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Nitrous Oxide Emissions in No-Tillage Onion (*Allium cepa* L.) Crops Are Increased by Oilseed Radish Cover Crop and Poultry Manure Application

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ABSTRACT: The use of cover crops and poultry manure (PM) is an alternative to reduce the use of synthetic inputs and can contribute to the nutrient cycling in onions (*Allium cepa* L.) grown under a no-tillage system. However, this management practice may contribute to an increase in N_2O emissions to the atmosphere. The aims of this study were to evaluate the immediate effect on N_2O emissions of adding PM onto cover crop residues and to verify the effect of different no-tillage systems on N_2O emissions. Two studies (laboratory and field) were conducted with the addition of oilseed radish (OR), black oat (BO), and weed (WD) residues with and without PM under a no-tillage (NT) system. Emission of N_2O (kg ha^{-1}) was influenced by the different residue-management systems and was higher in treatments with OR residues (2.96 ± 0.67 kg ha^{-1} for OR and 5.28 ± 1.04 kg ha^{-1} for OR + PM). The other treatments behaved similarly with emissions of approximately 1.91 ± 0.17 kg ha^{-1} of N-N_2O. The highest N_2O emissions in the field study were found within the first 15 days and represented 50.3 % of the average emissions. Poultry manure showed high emissions when the cover crop was OR, but not when it was BO and WD.

Keywords: N_2O, nitrogen, cover crop residue, organic fertilizer, greenhouse gases.

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INTRODUCTION

The adoption of production systems that promote reduced dependence on external inputs is fundamental for maintaining the sustainability of agroecosystems. In this context, no-tillage (NT) has become an important alternative for reducing the environmental impacts of conventional soil preparation practices in areas where onion is grown (*Allium cepa* L.) (Souza et al., 2013). In NT, cover crop species such as black oat (*Avena strigosa* Schreb.) and oilseed radish (*Raphanus sativus* L.), as well as organic fertilizers, such as poultry manure (PM), are used to supply nutrients to the soil, especially nitrogen (N). In addition, these species promote an increase of organic carbon (C) in soils (Loss et al., 2015), which may reduce greenhouse gas (GHG) emissions. Meta-analysis studies by Aguilera et al. (2013) and Shcherbak et al. (2014) compiled and analyzed information from research on the overall impacts of soil management practices on GHG emissions. However, because NT is a relatively recent system, little is known about the impacts of cultivating onion under NT on GHG emissions, especially nitrous oxide (N_2O).

Nitrous oxide has a global warming potential 298 times greater than carbon dioxide (CO_2) which is the most common anthropogenic gas (IPCC, 2007). Among the various sectors, agriculture contributes to about 37 and 50 % of the anthropogenic emissions of N_2O in Brazil (Brasil, 2014) and worldwide (IPCC, 2007), respectively. Soil management practices alter the flux of water and nutrients in the soil, which may or may not favor the emission of N_2O forms into the atmosphere. Therefore, the degree of N_2O flux in agricultural soils is associated with the management practices employed by farmers (van der Weerden et al., 2000), as well as the quantities and qualities of the residues deposited onto the soil. Residues are decomposed and mineralize C and nutrient forms, such as N in forms of nitrate (NO_3^--N) and ammonium (NH_4^+-N), providing substrates for nitrification or denitrification processes, which contribute to N_2O emissions (Palm and Sanchez, 1991; Toma and Hatano, 2007; Thomsen et al., 2016). Furthermore, the quality of residues deposited onto the soil surface interferes with decomposition dynamics and N mineralization (Palm and Sanchez, 1991) Factors such as the C/N ratio, lignin content, cellulose content, non-structural biomass, and environmental conditions (temperature, moisture, and nutrient content in soil) directly influence the decomposition of plant residues (Oliveira et al., 2016; Thomsen et al., 2016). Residues with lower C/N ratios, such as those of oilseed radish, favor rapid decomposition and N mineralization into the soil (Redin et al., 2014), which may cause N_2O flux in agricultural soils with emission peaks up to four times greater than residues with higher C/N ratios, such as those of black oats (Bayer et al., 2015). Therefore, because of the distinct properties of each plant residue, the synchronization of nutrient decomposition and mineralization with the N demand by the crops can be hindered and may not meet crop needs at higher-demand stages (Oliveira et al., 2016).

With the use of cover crops, nutrients such as N are added to the soil through the biological fixation of N, which occurs in some species (Doneda et al., 2012), but plants also cycle N in the environment (Congreves and Van Eerd, 2015). However, native soil N or N derived from the cover crops commonly used in NT does not meet the demand for N by onions (Kurtz et al., 2013). Therefore, the application of nutrient sources such as PM is necessary (Bayrakdar et al., 2017). However, adding PM onto the residues can increase N_2O emissions (Hayakawa et al., 2009). Therefore, our hypotheses were as follows: the use of cover crops in onion NT cultivation leads to the occurrence of more intense peaks of N_2O emission during the crop cycle, and the addition of PM onto cover crop residues potentiates decomposition, which increases N_2O emission. However, the use of black oat (*Avena strigosa* Schreb) as a cover crop reduces N_2O emission compared to oilseed radish. This study evaluated the immediate effect of adding PM onto cover crop residues on N_2O emission and sought to verify the effect of PM and cover crops on N_2O emission.

