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NITROUS OXIDE EMISSIONS FROM A TYPICAL ARGIUDOL SOIL WITH ORGANIC AND CHEMICAL AMENDMENTS

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ABSTRACT

Diversification in fertilizer sources will be necessary to meet the growing demand for food worldwide. For this reason, organic amendments emerge as a synthetic fertilizers alternative. Composting organic waste stabilizes the nitrogen (N) content and delays N release to the soil. Applying composted amendments to the soil could reduce the losses of N, including nitrous oxide (N_2O), a greenhouse gas with great potential for global warming. The objective of this work was to evaluate the N_2O emission in typical Argiudol soil after applying a traditional synthetic fertilizer, raw poultry manure, composted poultry manure and control soil. Cumulative N_2O emission rates during the 32 days of the trial were 1273, 965, 423, and 244 g N_2O-N/ha^{-1} from the soil using urea, poultry manure, composted poultry manure, and control, respectively. Our results suggest that the application of composted poultry manure to the soil produces lower N_2O emissions than the application of raw poultry manure or urea. The presence of more stabilized compounds in the composted manure decreases the soil nitrate availability.

Keywords: amendment – greenhouse gases - organic fertilizer - nitrogen losses.

EMISIONES DE ÓXIDO NITROSO DESDE UN SUELO ARGIUDOL TÍPICO CON ENMIENDAS ORGÁNICAS Y QUÍMICAS

RESUMEN

El aumento de las fuentes de fertilización será necesario para satisfacer la creciente demanda de alimentos en todo el mundo. Por este motivo, las enmiendas orgánicas surgen como una alternativa a los fertilizantes sintéticos. El compostaje de residuos orgánicos estabiliza el contenido de nitrógeno (N) y retrasa la liberación de N al suelo. La aplicación de enmiendas compostadas al suelo podría reducir las pérdidas de N, incluido el óxido nitroso (N_2O), un gas de efecto invernadero con gran potencial de calentamiento global. El objetivo de este trabajo fue evaluar la emisión de N_2O desde un suelo Argiudol típico luego de aplicar un fertilizante sintético tradicional, guano de ave crudo y compostado y un suelo control. Las tasas emisión de N_2O acumuladas durante los 32 días que duro el ensayo fueron 1273, 965, 423 y 244 g de N_2O-N ha^{-1} desde el suelo con aplicación de urea, guano de ave, compost de guano de ave y control, respectivamente. Nuestros resultados sugieren que la aplicación de compost de guano al suelo produce menores emisiones de N_2O que la aplicación de guano de ave crudo o de urea. La presencia de compuestos más estabilizados en el compost de guano disminuye la disponibilidad de nitrato del suelo.

Palabras claves: enmienda - gases de efecto invernadero - fertilizantes orgánicos - pérdidas de nitrógeno.

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INTRODUCTION

Due to the increase in the average individual incomes and the population growth, projections for 2050 indicate the necessity to increase food production to supply worldwide demand. This food demand is expected to increase by 60% compared to 2005/2007 (Alexandratos, 2012; Godfray, 2018), and could affect the quality of soils, resulting in a decrease in productivity and the ability to provide ecosystem services (Popp et al., 2014).

World egg production increased by 25% from 2003 to 2013 (Rizzo et al., 2020), and part of the large amount of waste that it generates, is applied to the soil as fertilizer in agriculture (Quiroga et al., 2010). Poultry manure is a source of nutrients, mainly nitrogen (N), which could satisfy part of the nutritional requirements of crops (Gómez, 2000). However, although the direct application of raw organic waste to the soil, as fertilizer, can increase crop yield, this practice can promote nitrogen losses through volatilization of ammonia (NH_3), leaching of nitrate (NO_3^-), or by the emission of nitrous oxide (N_2O) (Mahmud et al., 2021). In this sense, increasing their N_2O emissions from croplands is expected due to the extensive use of nitrogen fertilizers and organic amendments associated with increased food production (Galloway et al., 2008). Therefore, it is essential to adjust the amount of waste required by the system, to minimize the environmental cost that N loss may cause. For this, it is necessary to develop fertilization strategies with low environmental impact.

