Nutr Cycl Agroecosyst (2012) 94:209–220
DOI 10.1007/s10705-012-9534-9

ORIGINAL ARTICLE

Soil nitrous oxide emissions under different management practices in the semiarid region of the Argentinian Pampas

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Received: 14 August 2012 / Accepted: 14 September 2012 / Published online: 25 September 2012
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Abstract The aim of this study was to analyze the influence of different crop sequences (soybean-corn and soybean–soybean) and tillage systems (no tillage and reduced tillage) on nitrous oxide (N_2O) soil emissions under field conditions. The experiment was carried out in Manfredi, Córdoba province, Argentina on an Entic Haplustoll and N_2O emissions were measured in the field during a year. N_2O fluxes were low during winter, but in late spring it peaked. For fallow, N-NO_3-content was the most important variable to explain N_2O emissions. For growing period water-filled pores was the main variable explaining N_2O emissions. Nitrogen fertilization of corn crop increased N_2O-N emissions, whereas no significant differences were found due to the tillage system. Measured annual N_2O-N emissions were generally lower than those calculated using the methodology proposed by the Intergovernmental Panel on Climate Change.

Keywords Greenhouse gases · No tillage · Reduced tillage · Corn · Soybean · IPCC

Introduction

The loss of soil carbon (C) and nitrogen (N) contribute directly and indirectly to increase emissions of greenhouse gases into the atmosphere (Metay et al. 2007). Certain agricultural management practices can promote the accumulation of carbon in the soil, especially when combined with the addition of significant residue volumes and nitrogen. These *prima facie* beneficial practices can create environmental and soil conditions favourable for N_2O emissions (Mosier et al. 2006).

The Pampas region is the main agricultural area of Argentina. It covers more than 50 million hectares (Burkart et al. 1998) including some of the world most productive soils (Hall et al. 1991). However, the western part of this region is semiarid with lower annual rainfall of marked seasonality (Buschiazzo et al. 1998).

No-tillage (NT) has been proposed as an alternative to conventional tillage to reduce soil degradation

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(Álvarez et al. 1998; Díaz Zorita and Grove 2002; Franzluebbers 2002) and as a consequence, reduce gas emissions that produce greenhouse effect (Robertson and Grace 2004). There are few studies on the potential effect of N_2O emissions into the atmosphere by agricultural crops in Argentina. Continuous agriculture with soybean, corn, sorghum and wheat, with an increasing predominance of soybean cropping are the main production systems. Soybean and corn crops cover an area of 21 Mha (FAO 2010) contributing significantly to total GHG emissions in Argentina (Secretaria de Ambiente y Desarrollo Sustentable 2005).

The main objective of this study was to quantify N_2O emissions under field conditions in a soil subjected to different crop sequences and tillage systems in the semi-arid Pampas of Argentina, and compare the measured emission with the ones calculated using the IPCC (2006) methodology.

Materials and methods

Site characterization

The study was carried out in the semi-arid pampas, in a long-term experiment in the INTA Manfredi Agricultural Experimental Station, Córdoba, Argentina (31.5° S, 63.5° W, 292 m a.s.l.). Average annual rainfall in the region is 750 mm, concentrated during spring and summer. Average annual temperature is 16.6 °C, with an average of 9.5 °C in the coldest month and 23.4 °C in the warmest (INTA 1987). The soil corresponds to an Entic Haplustoll of the Oncativo series, a deep, well drained soil, developed on silty-loam materials, with an available water storage capacity of 307 mm up to a depth of 200 cm (INTA 1987).

The experiment was installed in 1995 using experimental plots 110 m long by 35 m wide and a factorial experimental design with two replicates. The factors were tillage system with two categories: no-tillage (NT) and reduced tillage (RT), and crop sequence with two categories: soybean–soybean (*Glycine max* (L) Merrill; sy–sy) and soybean-corn (*Zea* mays; sy–mz). A site with a soil condition as close as possible to the original (covered by grasses for at least 30 years) was sampled as control (control).

The RT treatment consisted in an initial tillage with a disc harrow at the end of winter and a field cultivator tillage before sowing the summer crop. In the NT treatment, weeds were controlled with herbicides during fallow.

Sampling and analytical determinations

N_2O emissions were measured in situ during 1 year, from March 2009 until April 2010. Table 1 shows the evaluated managements during this study. Soybean was sown on December 15, 2009 and corn on December 17. The corn crop was fertilized at sowing with triple superphosphate (12 kg P ha^{-1}) and on January 15, 2010 with 107 kg N ha^{-1} in a mixture of UAN + ammonium thiosulfate (30-0-0) with 2.6 % S. The soybean crop was fertilized only with 12 kg P ha^{-1} at sowing.