MATERIALS AND METHODS

Field study

The field study was conducted from April to November, 2015, at the Experimental Station of the Company of Agricultural Research and Rural Extension of Santa Catarina (Epagri), located in the city of Ituporanga in the Alto Vale do Itajaí region of the state of Santa Catarina, southern Brazil (Latitude 27° 24′ 52″ S, Longitude 49° 36′ 9″ W, and altitude of 475 m a.s.l.). The climate of the region is humid subtropical (Cfa) according to the Köppen classification system, with an average annual temperature of 17.6 °C and an average annual rainfall of 1,400 mm (Souza et al., 2013). The average values of temperature, rainfall, and irrigation during the study period are shown in figure 1. The meteorological

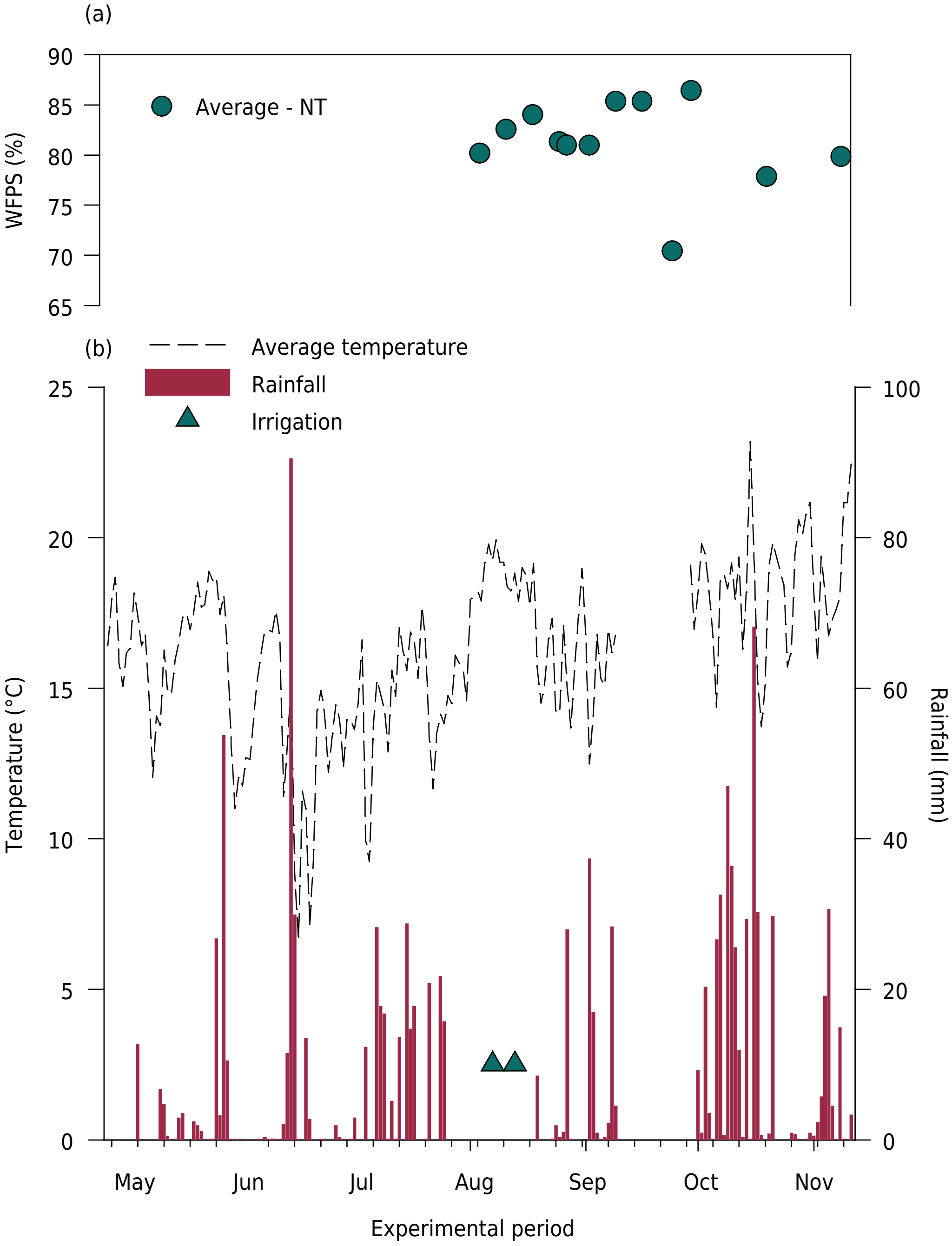

Figure 1. Water-filled pore space (a), average air temperature (b), rainfall (b), and irrigation (b) values throughout the onion growth cycle. No data were available from September 10-28. Transplanting occurred on August 1st.

data were obtained using the weather station of Epagri, located approximately 300 m from the study site.

The long-term experiment used in this study was installed in 2009 in an area that was under conventional tillage with plowing and harrowing for 30 years, and then under no-tillage since 1995. The experiment was conducted under no-tillage (NT) without herbicide application. There were six treatments with different cover crop species (pure and intercropped) grown in the fall/winter preceding the onion (*Allium cepa* L. cv. 'Empasc 352' - Bola Precoce) crop. After harvesting the onion, velvet bean (*Stizolobium aterrimum* Piper & Tracy) (80 kg ha^{-1}) was grown in all treatments for soil cover and dry matter supplementation to the winter treatments. The onion crop was fertilized with PM in all of the treatments. The plots had dimensions of 5 × 5 m, and they were arranged in a randomized block design with eight replicates. The cover crop treatments selected for this study were weeds (WD), black oats (BO), and oilseed radishes (OR). To evaluate the immediate effect of PM application, microplots (5.0 × 2.5 m) in which onions were grown without the application of PM were demarcated within the plots. Thus, this study consisted of six treatments: WD + PM, BO + PM, OR + PM, WD, BO, and OR. The physical and chemical properties at 0.00-0.10 m layer during the installation of the treatments are shown in table 1. Further details on the management of the study area can be found in Loss et al. (2015).