The terrestrial biosphere can release or absorb greenhouse gases (GHG), and thus it has a vital role in regulating the atmospheric composition and climate (Tian et al., 2016). The N_2O is a GHG that has a half-life time in the atmosphere of 121 years (Intergovernmental Panel on Climate Change [IPCC], 2014) with a global warming potential of 265 times greater than CO^2 contributing around 6% to the global warming effect (Rapson & Dacres, 2014). Nitrification and denitrification are the main microbial processes that produce N_2O in the soil, with the N_2O emission produced by the nitrification process (aerobic) being lower than that produced by the denitrification process (anaerobic; Davidson 1991). Both processes are affected by the availability of N, temperature and water content, between other factors (Steenwerth & Belina, 2008). Globally, cropland area is around 13% of the ice-free land area and produces about 40% of total soil N_2O emissions emitted from agriculture (Paustian et al., 2016). In this context, evaluations of management practices that minimize the N_2O emissions are fundamental to offer adaptable mitigation strategies to different management.

Poultry manure composting is an alternative management that reduces the volume of waste, facilitating storage, transportation, and application (Tyson & Cabrera, 1993). Some studies showed that the composting process immobilizes N and stabilizes organic matter, delaying the release of nutrients (Bustamante et al., 2008; Tyson & Cabrera, 1993). The risk of N losses increases when the available N for crops is higher than the demand. For this reason, the slow release of nutrients from the composted waste can reduce harmful environmental consequences such as N losses by leaching or emission to the atmosphere (Snyder et al., 2009). Hence, countries with significant agricultural production possess a high potential to replace part of synthetic fertilizers uses with organic residues amendments. The use of these practices could contribute to the circular economy and the principles of sustainable agriculture. To achieve this, the quantification of possible externalities caused by organic amendments in the biogeochemical cycles is necessary.

The reduction of GHG emissions from agricultural systems is a key factor to sustainable production. The N_2O emissions quantification from amended soil with organic materials will allow the design of sustainable agricultural systems (Hénault et al., 2012). Although some authors studied N_2O emissions after residues application (Gregorutti & Caviglia, 2017; Hayakawa et al., 2009), few studies compared N_2O emissions generated in fertilization systems with raw and composted poultry manure. The aim of this study was to evaluate the N_2O emission from a control soil and after application of raw poultry manure, composted poultry manure and chemical fertilizer.

MATERIALS AND METHODS

Study site and experimental design

The study was performed during the winter 2017, from July 3 to August 4, on an experimental area under a pasture composed mainly of Festuca sp. and Trifolium repens. The experiment was made at the National Agricultural Research Center (CNIA) of the National Institute of Agricultural Technology (INTA) in Hurlingham, Buenos Aires, Argentina (34 ° 36 ‘15 “S, 58 ° 40’ 16” O). The soil was classified as a typical Argiudol (INTA, 2019). The topsoil has a silty-loam texture, while the subsoil has a clay loam texture.

The experiment had a randomized complete block design (RCBD) with three blocks and four treatments. Treatments consisted of poultry manure (PM), composted poultry manure (CPM), urea (U) as synthetic fertilizer, and control (C, no added N) (n = 3 for each treatment). Within each block, a plot of 25 m^2 was settled randomly for treatments application. 260 kg ha^{-1} of urea, 1770 kg ha^{-1} of PM and 6944 kg ha^{-1} of CPM were applied. The doses of PM, CPM, and U were calculated considering the pasture requirement (120 kg N ha^{-1}), the N-NO_3^- the content of the soil, and the different contents of N of the applied materials were considered. The application of the amendments was done superficially and by hand. During the experiment, the average temperatures were 12 °C and 13°C for soil and air, respectively, and the accumulated precipitation was 93,6 mm.

AMENDMENTS PRECEDENCY

Poultry manure (PM) was obtained from an automated poultry farm located at CNIA, INTA. The compost (CPM) was made by mixing 50% PM and 50% horse litter (v / v), using an open composting system with manual turning. The composting process lasted 90 days, reaching the hygiene requirements (temperature ≥ 55 ° C) established in the Argentine Composting Standard (SCyMA & SENASA, 2019). The characterization of PM and CPM is shown in Table 1.

Table 1. Mean values of total organic carbon (%), total nitrogen Kjeldahl (%) and the C / N ratio of the poultry manure and the composted poultry manure. Values are expressed on a dry weight basis (Mean ± SEM).