During the growing season N_2O samplings were performed every 10–15 days, plus every time after a >20 mm rainfall event was recorded. During fallow, sampling was carried out approximately every 30 days, even though rainfall was very scarce and virtually no significant rains were registered.

N_2O emission was measured using two closed chambers (Conen and Smith 1998) randomly placed in

Table 1 Tillage systems and crop sequences (crop residue during winter fallow and summer crop) of the long-term experiment during the N_2O measurement period (2009–2010)

Tillage system	Crop sequence	Residue during winter fallow	Summer crop
Reduced tillage	sy–mz (A)	Soybean	Corn
	mz–sy (B)	Corn	Soybean
	sy–sy	Soybean	Soybean
No-tillage	sy–mz (A)	Soybean	Corn
	mz–sy (B)	Corn	Soybean
	sy–sy	Soybean	Soybean

sy–mz (A) fallow with soybean residue, corn crop during the 2009/2010 season; mz–sy (B) fallow with corn residue, soybean crop during the 2009/2010 season and sy–sy soybean monoculture each experimental unit. Each chamber consisted of a rectangular 43 cm × 29.5 cm iron frame inserted in the soil to a depth of 5 cm covered with an inverted 9.36 cm deep PVC tray slightly shorter than the frame. The joint between the upper surface of the frame and the floor of the tray was air-tight, and the internal volume of the chamber was 11,880 cm^3. After collection, samples were injected into previously evacuated 13 ml vials. Gas samples were analyzed using a Perkin Elmer gas chromatograph Model Auto System XL (Perkin Elmer, Wellesley, USA) equipped with a Porapak Q packed column (3 m long, id 0.32 cm) and an electron capture detector. Gas molar volume (*Vm*) was corrected for air temperature measured at the time of sampling and N_2O flux (*f*) were calculated using Eq. 1:

$$f = \Delta C/\Delta t \times V/A \times m/Vm \qquad (1)$$

where $\Delta C/\Delta t$ is the change in N_2O concentration in the chamber during incubation time Δt; *V* and *A* are the volume (11,880 cm^3) and the area covered (1,268.5 cm^2) by the chamber, respectively. *m* is N_2O molecular weight.

Nitrogen as nitrate content (NO_3^-–N) was monitored in the soil up to a depth of 5 cm on the same dates as N_2O emissions were determined, taking a composite sample near each chamber in each experimental unit. Phenoldisulfonic acid was used for nitrate determination on wet samples (Bremner 1965).

Soil gravimetric moisture content in the first 5 cm of soil on the dates N_2O emissions were measured, was determined on two samples per plot. Samples were oven-dried to constant weight at 110 °C. Gravimetric soil water content was then calculated and the value of bulk density determined by the cylinder method with a volume of 100 cm^3 (Burke et al. 1986) measured at the site of each closed chamber. Then the water-filled soil pore space (WFPS) was calculated using Eq. 2 (Robertson and Groffman 2007):

$$\mathrm{WFPS}(\%) = (\text{soil water content} \times \text{bulk density} \times 100)/(1 - (\text{bulk density}/2.65)) \qquad (2)$$

N_2O emission estimated using the methodology proposed by the IPCC

The inventory of N_2O emission was calculated according to IPCC guidelines (IPCC 2006). The emission factor used for direct emissions (EF1) was 1 %. Direct emissions include N present in the previous crop residue and N added as fertilizer. N_2O emissions according to IPCC were calculated based on historic yields (15 years) of each trial treatment. We used harvest indices for soybean and corn of 0.37 (Vega et al. 2000) and 0.45 (Echarte and Andrade 2003), respectively. The amount of residue corresponding to roots was estimated as 22 % (IPCC 2006). We used a N content of 1 % for corn residue (Álvarez and Steinbach 2012) and 3 % for soybean (Gutiérrez Boem 2012).

Statistical analysis

Treatment effects on N_2O emissions were compared using a mixed model (ANOVA) where crop sequence, tillage system and their interactions were considered fixed effects while sampling date was considered a random effect. To improve the accuracy of comparisons between treatments, three co-variables were incorporated to the model: NO_3^-–N content, WFPS and air temperature. Significant differences were detected when the Fisher LSD test for comparison of means ($P \leq 0.05$) was applied (InfoStat 2010).

We also used multivariate methods based on regression tree algorithms and/or classification, where N_2O emission was considered the dependent variable and NO_3^-–N content, WFPS, air temperature, tillage system and crop sequence the regressor variables (InfoStat 2010).

Results

N_2O fluxes

During fallow mean daily temperatures ranged from 3.8 to 30.7 °C (Fig. 1). In winter there was very little rainfall (Fig. 1) with only three rainfall episodes > 20 mm before sowing. During the growth period (January to March 2010) average daily temperature varied between 16.5 and 27.1 °C. Total rainfall was 492 mm distributed in 22 events, 50 % of these were greater than 20 mm (Fig. 1).

