron capture detector (Agilent Network GC System, AECD, Santa Clara, USA) and a 30 m × 530 μm × 25 μm Molsieve HP-Plot column. The oven, injector and detector temperatures were 150, 100 and 300°C, respectively. The carrier gas was N_2 and the injection volume was 0.5 cm³. N_2O emission (*f*) was calculated as:

$$f = \frac{\Delta C}{\Delta t} \times \frac{V}{A} \times \frac{m}{V_m} \qquad (1)$$

Where: $\Delta C/\Delta t$ – change in N_2O concentration (ΔC) measured in parts per million (ppm) within the chamber during the incubation time (Δt) measured in minutes; V – volume of the chamber (0.998 dm³); A – area of soil covered by the camera (0.095 m²); m – N_2O molecular weight (44 g/mol); V_m – molar volume of N_2O (dm³/mol). The gas flow was calculated as the increase in concentration during the incubation period.

To evaluate the residue decomposition, at each sampling date, remaining undecomposed stubble in each pot was recovered and separated from the soil, making raisins water through a 0.5 mm sieve. The water acted as a soil dispersant separating it from stubble. The recovered residue was dried at 60°C for 48 h and weighed. Soil temperature at 10 cm depth and surface air temperature were measured in one pot at each sampling date. After N_2O sampling, soil samples were extracted from each pot and soil characteristics were determined in the laboratory. $N\text{-}NO_3^-$ concentration was determined colorimetrically (Keeney and Nelson 1982) and gravimetric water content (GWC) was determined by drying at 105°C to constant weight. At the finish of the experiment, a soil sample was taken inside each chamber to determine its bulk density (BD) by the cylinder method (100 cm³, 5 cm in diameter). Soil BD and particle density (assuming 2.65 g/cm³) were used to calculate the water filled pore space (%WFPS). Finally, C and N contents were determined by the dry combustion method using an automatic elemental analyzer (LECO CN Analyzer, St. Joseph, USA) for each of the crop residues, and the C/N ratio was calculated.

Data analysis was carried out using InfoStat software version 1.0, Group Infostat (Cordoba, Argentina).

RESULTS

Mean soil bulk density was 1.12 g/cm³ (SE = 0.03 g/cm³). Soybean stubble had a N and C concentration of 1.02% and 53.6%, respectively, with a C/N ratio of 52.46; while corn stubble had a N and C concentration of 0.52% and 55.7%, respectively, with a C/N ratio of 106.58. The WFPS values varied between 58% and 90% and the soil temperature ranged from 15°C to 26°C.

Maximum decomposition rates were recorded at the beginning of the experiment and then declined at different rates depending on the treatment,

affected mainly by the position of crop residues (on soil surface or incorporated in the soil matrix, Figure 1).

At the start of the experiment, treatments with both corn and soybean stubble on the surface showed high N_2O emission values, decreasing with time and a calculated relative area under the curve of 100% and 66.91%, respectively (Figure 2a,c). In treatments with incorporated corn or soybean residues, N_2O emission was moderate and constant throughout the experiment, with relative values of area under the curve of 55.44% and 54.79%, respectively (Figure 2b,d). In bare soil (without stubble) N_2O emission peaked at day 30 and the relative value of the area under the curve was very high (90.49%), showing the importance of N_2O emissions from bare soil (Figure 2e).

No relationship between soil $N-NO_3^-$ concentration and N_2O emission in any treatment and any of the sampling dates (days 10, 30, 60 and 150) was found (Figure 3a). However, N_2O emission was low when WFPS was lower than 77% and highly variable when WFPS exceeded 77% (Figure 3b). When WFPS > 77%, N_2O emission was analysed separately.

When WFPS exceeded 77% (Figure 4), treatments with stubble on the surface (both corn and soybean) showed a positive linear relationship between N_2O emission and $N-NO_3^-$ content (Figure 4a,c), with slopes that explained only 38% and 33% of N_2O emission variability for corn and soybean, respectively. The incorporated corn residue treatment could also be fitted into a linear function, with significantly lower slope but higher coefficient of determination (43%; Figure 4b). No relationships were found in the incorporated soybean residue and in the soil without stubble application (Figure 4d,e).