Tabla 1. Valores medios de carbono orgánico total (%), nitrógeno total Kjeldahl (%) y la relación C / N del guano de ave y del guano de ave compostado. Los valores se expresan sobre una base de peso seco (Media ± SEM).

	Total Organic Carbon (%)	Total Nitrogen (%)	C/N Ratio
Composted poultry manure	16,26 ± 0,48	1,73 ± 0,07	9,40 ± 0,54
Poultry manure	35,65 ± 0,13	6,78 ± 0.55	5,26 ± 0,45

NITROUS OXIDE EMISSION

Fifteen N_2O samplings were taken in 32 days. They were collected 1, 2, 3, 4, 5, 7, 9, 11, 14, 16, 18, 21, 23, 25, and 32 days after the application (DAA) of the treatments. The sampling effort tried to capture as well as possible the changes in N_2O emissions to minimize the error. The sampling of N_2O emissions was performed using closed-static chambers (surface 0,13 m^2, height 0,125 m) with an iron frame base and a PVC cover according to the criteria of Rochette & Eriksen-Hamel (2008). The chamber headspace was connected to the exterior by a two-way valve for gas sampling. Bases were inserted into the soil (0,05 m depth) 24 h before the beginning of the monitoring period, and they were not moved or rotated during the trial period t (Alves et al., 2012; Chirinda et al., 2019). Gas samples were taken from the chamber headspace at intervals of 0, 15, and 30 min after closing the chambers. The collection was made with a syringe (60 mL) and a part of it was transferred into 10 cm^3 glass vials after evacuation using a manual vacuum pump with a manometer (Cosentino et al., 2020). Gas sampling was performed between 09:00 and 12:00, which best represents the average daily N_2O emission in the study area (Cosentino et al., 2012). Within seven days of sampling, N_2O was analyzed in the laboratory with a GC 6890 Agilent Technologies Network gas chromatograph (Agilent Network GC System, A´ ECD, Santa Clara, CA, USA).

The N_2O emission (f) was calculated as:

$$f=\frac{\Delta C}{\Delta t}\times\frac{V}{A}\times\frac{m}{V_m} \qquad \text{Eq. 1}$$

where ΔC/Δt is the change in N_2O concentration in the chamber during the deployment time Δt, V is the volume of the chamber (16,3 dm^3), A is the soil area (0,13 m^2) covered by the chamber, m is the molecular mass of N_2O and Vm is the molar volume of N_2O. Gas emission was calculated as the increase in concentration during deployment time (period while the chamber is closed).

Once a week and at the same time as the N_2O emission, topsoil temperature was measured at 0,10 m depth beside each chamber. After gas sampling, soil samples (0–0,2 m depth) were taken from the chamber perimeter and analyzed for NO_3^- -N by nitration of salicylic acid method (Cataldo et al., 1975). The bulk density (BD) was determined by the cylinder method with 100 cm³ and 0.05 m in diameter (Blake, 1965) and gravimetric water content (GWC, by drying in an oven until constant weight). Water filled pore space (WFPS) were calculate using bulk density and gravimetric water content, and assuming a particle density (Dp) of 2,65 Mgm^{-3}.

$$\text{WFPS (\%)} = (\text{GWC} * \text{BD} * 100) / [1 - (\text{BD} / \text{Dp})] \qquad \text{Eq. 2}$$

Cumulative emissions for the total trial period (32 days) after the application were calculated using the linear interpolation method, and the emission factors were determined (Dorich et al., 2020). To interpolate the punctual emissions, N_2O emissions were converted to a daily scale. N_2O emission values unmeasured were calculated from the average between the emissions measured the day before and the day after. Finally, emission factors were calculated from the difference in the total emissions from each treatment (MT), and the control treatment (MC), divided by the N applied, as described by Equation:

$$EF = \frac{M_T - Mc}{Treatment\ N\ applied} \qquad \text{Eq. 5}$$

where EF is emission factor (N_2O–N emitted as % of N applied) and Treatment N applied is the N applied (total kg N ha^{-1}).

Statistical differences in the N_2O emission soil temperature, WFPS, and soil NO_3^- -N between treatments for each date were tested with ANOVA. The software used was INFOSTAT (Di Rienzo et al., 2008). When the ANOVA indicated significant differences ($p < 0.05$), the treatment means were compared using the Tukey test ($\alpha = 0,05$). Linear regressions and correlation analysis were also performed using INFOSTAT..