Before sowing WFPS exceeded 40 % in three moments preceded by >20 mm rainfall events. During fallow the sy–sy RT treatment had on average the lowest WFPS (22.8 %); during the growing period, WFPS values under NT (Fig. 2a) were above the ones

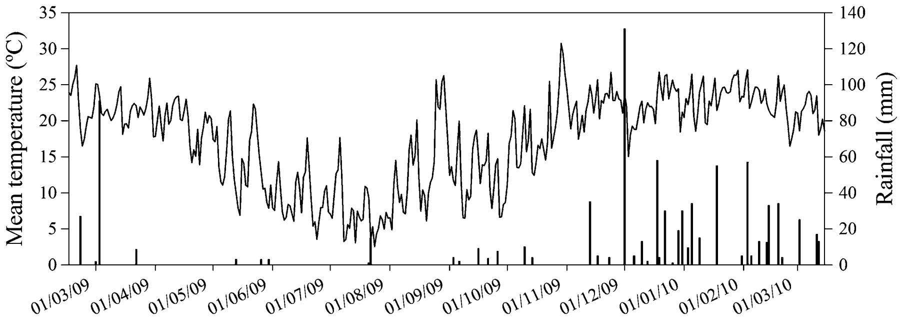


Fig. 1 Evolution of average daily mean temperature (*line*) and rainfall events (*vertical bars*) during the evaluation period (March 2009 to March 2010)

recorded under RT (Fig. 3a). Water content under no-tillage remained above 50 % WFPS for most of the growing season.

During fallow nitrate values were generally low (Figs. 2b, 3b). Close to sowing nitrate content was higher when preceded by a 130 mm rainfall event. After sowing (Figs. 2b, 3b) nitrate levels were between 17.5 and 35 mg NO_3^-–N kg^{-1} soil, except on January 19, 2010 when it peaked in all treatments under both soybean and corn. Corn crops were fertilized 4 days before that sampling and NO_3^-–N content was 179 mg kg^{-1} soil for RT sy–mz and 110 mg NO_3^-–N kg^{-1} soil for NT sy–mz. NO_3^-–N values in soybean crops were between 85 and 146 mg kg^{-1} soil.

N_2O fluxes remained low mainly during winter fallow, but in December 3 (late spring in southern hemisphere) it peaked reaching 84 µg N_2O–N m^{-2} h^{-1} (Figs. 2c, 3c). These N_2O emissions were accompanied by WFPS values above 50 % and NO_3^-–N content of 40 µg N_2O–N kg^{-1} soil, averaged over all treatments. After December N_2O fluxes showed variations between 1.72 and 117 µg N_2O–N m^{-2} h^{-1}, following the soil moisture values. In corn crops, both under NT and RT, and at most sampling occasions, N_2O flows were higher than those of the other treatments. The highest emission during crop growing seasons was registered in a NT corn crop (about 120 µg N_2O–N m^{-2} h^{-1}), sampled after fertilization. Maximum emissions of around 100 µg N_2O–N m^{-2} h^{-1} were observed in RT corn crops.

Control treatment shows that N_2O emissions followed the NO_3^-–N content during the entire period, both with low values (Fig. 4b, c). Water contents above 50 % coincided with low NO_3^--N values and N_2O emissions. This hydric condition prevailed during the whole growing season, averaging 78.5 % of WFPS (Fig. 4a). N_2O emissions (Fig. 4c) showed a peak of 82.8 µg N_2O–N m^{-2} h^{-1} at the end of the growing cycle, which was accompanied by 83 % WFPS and 17.2 mg NO_3^-–N kg^{-1} soil.

As N_2O emissions show a different pattern in winter-spring (fallow) and spring-summer (growing period), statistical analysis were performed separately.

For the fallow period (March to December 2009), only crop sequence showed significant differences ($P \leq 0.01$) (Table 2). The highest emissions were measured in sy–mz (A) on soybean residue (8.92 µg N_2O–N m^{-2} h^{-1}), followed by sy–sy (7.06 µg N_2O–N m^{-2} h^{-1}) and mz–sy (B) on corn residue (6.31 µg N_2O–N m^{-2} h^{-1}). WFPS, NO_3^-–N and average air temperature, analyzed as covariates in the model, yielded no significant differences ($P = 0.162$, $P = 0.354$, $P = 0.225$, respectively).

As was the case during the fallow period, during the growing season crop sequence was the only factor that determined significant differences ($P \leq 0.01$) in N_2O-N emissions (Table 3). No significant effects were found for WFPS, NO_3^-–N and average air temperature ($P = 0.06$, $P = 0.53$, $P = 0.55$, respectively).