In April of 2015, BO and OR were sown at sowing densities of 120 and 20 kg ha^{-1}, respectively. The sowing was done by hand (broadcast), after which a cereal seeder was driven through the area twice to provide better contact of the seeds with the soil. The amount of dry matter (DM) produced by BO, OR, and WD was measured 90 days after their sowing by randomly collecting three subsamples of 0.25 m^2 in each plot, which were combined in a composite sample. The BO and OR were at full flowering at that time. The collected material was dried in an oven with air circulation at 65 °C to a constant weight, weighed, and then ground. Contents of total N and organic C were determined in the ground material, as described by Tedesco et al. (1995). For the analysis of the contents of cellulose, lignin, and non-structural biomass, the methodology described by Aber and Martin (1999) was used. The chemical composition of the residues and the amounts of DM, C, and N added to each treatment are shown in table 2.

Table 1. Physical and chemical properties at 0.00-0.10 m layer at the installation of the treatments: oilseed radish (OR), black oat (BO), and weeds (WD)

Property	WD	BO	OR
Clay (g kg^{-1})	313.2	305.8	331.2
Sand (g kg^{-1})	478.9	458.3	473.4
Silt (g kg^{-1})	208.1	236.4	195.8
TOC (g kg^{-1})	23.2	23.9	25.4
pH(H_2O)	6.3	6.0	6.3
Available P (mg kg^{-1})	164.8	217.2	161.0
Available K (mg kg^{-1})	379.0	360.0	393.0
N-NO_3^- (mg kg^{-1})	7.0	8.7	17.5
N-NH_4^+ (mg kg^{-1})	5.2	5.2	21.0
Ca^{2+} (cmol$_c$ kg^{-1})	8.6	9.0	7.3
Mg^{2+} (cmol$_c$ kg^{-1})	1.9	1.6	1.9
K^+ (cmol$_c$ kg^{-1})	na	na	na
Density	1.4	1.4	1.4

Sand, silt, and clay determined by the Pipette method; TOC (total organic carbon) determined by wet oxidation (Walkley-Black); pH(H_2O) at a soil:solution at a ratio 1:1; P and K were extracted by Mehlich-1; N-NO_3^- and N-NH_4^+ were determined by Kjeldhal method; Ca^{2+}, Mg^{2+}, and K^+ extracted by KCl 1 mol L^{-1}; density was determined by volumetric ring method; na = not available.

Table 2. Chemical properties of the residues of weeds (WD), black oats (BO), oilseed radishes (OR), and poultry manure (PM) used in the field and laboratory studies

Property	WD	BO	OR	PM
	g kg^{-1}			
Total organic carbon	407.9 ± 1.5	367.2 ± 4.3	394.1 ± 18.4	193.2 ± 1.2
Total N	23.7 ± 0.7	23.8 ± 1.7	37.1 ± 2.5	20.0 ± 0.3(1)
Cellulose	381.3 ± 7.1	550.4 ± 27.4	244.1 ± 7.8	ne
Lignin	24.1± 2.3	26.2 ± 7.0	53.4 ± 1.7	ne
Non-structural biomass	594.6± 4.9	456.7 ± 33.4	702.4 ± 7.0	ne
C/N ratio	17.2 ± 0.5	15.4 ± 1.3	10.6 ± 0.2	9.66 ± 0.1
Lignin/N ratio	1.0 ± 0.1	1.1 ± 0.2	1.4 ± 0.1	ne
Cellulose/lignin ratio	15.9 ± 1.7	22.0 ± 6.0	4.6 ± 0.2	ne
	Amount added (kg ha^{-1})			
Dry matter	930.0 ± 110.8	4,600.0 ± 818.0	4,130.0 ± 576.7	2,160.0 ± 0.0
TOC	379.3 ± 45.9	1,688.9 ± 301.6	1,627.8 ± 207.4	417.3 ± 2.6
Total N	22.0 ± 2.3	109.3 ± 25.5	153.3 ± 24.7	100.0 ± 15.0

(1) 3,840 mg kg^{-1} of NH_4^+-N and 80 mg kg^{-1} of NO_3^--N. The values are presented as media ± standard deviation of the mean (n = 3); ne = not evaluated. Total organic carbon determined by the method proposed by Tedesco et al. (1995); total N determined by dry combustion; cellulose, lignin, and non-structural biomass determined according the method proposed by Aber and Martin (1999).

The management of the cover crops and weeds (WD) was carried out in July (95 days after sowing) with a knife roller. The planting of onion was carried out over the residues of the cover crops and weeds, after furrows were opened with a seeder adapted to no-tillage. The spacing used was 0.50 m between rows and 0.10 m between plants. The transplanting of cv. 'Empasc 352' - Bola Precoce onion seedlings was done by hand on the same day as the management of the cover crops and weeds. The treatments with the PM application received a dose of 5 Mg ha^{-1} of organic fertilizer, equivalent to 100 kg ha^{-1} N (19.2 kg of NH_4^+-N and 0.4 kg of NO_2^--N + NO_3^--N), 175 kg ha^{-1} of P_2O_5, and 125 kg ha^{-1} of K_2O. The total amount of PM was split so that half of the dose was applied on the day the onion seedlings were transplanted, and the other half of the dose was applied 35 days after transplanting (DAT). The poultry manure was applied manually to the soil surface on both dates.