RESULTS

The N_2O emission ranged between 0,4 and 574 µg N_2O-N m^{-2} h^{-1} with high variability even between repetitions. Despite the similar pattern observed by all the treatments over time, the N_2O emission rate presented significant differences ($p < 0.05$) between the treatments in 10 of the 15 sampling dates (Figure 1a). On average, the treatment with the application of U presented the highest N_2O emission, followed by the treatment with the application of PM.

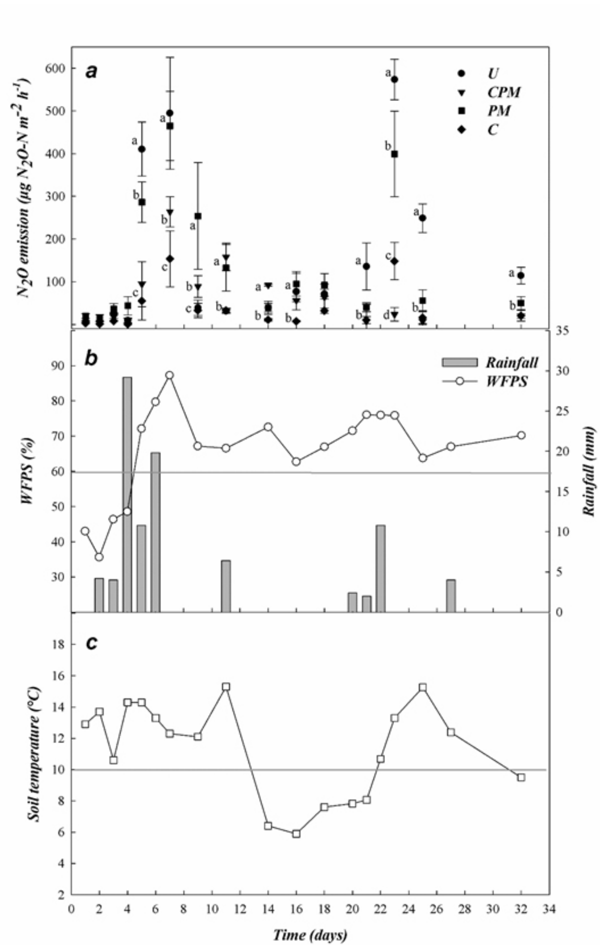

Figure 1. Evolution of a) the emission of N_2O in the Control (C, ♦) and after the application of Poultry Manure (PM, ■), Composted Poultry Manure (CPM, ▼) and Urea (U, ●); b) WFPS (- O -) and rainfall ▭, and c) the soil temperature (- □ -). The horizontal line represents the water filled pore space (WFPS) value of 60% (b) and the corresponding temperature value of 10 °C (c). Different letters indicate significant differences between treatments for each measurement day.

Figura 1. Evolución de a) la emisión de N_2O en el Control (C, ♦) y luego de la aplicación de Guano de Ave (PM, ■), Guano de ave Compostado (CPM, ▼) y Urea (U, ●); b) Espacio Poroso Saturado con Agua WFPS (- O -) y lluvia ▭, y c) la temperatura del suelo (- □ -). La línea horizontal representa el valor del espacio poroso lleno de agua (WFPS) del 60% (b) y el valor de temperatura correspondiente de 10 ° C (c). Letras diferentes indican diferencias significativas entre tratamientos para cada día de medición.

At 5, 21, 23, 25, and 32 DAA, treatment U presented significantly higher N_2O emission rates compared to the other treatments, followed by PM, and lastly by the CPM and C treatments. However, PM presented the highest N_2O emission on 9 DAA, followed by treatment CPM and finally by U and C (without significant differences between both). The treatments with CPM application and the control presented the lowest emission values of N_2O at 5, 7, 16, 18, 21, 23, 25, and 32 DAA, with significant differences between them at 7 and 23 DAA. For the rest of the days, no significant differences were observed in N_2O emission between treatments (Figure 1a).