The regression tree algorithms showed that for the fallow period, NO_3^-–N content was the most important variable to explain N_2O emissions (Fig. 5a). When NO_3^-–N was above 28 mg NO_3^-–N kg^{-1} soil, N_2O emissions were higher, when NO_3^-–N content was below that threshold N_2O emissions were influenced mainly by WFPS. Regression algorithms showed that the second node indicated that N_2O emissions were highest when the soil had more than 43 % WFPS. When the WFPS was equal or less than that value, emissions were influence by average temperature with a threshold of 10 °C.

During the growing period, WFPS was the most important variable explaining N_2O emissions (Fig. 5b). The highest emissions were measured when WFPS >52 %; below that threshold, the tillage system

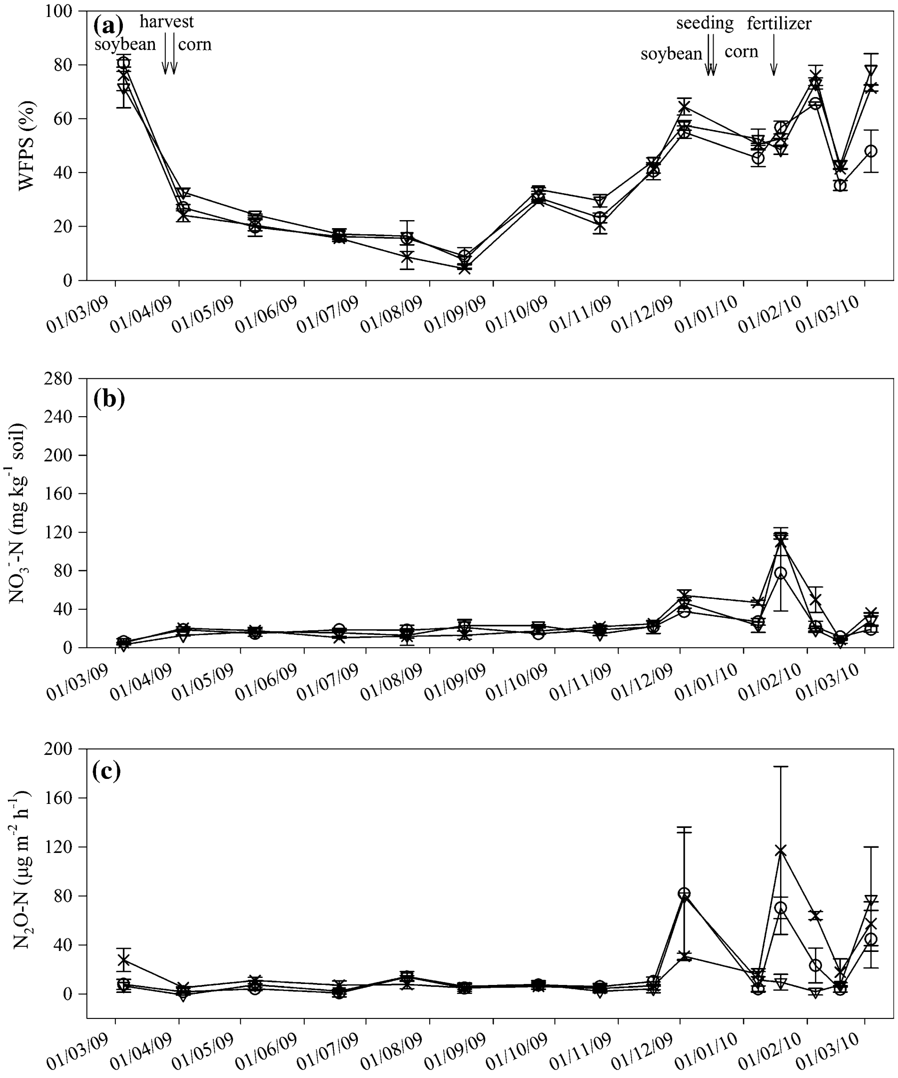


Fig. 2 Evolution of **a** water-filled soil pore space; **b** NO_3^-–N content; **c** N_2O–N emissions under no-tillage for *multi symbol* sy–mz (A), *triangle* mz–sy (B) and *open circle* sy–sy, from March 2009 to March 2010. *Vertical bars* indicate standard error

determined N_2O emissions. According to the regression algorithms the second node indicates that under no-tillage N_2O emissions were lower than under reduced tillage. The rest of the regressor variables were less important.