Nitrous oxide emission was evaluated using the static chamber-based method according to Aita et al. (2014), from onion transplant to harvest (August to November of 2015), which totaled 99 days of evaluation. During this period, 15 collections (1, 3, 8, 10, 15, 17, 22, 24, 30, 37, 44, 52, 57, 77, and 99 DAT) were carried out, preferably between at 09:00 and 10:00 a.m., which, according to Jantalia et al. (2008), is when the N_2O content in samples represents the average daily emission of this gas. After the transplanting the onions, three galvanized steel supports (0.40 m wide × 0.40 m long × 0.10 m high) were installed between the rows at a soil depth of 0.05 m. Gas samples were collected using a polypropylene syringe at 0, 20, and 40 min after fitting the chambers into the supports. After collection, the samples were transferred to evacuated vials (Labco Exetainer®, Lampeter, United Kingdom). The N_2O content was determined in a gas chromatograph (Shimadzu GC-2014 model 21 Greenhouse, Japan), within a maximum period of 14 days after sample collection. The fluxes were calculated by taking into account the variation in N_2O content in the chamber while it was closed, the chamber volume, the area of the soil occupied by the chamber, and the molecular weight of N_2O (Jantalia et al., 2008).

The residues of cover crops and WD were added to the N_2O evaluation bases in proportion to the dry matter yield of each species. A similar procedure was applied to PM, where the amount applied in the area was delimited by the base equivalent to the dose of 2.5 Mg ha^{-1} used at transplanting and 35 days after transplanting. During the evaluations, the internal area of the supports was kept free of plants.

Cumulative N_2O emissions were obtained by integrating the daily averages. Thus, the average flux between two consecutive collections was calculated by multiplying the resulting value by the time interval (in days) between the two collections.

During the gas sampling, the soil temperature was measured at 0.00-0.05 m using a digital thermometer. Soil samples were collected at 0.00-0.10 m layer using a tracer to determine gravimetric moisture and mineral N content (NH_4^+-N and NO_3^--N). Soil mineral N was extracted using 1 mol L^{-1} KCl solution and analyzed in a Kjeldhal distiller (Tecnal brand, model TE-037, Brazil), according to Tedesco et al. (1995) (data not shown). Gravimetric soil moisture was obtained by drying the soil samples in an oven with forced air circulation at 105 °C for 24 h, according to Tedesco et al. (1995). Based on the values of moisture, soil density, and total porosity (data collected in August 2014), water-filled pore space (WFPS, %) was calculated according to the method used by Siqueira Neto et al. (2009).

Laboratory study

The experiment was conducted with the objective of verifying the isolated effect of the addition of cover crops residues and PM onto the soil. Therefore, samples of a *Cambissolo Húmico* (Santos et al., 2013) or Inceptisol (Soil Survey Staff, 2006) were collected from the 0.00-0.10 m layer in an NT area adjacent to the field experiment. The soil was passed through a 4 mm mesh sieve, and the remaining crop residues were removed by hand.

The OR and BO residues as well as the PM were the same as those used in the field study. Plant residues were collected at full flowering, dried in an oven with forced air at 65 °C, and cut into 1-2 cm pieces in order to provide a better distribution on the soil surface. The properties of the residues and PM are shown in table 2.

The experimental design was completely randomized and the treatments were as follows: without residues, PM with WD or OR, and BO with or without PM. The study was conducted in a BOD incubator in the absence of light and at a temperature of 25 ± 0.5 °C. During incubation, soil moisture varied, and it was maintained by applying wetting and drying cycles, while seeking WFPS values between 40-80 %. Water was added when soil moisture resulted in a WFPS of 40 %. The amount of water added was enough to raise moisture to a level where WFPS reached 80 %. Afterwards, the treatments were placed onto 0.55 × 0.35 × 0.13 m (length × width × height) polypropylene trays covered with plastic film. Throughout the study, moisture was monitored every 5 days by weighing the vials, and distilled water was added onto the soil and the organic residues. Every 5 days, the plastic film was removed from the trays for 30 min to avoid O_2 deficiency.

Each experimental unit consisted of a 110-mL capacity acrylic cylindrical vial filled with 118 g of wet soil (equivalent to 93 g dry soil). In the vials, the humidity was increased to 70 % of field capacity. The soil inside the vials was densified to a height of 4 cm, resulting in a density of 1.1 Mg m^{-3}. The experimental units were preincubated for 7 days to stabilize the microbiological activity of the soil. The amounts of BO and OR residues added onto the soil surface in each acrylic vial were equivalent to 4.6 and 4.1 Mg ha^{-1}, respectively. Poultry manure was added onto the plant residues in an amount equivalent to 5.0 Mg ha^{-1}. The amounts of residues and PM were equal to the amounts used in the field areas under NT.

The N_2O emissions were quantified in four replicates using the same experimental units. We set up 24 experimental units (6 treatments × 4 replicates) for this evaluation. During the evaluation of N_2O emissions, each experimental unit was placed inside 600-mL glass flasks. The flasks were kept open until 1 h prior to the gas sampling. Gas sampling was done with syringes immediately after the flasks were closed and one hour later. Samples were placed in evacuated vials (Labco Exetainer®, Lampeter, United Kingdom) and, shortly thereafter, the content of N_2O were analyzed by gas chromatography, as described in the field study. Fifteen air samplings were done throughout the incubation period (1, 3, 8, 10, 15, 17, 22, 24, 30, 37, 44, 52, 57, 77, and 99 days after the start of incubation). The N_2O fluxes and cumulative emissions were calculated according to the procedures described in the field study.