On 1, 2, 3, and 4 DAA, the N_2O emission values were low and in concordance with low WFPS values (less than 60%, Figure 1b). Since 5 DAA, the N_2O emission values were higher and mainly followed the changes in the WFPS. On 14, 16, 18, 21, and 32 DAA, N_2O emissions were lower than those expected from the WFPS, probably due to the low soil temperatures (Figure 1c). When the soil temperature was less than 10 °C, the N_2O emission values were intermediate and less variable. Finally, on 5, 7, 9, 11, 23, and 25 DAA, when the soil temperature exceeded 10 °C, and WFPS was higher than 60%, the N_2O emission values were high and highly variable (Figure 1).

The soil NO_3^- -N content presented significant differences ($p < 0.05$) between treatments at 7, 14, 21 and 32 DAA (U > PM > CPM = C). U treatment presented the highest values in all the dates evaluated, with significant differences compared to the other treatments at 7, 14, and 21 DAA. The U treatment was followed by PM and lastly by CPM and C (Figure 2). In addition, during the first 21 DAA, the nitrate content in the soil increased at a higher rate with the application of U, followed by PM, and finally by C and CPM soils. Despite those differences, the soil NO_3^--N during the experiment was higher than the threshold of 5 mg kg^{-1} according to Dobbie et al. (1999), and then it was not considered a limiting factor for N_2O emissions.

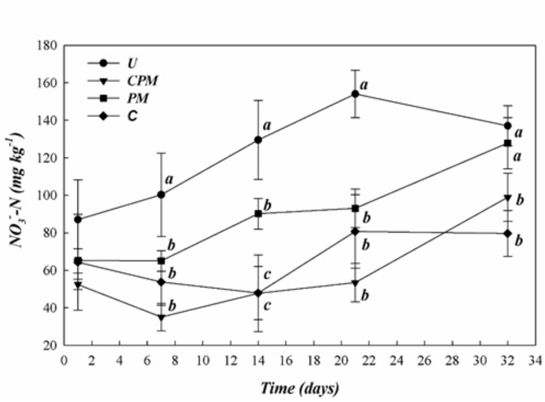

Figure 2. Evolution of the soil nitrate content (NO_3^--N) in Control (C, ♦) and after the application of the Poultry Manure (PM, ■), Composted Poultry Manure (CPM, ▼) and Urea (U, ●). Bars indicate the standard error of the mean (SEM). The different letters indicate statistically significant differences between the treatments for each sampling date.

Figura 2. Evolución del contenido de nitrato del suelo (NO_3^--N) en el Control (C, ♦) y después de la aplicación del Guano de Ave (PM, ■), Guano de Ave Compostado (CPM, ▼) y Urea (U, ●). Las barras indican el error estándar de la media (SEM). Las diferentes letras indican diferencias estadísticamente significativas entre los tratamientos para cada fecha de muestreo.

When all the treatments and moments were analyzed together, a direct relationship between the N_2O emission and the soil NO_3^--N content of the soil was not demonstrated (data not shown). When analyzing each sample date in isolation, the highest N_2O emissions occurred in the treatments with the highest content average NO_3^--N. However, there were not significant correlation between those variables (Figure 2).

At 32 DAA the cumulative emission rates were on average 1273 ± 30,78 g N_2O-N ha^{-1} from U, 965 ± 129,25 g N_2O-N ha^{-1} from PM, 423 ± 67,06 g N_2O-N ha^{-1} from CPM, and 244 ± 36,13 g N_2O-N ha^{-1} from C. Then, the soil N_2O emission with CPM application was twice than C treatment, while soil emissions from PM and U were similar (without significant differences between both) and approximately 4,5 times higher than those observed in C (Figure 3).

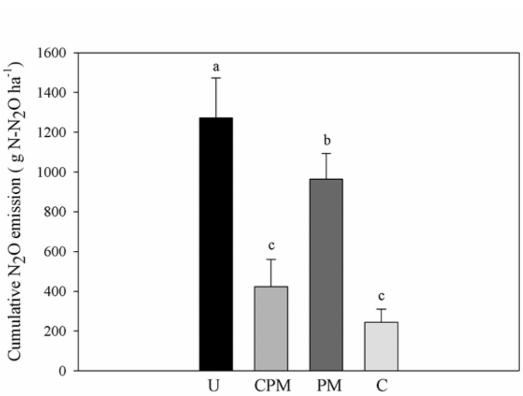

Figure 3. Cumulative emissions of N_2O in the Control (C) and after the application of the Poultry Manure (PM), Composted Poultry Manure (CPM) and Urea (U) 32 DAA. The different letters indicate statistically significant differences between the treatments.