Measured and estimated IPCC based annual N_2O emissions

Annual N_2O emissions were calculated by linear interpolation between successive dates as suggested by Jantalia et al. (2008) and Metay et al. (2007). N_2O emission measurements ranged between 1.09 and 2.41 kg N_2O–N ha^{-1} year^{-1} (Table 4). Overall annual emissions were higher in RT than in NT, the highest corresponding to sy–mz (A). This shows the effect of nitrogen fertilization during the corn growing season, the only N-fertilized treatment. The lowest annual N_2O–N emissions corresponded to sy–mz NT (B), which had values similar to those of the control treatment.

Estimated emissions according to IPCC guidelines (2006) using historical yield data showed that, for the considered situations, the measured annual N_2O–N loss was generally lower than that estimated using the IPCC methodology (Fig. 6).

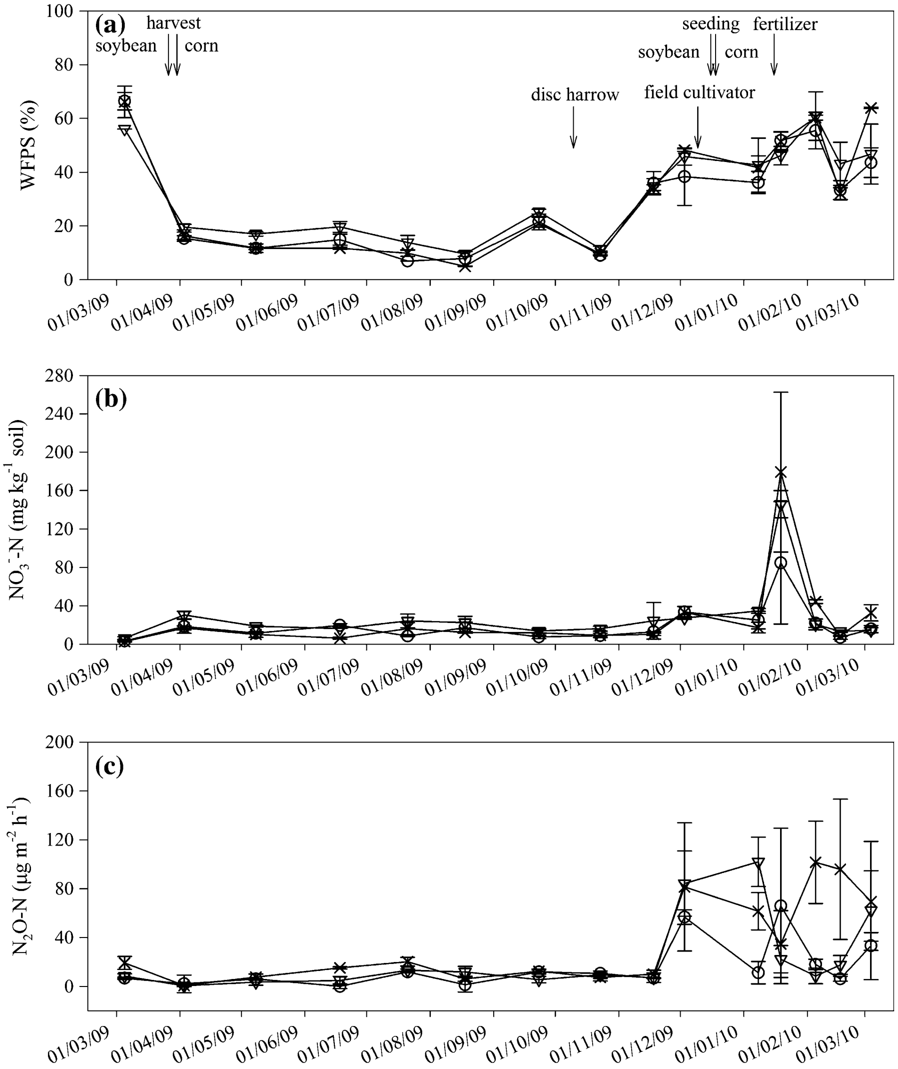


Fig. 3 Evolution of **a** water-filled soil pore space; **b** NO_3^-–N content; **c** N_2O–N emissions under reduced tillage for: *multi symbol* sy–mz (A), *triangle* mz–sy (B) and *open circle* sy–sy from March 2009 to March 2010. *Vertical bars* indicate standard error