The levels of ammonium (NH_4^+-N) and nitrate + nitrite (NO_3^--N + NO_2^--N) in soil were evaluated in three replicates. We set up 108 experimental units (6 treatments × 3 replicates × 6 evaluation dates) for this evaluation. The acrylic vials with the treatments were placed onto two 0.55 × 0.35 × 0.13 m (length × width × height) polypropylene trays covered with plastic film. The soil mineral N contents (NH_4^+-N and NO_3^--N + NO_2^--N) were determined 1, 7, 21, 42, 63, and 99 days after the start of incubation, using the methodology of Tedesco et al. (1995), as described in the field study.

Statistical analyses

Data were analyzed for normality and homogeneity using the Shapiro-Wilk test and then subjected to analysis of variance. The effect of adding residues and PM on the contents of NH_4^+-N and NO_3^--N was tested for normality and homogeneity using the Shapiro-Wilk test and then subjective to analysis of variance (ANOVA), and later compared by the Tukey test ($p<0.05$). The effect of soil management on N_2O emissions was evaluated through the descriptive analysis of the data, based on the standard error of the mean. Cumulative emission values were tested for homogeneity and normality and later compared by the Tukey test ($p<0.05$) using Sisvar® software (Version 5.4).

RESULTS

Field study

From August to November of 2015, the average daily air temperatures ranged from 16.1 to 18.7 °C, in which the coldest month was September and the hottest was November (Figure 1b). Rainfall ranged from 40.5 (August) to 378.4 mm (October). The management systems had an effect on the WFPS values (Figure 1a), with the minimum value found in BO (71 % on August 4) and the maximum value in OR + PM (98 % on August 25). The average values of WFPS in treatments under NT ranged from 70-86 % and were higher than 80 % saturation in 9 of the 12 soil samples that were collected.

The N_2O fluxes in soil ranged from -33.74 ± 47 μg m^{-2} h^{-1} of N_2O^--N in BO and BO+PM (average) at 99 DAT to 2,523.6 ± 536.4 μg m^{-2} h^{-1} of N_2O^--N in OR+PM at 01 DAT (Figure 2a). The highest N_2O emissions were verified within 15 days of the management of cover crops (average of 960.4 ± 483.0 μg m^{-2} h^{-1} of N_2O^--N). A significant peak in N_2O emission was verified 15 days after management in all treatments, especially in OR + PM (994.3 ± 215.1 μg m^{-2} h^{-1} of N_2O^--N).

The cumulative N_2O emissions in the period after the management (1 DAT) ranged from 161.32 ± 7.4 g ha^{-1} of N_2O^--N in WD + PM to 879.7 ± 317.7 g ha^{-1} of N_2O^--N in OR + PM (Figure 2b). The OR treatment showed intermediate behavior, with cumulative emissions of 443.0 ± 126.5 g ha^{-1} of N_2O^--N, followed by BO, BO + PM, WD, and WD + PM, which had emissions equivalent to 217.46 ± 75.56, 184.50 ± 45.87, 178.06 ± 48.34, and 161.33 ± 98.47 g ha^{-1} of N_2O^--N, respectively.

The cumulative percentage emissions within 15 DAT (in g ha^{-1} of N_2O^--N) represented 50.3 % of the emissions on average. Up to 44 days after management (approximately half the crop cycle), cumulative N_2O emissions were approximately 88 % of those of the total crop cycle.

The cumulative N_2O emissions throughout the cycle (in kg ha^{-1}) were higher in treatments with OR residues, especially the OR + PM, which had the highest cumulative values ($p<0.05$) of 5.28 ± 1.04 kg ha^{-1} of N_2O^--N (Figure 2b). The N_2O emissions did not differ