Figura 3. Emisiones acumuladas de N_2O en el Control (C) y después de la aplicación de Guano de Ave (PM), Guano de Ave Compostado (CPM) y Urea (U) a los 32 DAA. Letras diferentes indican diferencias significativas entre tratamientos.

The emission factor (EF) for urea added to the soil was significantly greater than for PM and CPM ($p < 0.05$), with means of 0.86% (SE 0,03%). Finally, the EF for PM was significantly greater than for CPM ($P < 0.05$), with means of 0.6% (SE 0,13%) and 0,15% (SE 0,12%), respectively.

DISCUSSION

On 1, 2, 3, and 4 DAA, the N_2O emissions were low, probably related to the low WFPS values (less than 60%, Figure 1b). The soil water availability plays a central role in the oxygen dynamics and, therefore, in the activity of the different soil microorganisms (nitrifiers and denitrifiers). When the WFPS is low, the primary process driving the N_2O emission is the nitrification (aerobic), while when the WFPS increases, the denitrification gains relevance (anaerobic; Davidson, 1991). Therefore, a minimum of 60% of WFPS is considered a threshold value to find detectable emission rates, while values close to 80% are considered optimal for denitrification and N_2O emissions (Schindlbacher et al., 2004; Zechmeister-Boltenstern et al., 2007).

Since 5 DAA, the N_2O emission was higher and mainly followed the changes in the WFPS. Shelton et al. (2000) obtained a correlation between the N_2O emission and the soil water content, at a WFPS range between 60 and 100%. On days 14, 16, 18, 21, and 32 DAA, N_2O emissions were lower than those expected from the WFPS contents, probably due to the low soil temperatures (Figure1c). Similar results were reported by other authors (Cosentino et al., 2013; Perez et al., 2021). Finally, on days 5, 7, 9, 11, 23, and 25 DAA, when soil temperature exceeded 10 °C, and WFPS was higher than 60%, the N_2O emissions were high and highly variables (Figure 1). Soil situations characterized by high temperatures and WFPS could generate relatively high N_2O production rates, as long the soil NO_3^- -N availability is not a limiting factor (Castaldi, 2000).

During the first 21 DAA, the soil nitrate content increased at a higher rate with the U application, followed by PM and finally by C and CPM. These differences were due to the form in which the N was found in each treatment. Several studies have shown that the composting process immobilizes N and produces mineral N-associated organic matter that can be used as a source of organic materials delaying nutrient release (Bustamante et al., 2008; Tyson & Cabrera, 1993). The slow release of nutrients can reduce adverse environmental impacts such as N leaching in-depth or losses as N_2O (Snyder et al., 2009). Rizzo et al. (2015) worked with similar materials to use in the present experiment. These authors evaluated the composting process of poultry manure, reporting higher unstable organic matter (labile organic matter) contents and a large part of N as NH_4^+ -N in the raw poultry manure before composting. While in the composted poultry manure, the organic matter was stabilized, and the N content was as organic N and as NO_3^- -N.

When all the treatments and moments were analyzed together, a direct relationship between the N_2O emission and the soil NO_3^- -N content of the soil was not observed, this is possibly due to the multifactorial effect of the regulatory variables of N_2O emissions. The ecological stoichiometry approach provides a tool for analyzing how the balance of the multiple factors required by soil organisms affects N_2O production (Hessen et al., 2004; Sterner & Elser, 2002). Similar results were found by Cosentino et.al (2013) in an agricultural field in Argentina.

The highest N_2O emissions were observed in those treatments with the highest NO_3^- -N contents. However, there were not significant correlation between those variables (Figure 2). Similar results were shown by other authors who reported an increase in soil NO_3^- -N after adding organic amendments (Masaka et al., 2014; Roig et al., 2012). According to Dalal et al. (2003), the rate of N_2O emission by denitrification increases with NO_3^- -N content if the soil presents predisposing conditions of moisture, temperature, and availability of labile carbon.

In the present research, the N_2O emission rates accompanied the changes in values of WFPS and temperature when they were between 30-90% and 6-16 °C, respectively. Generally, the highest N_2O emission rates were observed at high levels of soil NO_3^- -N contents on those sampling dates where neither the soil temperature nor the WFPS limited the N_2O production. Similar results were reported by Dalal et al. (2010), showing a positive correlation between the emission of N_2O and soil NO_3^- -N content when the soil temperature ranged between 10 and 30 °C and the WFPS was between 30% and 80%.