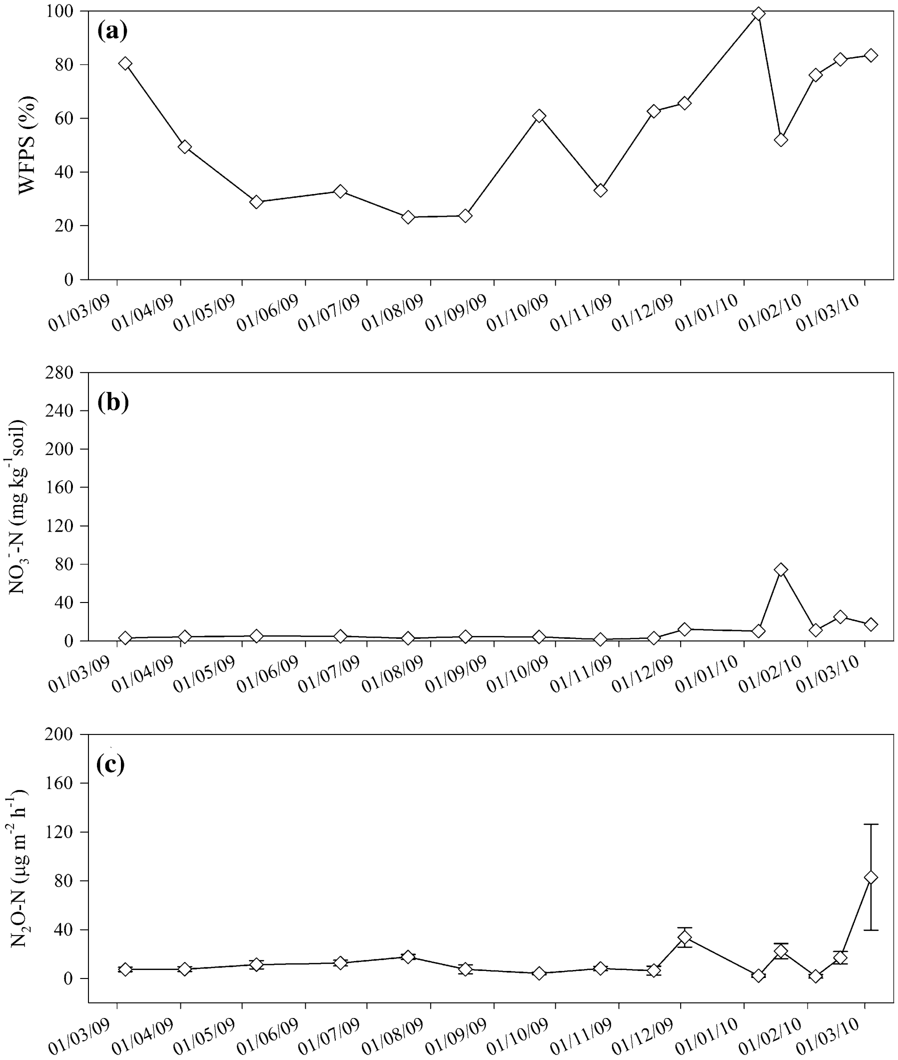
Discussion

N_2O fluxes

Emissions were generally low during fallow. Meteorological data between March and December show that conditions were not optimal for the soil N_2O formation. Occasional and low magnitude rainfall supported the assumption that there were no periods of anaerobiosis (Abril et al. 2005) as shown in Figs. 2a, b, 3a, b where WFPS values and NO_3^-–N content are generally low.

There were two moments when emissions were above the mean (Figs. 2c, 3c). In March soil moisture content was favorable for denitrification processes, however nitrate levels were very low but not zero. Several authors (Panek et al. 2000; Holtgrieve et al. 2006) mentioned a positive correlation between inorganic N availability and N_2O emissions while others (Metay et al. 2007) do not find a clear association as is the case of our study (Fig. 7). Moisture contents may have contributed to the fact that N_2O emission can be explained by both nitrification and denitrification. Davidson (1991) estimated the relative contribution of each process to N_2O flux as a function of soil moisture content, finding a maximum net flow around 60 % WFPS, the point at which nitrification and denitrification contribute equally to the N_2O flux. By contrast, Linn and Doran (1984) found that at 60 % WFPS, denitrification is insignificant. This makes us assume

Fig. 4 Evolution of **a** water-filled soil pore space; **b** NO_3^-–N content; **c** N_2O–N emissions of the control (*open diamond*) from March 2009 to March 2010. *Vertical bars* indicate standard error



that N_2O emissions measured at that moment can be due mainly to denitrification under no-tillage while under reduced tillage nitrification is probably the main pathway till nearly the end of the fallow period.

At the end of fallow in both tillage systems, there is a significant pulse of N_2O emissions that can only be partially justified by WFPS. The effect of the environmental conditions produced by the fallow on N_2O emissions may be explained by the fact that during the dry season there is accumulation of nitrifiable-N, which is slowly converted into nitrates, a process that accelerates when the spring rains start (Fasbender and Bornemisza 1987). We also found that, after low rainfalls during fallow, a significant rain in late Spring (beginning of December) caused high levels of NO_3^-–N and consequently high losses of N_2O–N. Saggar et al. (2004) suggest that in climates with a marked dry season, the first rain on dry soil produces a pulse of N_2O emission which may contribute significantly to the total annual emission. This coincides with the results we obtained at the end of the fallow period (Figs. 2c, 3c). During most of the winter N_2O fluxes were very low. This agrees with Levine et al. (1996) and Sanhuesa et al. (1990) findings in well-drained soils and with Metay et al. (2007) during the dry season in the Brazilian Cerrado.