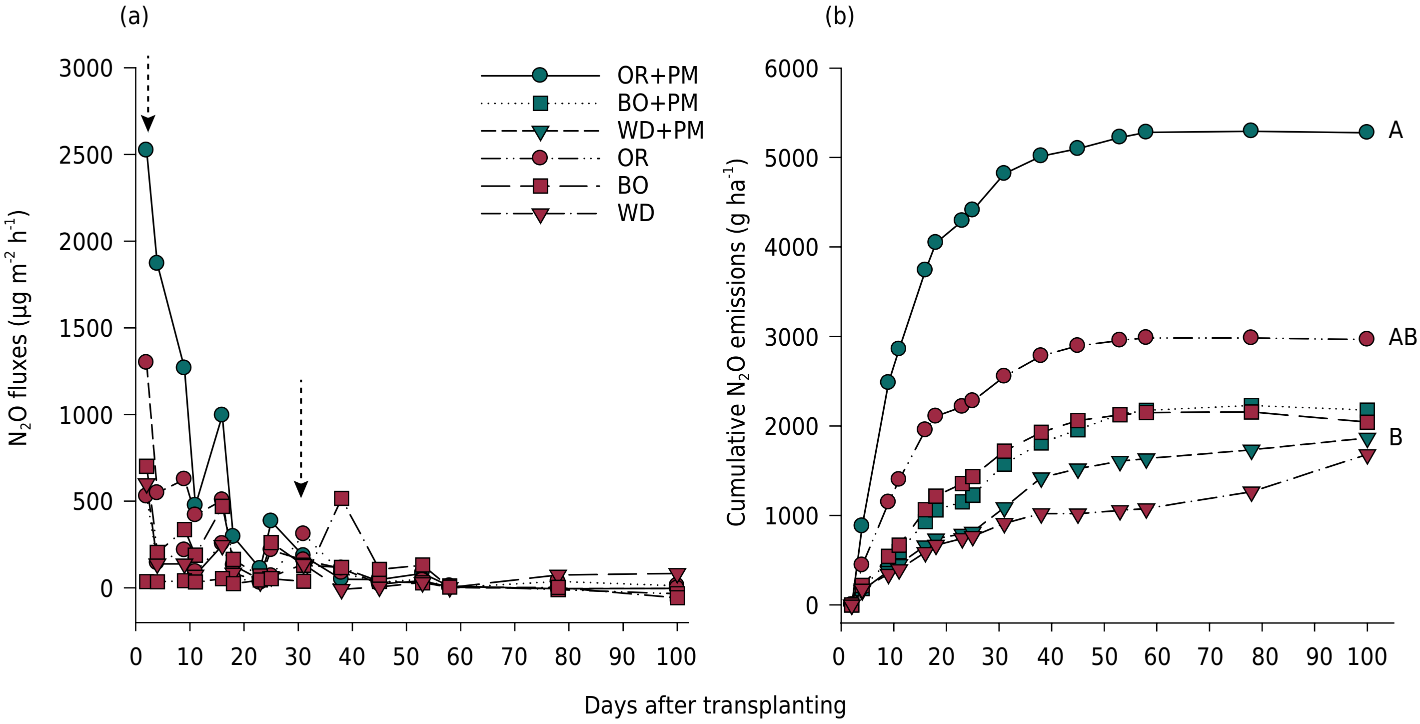

Figure 2. Fluxes (a) and cumulative emission (b) of N_2O^--N in soil with residues from weeds (WD), weeds + poultry manure (WD + PM), oilseed radishes (OR), oilseed radishes + poultry manure (OR + PM), black oats (BO), and black oats + poultry manure (BO + PM). Dashed arrows indicate fertilization with PM. Means followed by the same letter are not statistically different from each other by the Tukey test at 5 % (n = 3).

statistically between WD, WD + PM, BO, and BO + PM, with an overall average of 1.91 ± 0.17 kg ha^{-1} of N_2O^--N. For the OR treatment, the application of PM increased cumulative emissions (by the end of the cycle) by approximately 44 %.

Laboratory study

The highest levels of N-NH_4^+ in soil were found one day after the start of incubation in treatments with the addition of PM (BO+PM and OR+PM) (Figure 3a). On the other hand, in the evaluation held 8 days after the application of PM, NH_4^+-N values decreased by 55 % in BO + PM and 67 % in OR+PM, compared to values measured on the first day of incubation. After 42 days of incubation, NH_4^+-N content in soil did not differ among treatments. The NH_4^+-N contents in the soil of the C, BO, and OR treatments remained stable and did not differ from each other throughout the incubation period (Figure 3a).

The addition of plant residues increased NO_3^--N content in soil above that found in the control (C) treatment until 44 days after the start of the incubation (Figure 3b). In general, the application of PM did not result in increased NO_3^--N content compared to the treatments with only BO and OR. On the first day of incubation, the amount of NO_3^--N in the soil of the control treatment was 17.46 mg kg^{-1}, compared to 25.83 mg kg^{-1} on average in the OR and OR+PM treatments and 44.44 kg kg^{-1} on average in the BO and BO+PM treatments. The N-NO_3^- content in soil after 42 days of incubation reached values of 45.28, 79.96, and 113.26 mg kg^{-1} in the C, BO, and OR treatments, respectively. At 63 days of incubation, there was a marked decrease in the NO_3^--N contents of treatments with organic residues, resulting in increased NO_3^--N values in the control treatment until the end of the incubation period.

In all treatments evaluated, the highest N_2O fluxes were observed on the first day after incubation, when the fluxes decreased in the following order: OR + PM = BO > BO + PM = OR > without residues (Figure 4a). After this high initial flux on the first day of