DISCUSSION

Mean BD of the soil in the pots was significantly lower than that of the field where the soil was obtained (1.12 (SE = 0.03) g/cm^3 vs. 1.4 (SE = 0.05) g/cm^3, respectively), possibly due to the fact that the soil in the pots had been sieved, causing particle loosening and an increase in total porosity (Materechera et al. 1994, Taboada et al. 2004).

During the experiment WFPS was > 58% and soil temperature >15°C. These soil conditions enabled a high decomposition rate throughout the experiment without limiting N_2O production (Keeney et al. 1979, Cosentino et al. 2013).

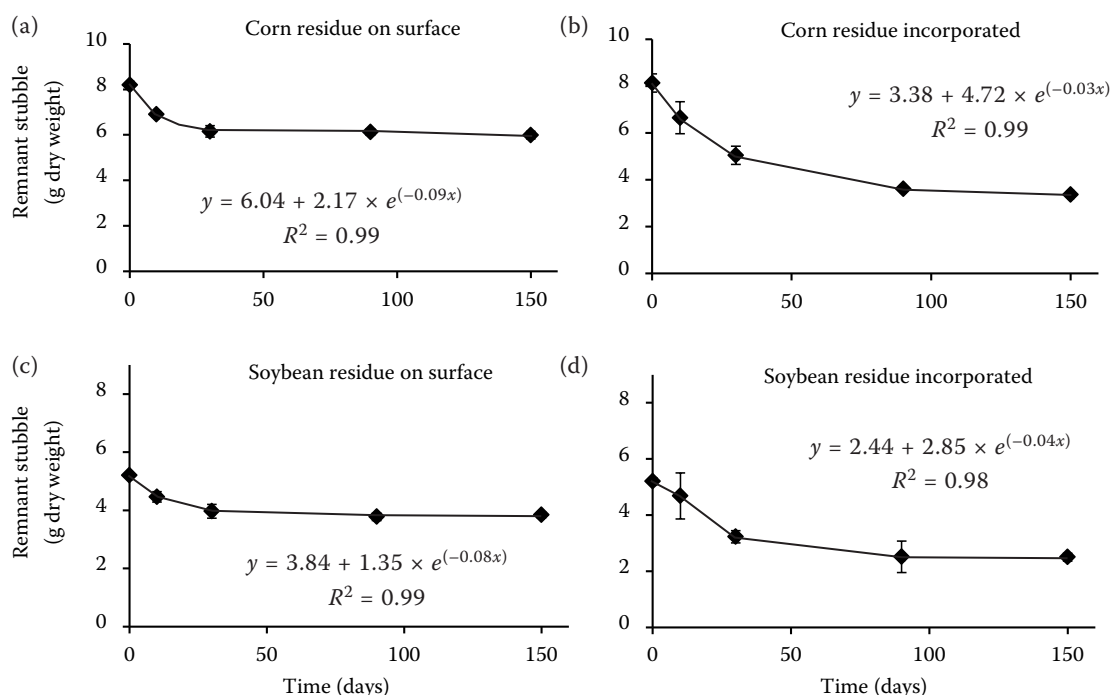Residue decomposition rate was lower when residues were on the soil surface than when they