During the growing season N_2O emissions were generally higher than during fallow (Figs. 2c, 3c). Under no-tillage, N_2O emissions followed nitrate content while WFPS levels were >50 % throughout the period. This trend was not so clear under reduced

Table 2 N_2O–N (μg m^{-2} h^{-1}) emissions during fallow for three crop sequences under two tillage systems: no tillage (NT) and reduced tillage (RT), and control

Crop sequence	Tillage system		Mean (μg N_2O–N m^{-2} h^{-1})
	NT (μg N_2O–N m^{-2} h^{-1})	RT (μg N_2O–N m^{-2} h^{-1})	
sy–mz (A)	9.16	8.67	8.92 a
mz–sy (B)	4.62	8.00	6.31 b
sy–sy	6.39	7.74	7.06 b
Mean	6.72 A	8.14 A	
Control	11.56		
Analysis of variance			
Crop sequence	(0.013)		
Tillage system	NS		
Crop sequence × Tillage system	NS		

Values followed by the same lowercase letters within a column are not significantly different ($P \leq 0.05$ Fisher LSD); values followed by the same capital letters within a row are not significantly different ($P \leq 0.05$ Fisher LSD); *NS* not significant. (A) Soybean residue during fallow; (B) corn residue during fallow

Table 3 N_2O–N (μg m^{-2} h^{-1}) emissions during the growing period for three crop sequences under two tillage systems: no tillage (NT) and reduced tillage (RT), and control

Crop sequence	Tillage system		Mean (μg N_2O–N m^{-2} h^{-1})
	NT (μg N_2O–N m^{-2} h^{-1})	RT (μg N_2O–N m^{-2} h^{-1})	
sy–mz (A)	52.95	76.11	64.53 a
mz–sy (B)	19.64	53.99	36.81ab
sy–sy	32.78	33.78	33.28 b
Mean	35.12 A	54.63 A	
Control	25.22		
Analysis of variance			
Crop sequence	(0.018)		
Tillage system	NS		
Crop sequence × Tillage system	NS		

Values followed by the same lowercase letters within a column are not significantly different ($P \leq 0.05$ Fisher LSD); values followed by the same capital letters within a row are not significantly different ($P \leq 0.05$ Fisher LSD); *NS* not significant. (A) Corn crop during summer; (B) soybean crop during summer

tillage where relationships between N_2O emission and nitrate content for different crop sequences showed a more erratic behavior, with WFPS levels slightly lower than those shown in no-tillage (Figs. 2a–c, 3a–c).

Corn crops produced higher N_2O emissions. It must be taken into account that it was the only crop receiving N fertilization. Metay et al. (2007) measured emission peaks under conventional tillage and no-tillage after nitrogen application. However, we detected emission peaks at different times after fertilizer application. Under no-tillage, a N_2O emission peak occurred shortly after N application followed by a significant rainfall event. On the contrary, under reduced tillage an emission increase was observed days after fertilization. Weitz et al. (2001) found that when fertilizer is applied during a dry phase, post-fertilization increase in N_2O flux occurs after a rain wetted the soil. This coincides with Linn and Doran (1984) findings that the maximum N_2O loss by denitrification occurred shortly after a rain event when WFPS was above 60 %.

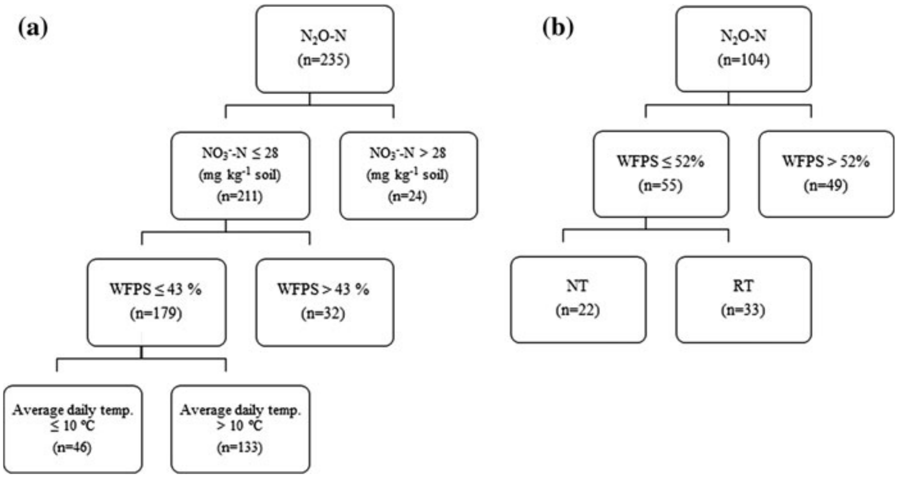


Fig. 5 **a** Regression tree for the fallow period and **b** regression tree for the growing period. Dependent variable: N_2O emissions; regressor variables: NO_3^-–N content, water-filled soil pore space (*WFPS*) air temperature; *n* number of observations. No-tillage (*NT*) and reduced tillage (*RT*)