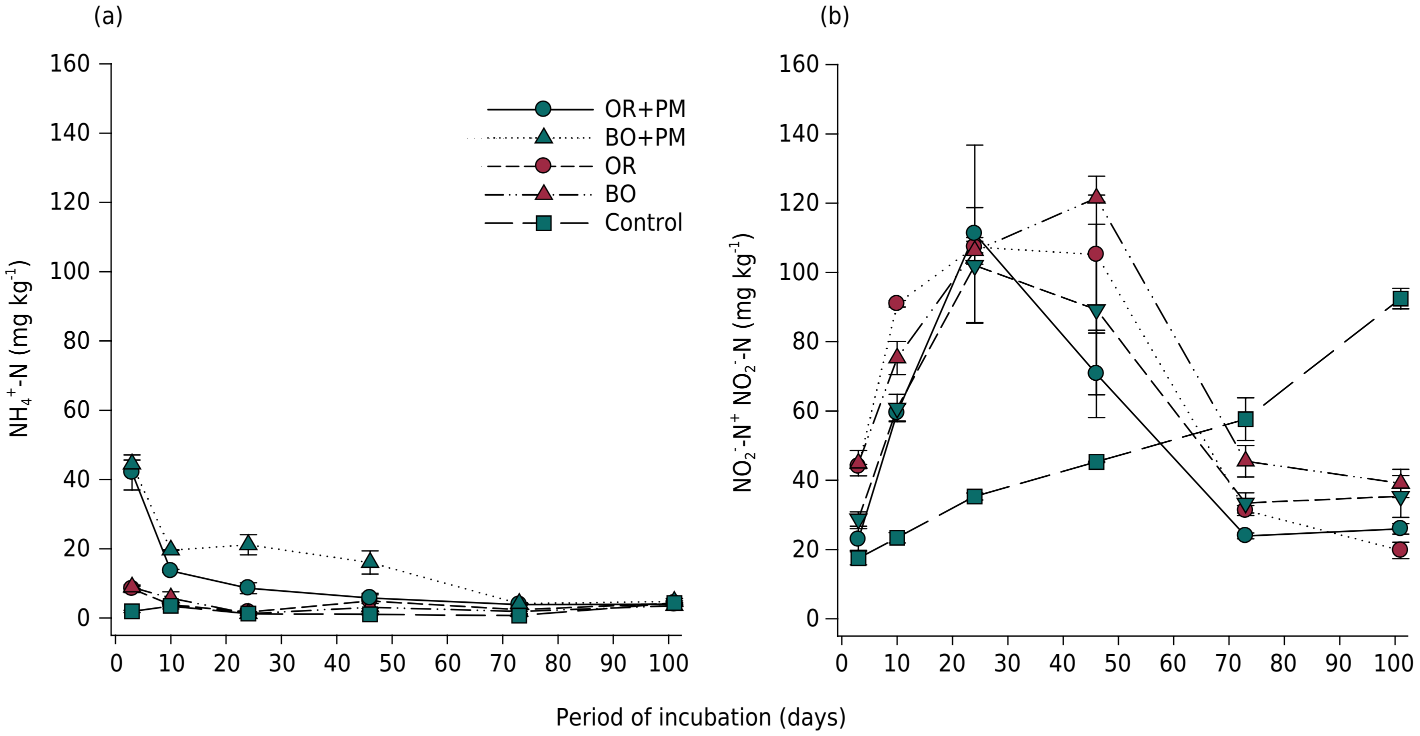

Figure 3. Temporal variations in NH_4^+-N (a) and NO_3^--N+NO_2^--N (b) contents in soil incubated with residues of oilseed radishes + poultry manure (OR + PM), black oats + poultry manure (BO + PM), oilseed radishes (OR), black oats (BO), and control (C). Vertical bars indicate the standard error of the mean (n = 3).

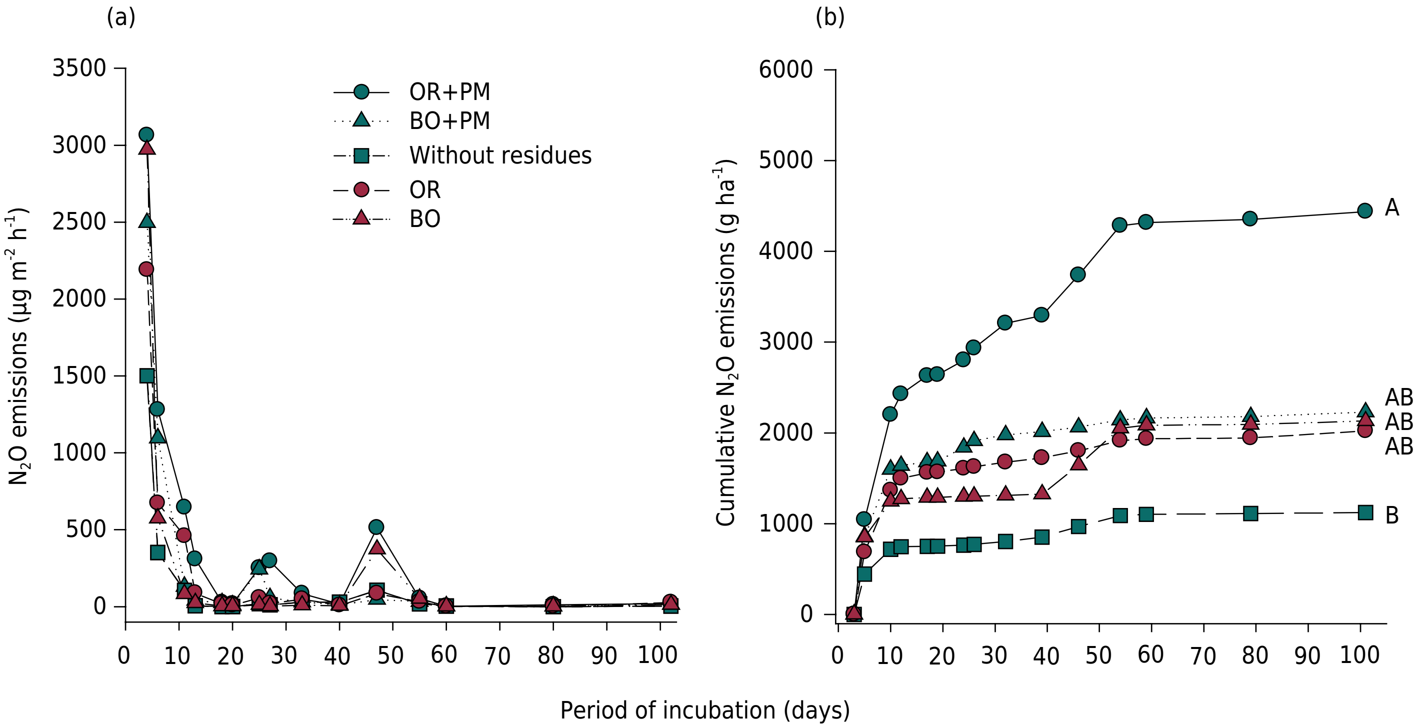

Figure 4. Fluxes (a) and cumulative emission (b) of N_2O-N in soil with the addition of residues of oilseed radishes + poultry manure (OR+PM), black oats + poultry manure (BO+PM), oilseed radishes (OR), black oats (BO), and without residues. Means followed by the same letter are not statistically different from each other by the Tukey test at 5 % (n = 4).