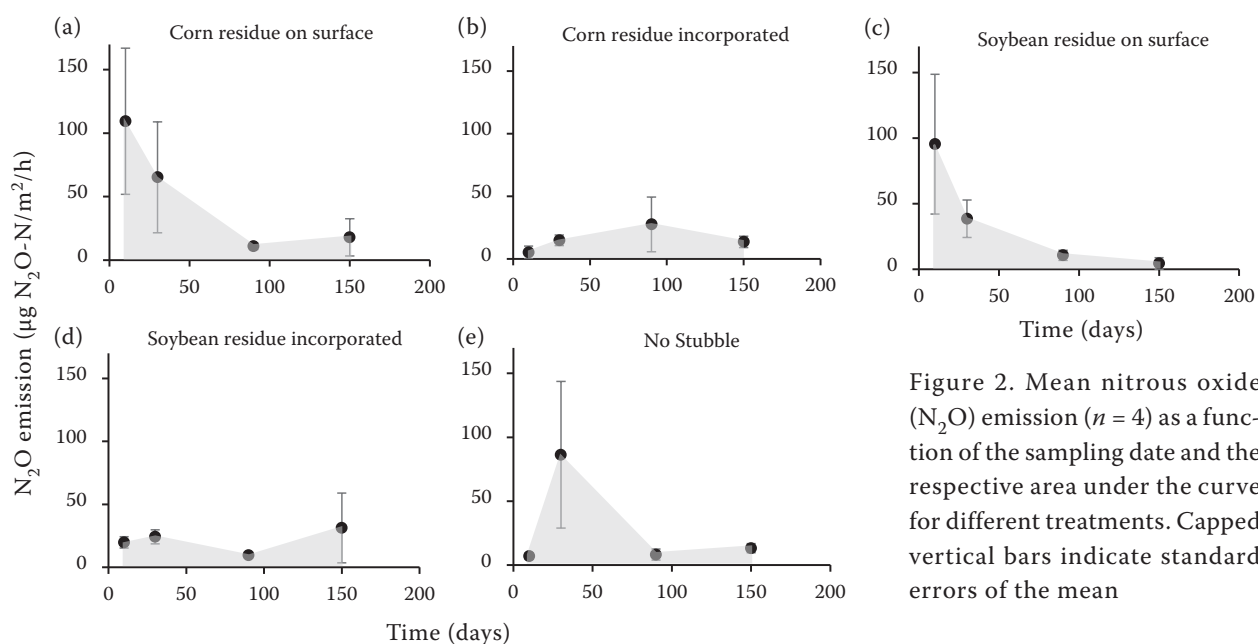Figure 1. Remaining stubble as a function of the sampling date. Capped vertical bars indicate standard errors of the mean

Figure 2. Mean nitrous oxide (N₂O) emission (*n* = 4) as a function of the sampling date and the respective area under the curve for different treatments. Capped vertical bars indicate standard errors of the mean

were incorporated in the soil for both soybean and corn residues. This was also shown by Lachnicht et al. (2004) and Khalil et al. (2005) in greenhouse experiments and in field experiments by Burgess et al. (2002). This higher decomposition rate was associated with the greater surface/volume ratio in the soil with incorporated residue which determined a closer contact between residue and soil microorganisms (Burgess et al. 2002).

Soil $N-NO_3^-$ availability did not appear to be linked to residue decomposition rates in any of the treatments (data not shown), possibly due to the high initial N immobilization by soil microorganisms. Indeed, it has been shown that when N concentration in residues is less than 2%, net N immobilization by soil microorganisms occurs

(Trinsoutrot et al. 2000). Similarly, N_2O emission dynamics did not follow nitrate availability, as it was affected mainly by residue position and not by its quality.