The cumulative emissions in the present research were higher than the reported by Gregorutti & Caviglia (2017). After 150 days of applying the equivalent of 450 Kg Nha^{-1} as poultry manure and 266 Kg N ha^{-1} of chicken litter compost, observed cumulative N_2O emissions of approximately 240 g N ha^{-1} and 100 g of N

ha^{-1}, respectively. The authors attribute the low emissions to low WFPS, which never exceeded 60% (Gregorutti & Caviglia, 2017). The cumulative N_2O emissions observed in the present study were higher than the found by authors such as Hayakawa et al. (2009). They applied 120 kg of N ha^{-1} of manure to a spinach crop, with temperatures between 15 to 30ºC and WPFS between 40 and 70%, and they obtained accumulated N_2O emission values of 330 g of N_2O-N ha^{-1} after 37 days. One of the reasons for the high emission observed in the present trial could be the high rate of denitrification and, consequently, the production of N_2O (Akiyama & Tsuruta, 2003).

However, other authors such as Thornton et al. (1998) reported higher accumulated emissions, with values of 3870 g of N_2O-N ha^{-1} and 1640 g of N_2O-N ha^{-1}, 150 days after applying 336 kg of N ha^{-1} of manures. The authors applied raw and composted manure (with 3,4% and 3,5% of total N respectively) to a batch with Bermuda Grass, with a mean temperature of 23 ºC and WFPS between 20% and 80%. The authors attributed these results to the high amount of residue applied to the soil. Kim et al. (2019) observed N_2O emission of 10.8 kg ha^{-1} yr^{-1} by applying composted poultry manure. They attribute the N_2O emission mainly to the nitrification process since soil moisture was low. Finally, as observed in the present research, Martín-Olmedo & Rees (1999) reported high N_2O emissions five days after applying poultry manure. The authors suggest that the peak of N_2O emission was related to the content of available organic carbon in the manure, which is quickly used by N_2O-producing microorganisms.

The EF for urea added to the soil (during 32 DAA) was 0,86%; this value is a little less that annual value reported by the IPCC for the urea (2019). The high N_2O emission reported during the present trial was possibly associated with the high percentage of WFPS, which encourage denitrification emissions. Similarly, the EF for PM and CPM (during 32 DAA) presented mean values of 0.6% and 0.15%, respectively. Thus, EFs were greater than the annual value reported by the IPCC (2019). The IPCC states that the EF for poultry waste is between 0,000-0,014 with an average value of 0,004, lower than the value obtained here; without reporting EF for soils with the application of composted manure (IPCC, 2019). The difference between EF obtained in the present research and reported by IPCC, is possibly due to the forms in which N are found in the residues. Adding N to the soil, mainly NO_3^-, affects microbial activity and therefore N_2O emissions. However, unlike what happens with inorganic fertilizers such as urea, the time and intensity with which organic fertilizers affect the activity of the microorganisms involved in the production of N_2O from the soil is specific of each residue. For this reason, EF from organic waste cannot be predicted from simple measurements such as total N, which is a reasonably good estimator of EF from synthetic fertilizers as urea (Kim & Dale, 2008).

The higher soil cumulative emission and EF values after applying U and PM compared to those from the soil with CPM application was possibly due to the differences in the N forms to each material. The immobilization of nutrients during composting leads to a lower content of inorganic N readily available to soil microorganisms, decreasing the N_2O production by nitrification and denitrification processes.

CONCLUSION

According to our results, the application of composted poultry manure to the soil produced lower losses of N as N_2O than the application of raw poultry manure or chemical fertilizers like urea. In addition, the presence of more stabilized compounds in the composted manure decreases the soil nitrate availability. This less soil nitrate availability could maximize the synchronization between the availability of resources and the grassland demand, minimizing the environmental losses. For this, soil amendment with composted material could be considered sustainable alternative management to reduce the use of synthetic fertilizers, improve soil health and contribute to climate change mitigation. Finally, to advance on this line of research, more studies should be carried out to validate the emission factors for these manure management alternatives. The use of default IPCC emission factors could be underestimating their impact on the environment.

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