incubation, the N_2O fluxes decreased until 17 days of incubation, when no differences were observed between treatments with BO, OR, BO + PM, and the soil without residues. Peaks of N_2O emission were observed at 22, 24, and 44 days of incubation, in which the BO + PM, BO, and OR + PM treatments exceeded the fluxes measured in the other treatments. The cumulative N_2O emission in BO (2,130.55 g ha^{-1} of N_2O^--N) and OR (2,021.93 g ha^{-1} of N_2O^--N) treatments were 1.9 and 1.8 times higher than the treatment without residues (968.58 g ha^{-1} of N_2O^--N), respectively (Figure 4b). The addition of PM onto OR residues (OR+PM) (4,437.33 g ha^{-1} of N_2O^--N) resulted in cumulative N_2O emissions 2.19 and 3.95 times higher than the OR and without residues treatments, respectively. When PM was applied together with BO (2,228.41 g ha^{-1} of N_2O^--N), no increase in cumulative N_2O emissions was observed, compared to the treatment with only BO residues (Figure 4b).

DISCUSSION

The highest values of N_2O emission, especially in the period after crop residue and PM addition, can be attributed to the increased availability of C and N for the microbial processes of nitrification and denitrification responsible for the production of N_2O in soil (Toma and Hatano, 2007; Hayakawa et al., 2009; Frimpong et al., 2011). These results are in agreement with those obtained in other studies, such as Gomes et al. (2009), who verified the effects of the addition of grass and legume residues in NT on N_2O emissions within the first 45 days. Initially, the highest N_2O emission can be attributed to the nitrification process, due to the high NH_4 content present in PM. After the initial period of the experiment (15 DAT, approximately), denitrification was most likely the predominant process in N_2O emission. This is because, when maintaining residues on the soil and adding PM, there is an increase in the number of macroaggregates (Loss et al., 2015), and an increase in microporosity, which favors the formation of anaerobic sites through the consumption of oxygen (O_2) by heterotrophic bacteria (Siqueira Neto et al., 2009; Li et al., 2016).

The positive and negative values indicate the absorption into, and net flux of N_2O to the atmosphere from, the soil, respectively (Figure 2a). The highest N_2O emission peaks found after the management of the cover crops and the addition of PM could be related to the addition of OR residues. These residues decompose rapidly, especially because of the lower C/N ratio, higher cellulose content, and lower lignin content, which favor the rapid mineralization of N (Redin et al., 2014). This contributes to the increase of mineral N content in soil and consequently higher N_2O emissions (Huang et al., 2004; Li et al., 2015).

In general, the cumulative N_2O emissions in the soil management systems we evaluated were higher than those found in other studies conducted in southern Brazil were. For example, in evaluating N_2O emissions in NT associated with rotations between oat/corn and vetch/corn, Bayer et al. (2015) found cumulative values of 0.80 ± 0.07 and 0.07 ± 0.06 kg ha^{-1} of N_2O^--N for vetch/corn and oat/corn rotations, respectively. However, in onion production areas located in Hokkaido (Japan), cumulative N_2O emissions ranged from 3.5-15.6 kg ha^{-1} of N_2O^--N in the study of Kusa et al. (2002) and 5.6-1.8 kg ha^{-1} of N_2O^--N in Toma and Hatano (2007). One of the possible explanations for the high cumulative N_2O emissions may be a low efficiency of onion crop in absorbing N in comparison to crops with a larger biomass, such as corn.

The highest N_2O emissions occurred during the first 15 days of the field experiment, which was a period of low onion N demand. According to Kurtz et al. (2016), the accumulation of dry matter and nutrients was slow until 60 DAT, when bulbification begins. Therefore, when the field experiment results were compared with those of the laboratory experiment, we determined that the high rates of N_2O emissions were probably associated with the high C and N contents available from residues of cover crops and PM. In a meta-analysis study, Shcherbak et al. (2014) found that N_2O emissions increase as N inputs in the soil exceed crop requirements on a global scale. Zhao et al. (2015) found that N doses above 180 kg ha^{-1} of N in wheat crops caused significant increases in N_2O emission rates, without resulting in increased crop yields. This information is consistent with that found in this study, where the N doses added in treatments with the addition of plant residues and PM were greater than 200 kg ha^{-1} of N. In addition, the high values of WPFS were a determining factor for the high N_2O emission rates. The results indicate that treatments with the addition of OR residues, especially OR + PM, had higher cumulative emissions throughout the cycle than the other treatments.

CONCLUSIONS

Addition of PM resulted in high N_2O emissions with the OR cover crop, but not with BO and WD. Most of the N_2O emissions in both management systems occurred within 15 days of transplanting the onion seedlings. The cumulative N_2O emission values that were above those reported in the literature could be associated with the crop system condition, which included the maintenance of higher humidity as well as C and N levels. Moreover, emissions can be maximized by the low utilization of N derived from the decomposition of cover crop residues and poultry manure by onions at the beginning of their growth cycle.

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