Rochette (2010) divides factors that regulate N_2O emission in two groups: proximal and distal. Proximal factors, among which is the residue C/N ratio, are those that directly affect soil N_2O emission; while distal factors, e.g. contact between soil and residue, act indirectly. In this context, one would expect a greater influence of stubble quality (a proximal factor) on N_2O emissions than residue position (a distal factor). However, our results contradict this as residue position was more important than residue quality. Cumulative N_2O emissions were higher in treatments with stub-
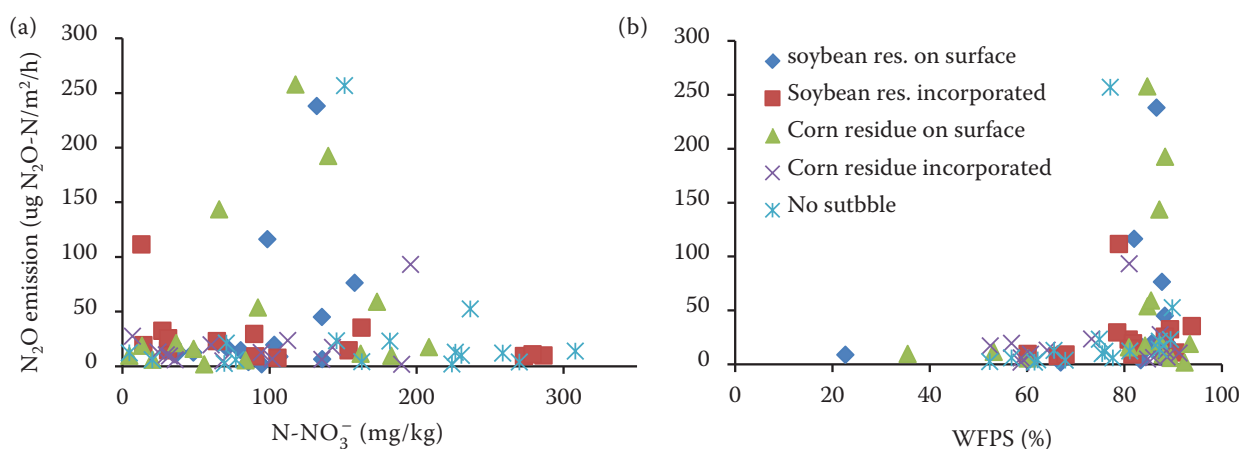

Figure 3. Nitrous oxide (N₂O) emission as a function of (a) the soil nitrogen concentration in the form of nitrate (N-NO₃⁻) and (b) water filled pore space (WFPS)
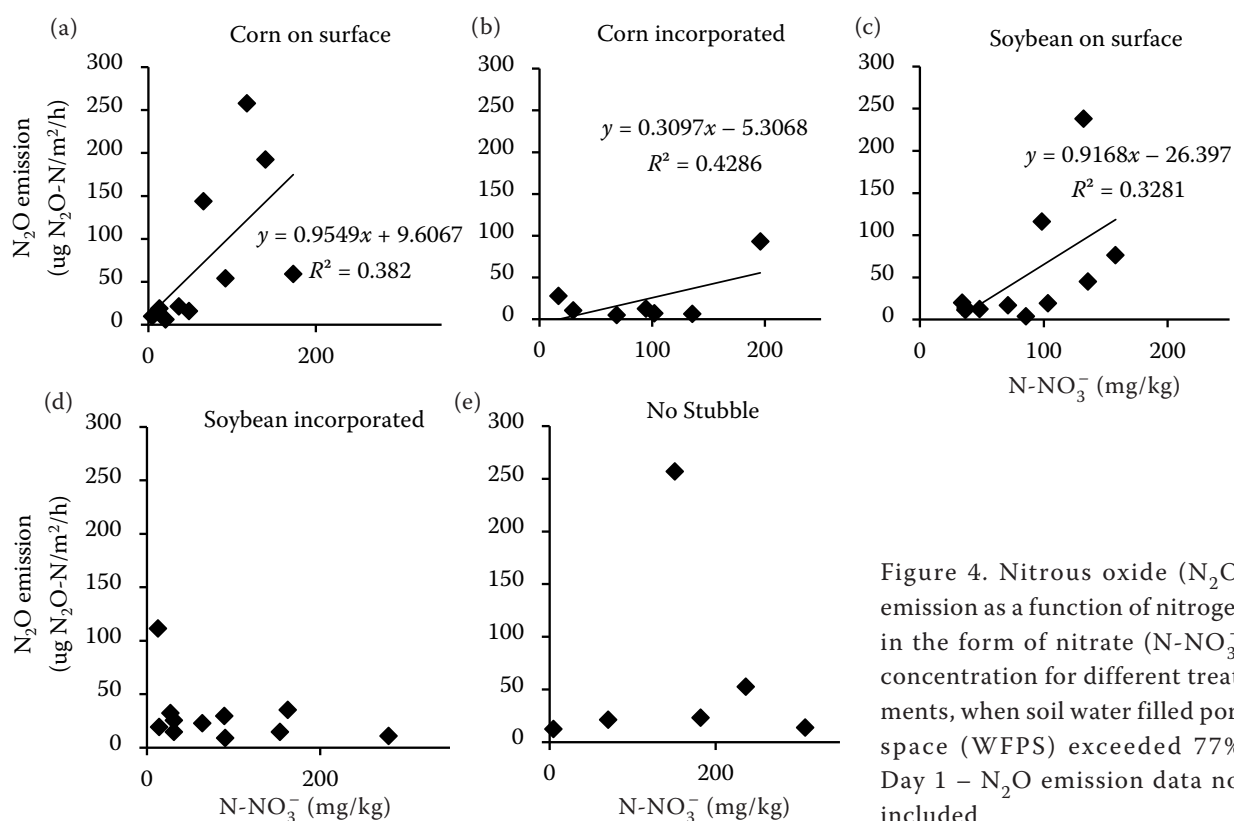
Figure 4. Nitrous oxide (N_2O) emission as a function of nitrogen in the form of nitrate ($N-NO_3^-$) concentration for different treatments, when soil water filled pore space (WFPS) exceeded 77%. Day 1 – N_2O emission data not included

ble on the surface than in those with the residue incorporated in the soil. These results differ from those obtained by other authors (Baggs et al. 2000, Khalil et al. 2005) who found that the application of residues with high C/N ratio stimulate microbial immobilization of N released during degradation, which reduces N_2O emission. On the contrary, the application of N-rich (low C/N ratio) crop residues can increase soil N_2O emission.

The threshold WFPS value indicates the percentage of WFPS at which the relative contribution of nitrification and denitrification processes that determine N_2O emissions changes (Linn and Doran 1982). In our study, this WFPS value was near to 77%, which separated low N_2O emission values from the highly variable ones (Figure 3b). This value was higher than that obtained in the field (58.5%, Cosentino et al. 2013) and higher than the ones given by other authors (Linn and Doran 1982, Alvarez et al. 2012). The higher threshold value of the pot soil can be attributed to soil sieving, which reduced the size of aggregates and the proportion found under permanent anaerobiosis conditions. Sexstone et al. (1985) did not find permanent anaerobic zones when aggregates had less than 4 mm diameter. Thus, in our experiment, soil had

to have a greater WFPS than that observed in the field (77% vs. 60%) for N_2O emissions to change from low and relatively constant (WFPS < 77%) to highly variable (WFPS > 77%).

The higher the soil moisture content, the greater the WFPS value and the higher the proportion of soil under anaerobiosis conditions as denitrification (anaerobic) prevails over nitrification (aerobic) resulting in higher N_2O emissions. Clayton et al. (1997) defined an WFPS value of 65% as the critical threshold at which N_2O emission increases significantly. In addition, Alvarez et al. (2012) determined in a Typic Haplustol, that the main factor determining N_2O emission was a WFPS threshold of 52%, indicating that different soils have different WFPS thresholds.

When WFPS exceeded 77%, the high variability of N_2O emissions (Figure 3b) was partly explained by $N-NO_3^-$ content in corn residue both on the surface and incorporated in the soil and soybean stubble on the surface (Figure 4). This coincides with results obtained in the field where $N-NO_3^-$ content was a third-ranking factor after soil temperature and WFPS percentage, controlling N_2O emissions (Cosentino et al. 2013), as was also observed in an Australian vertisol by Dalal et al. (2010).

Soil N$_2$O emission rate was affected by soil water filled pore space with a threshold value near to 77% that separated N$_2$O emissions in two groups. When the WFPS exceeded this threshold, N$_2$O emission was partially explained by the soil N-NO$_3^-$ concentration.

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