Table 4 Measured N loss as N_2O (kg N_2O–N ha^{-1} year^{-1}) under two tillage systems: no-tillage (NT) and reduced tillage (RT) and two crop sequences: soybean–corn (sy–mz) and soybean–soybean (sy–sy), and a control (March 2009 to March 2010)

2009/2010	Tillage system		Mean (kg N_2O–N ha^{-1} year^{-1})
Crop sequence	NT (kg N_2O–N ha^{-1} year^{-1})	RT (kg N_2O–N ha^{-1} year^{-1})	
sy–mz (A)	1.55	2.41	1.98
mz–sy (B)	1.09	1.80	1.45
sy–sy	1.29	1.16	1.23
Mean	1.31	1.79	
Control			1.10

sy–mz (A): soybean residue during fallow and corn summer crop, mz–sy (B) corn residue during fallow and soybean summer crop

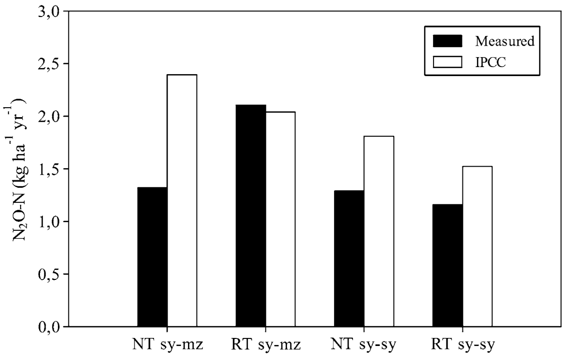


Fig. 6 Measured and estimated (IPCC 2006) annual N_2O–N emissions for soybean-corn (sy–mz) and soybean–soybean (sy–sy). No-tillage (*NT*) and reduced tillage (*RT*); measured emissions as in Table 4

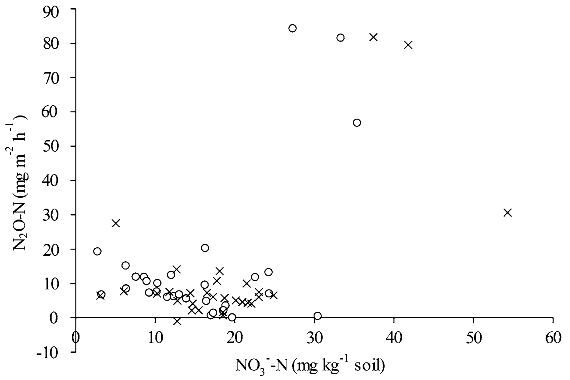


Fig. 7 N_2O–N emissions in relation to NO_3^-–N soil content during fallow, *open circle* RT, *multi symbol* NT

The soybean crop treatments sometimes showed N_2O fluxes greater than or equal to the fertilized treatments (corn crop). According Weitz et al. (2001) the available nitrogen in the residue can temporarily increase N_2O emissions. This can be explained by the fact that when the soybean crop begins to mature there is a large supply of easily degradable plant material with a very low C/N relationship, releasing mineral-N at the end of the crop cycle (Casado-Murillo and Abril 2011).

The poorly defined N_2O emission differences between the NT and RT observed in this study do not coincide with those reported by other authors (Linn and Doran 1984), who found N_2O losses during the summer crop growing season two times higher under no tillage than under conventional tillage. On the other hand, Rochette (2008) showed that increased N_2O emissions under NT can be expected on poorly aireated soils, not the case in our experiment that was done on well-drained soil.

Emissions of N_2O in control plots showed a similar trend but lower flow magnitudes than the treatments (Fig. 4c). This is consistent with Jantalia et al. (2008) findings that throughout the period evaluated, native vegetation showed the same flow trends with lower values than crop treatments.

Fallow and crop flux comparisons

Soybean monoculture produced the lowest N_2O fluxes (Table 4; Fig. 3). This may be because monoculture receives less crop residue input by not including another crop in its sequence. In this case, biological N fixation would not increase N_2O flux, which is consistent with IPCC (2006) directives, that advises not to consider soybean crops as an emission factor due to its contribution of atmospheric N fixation. The lack of tillage effect on N_2O flow that is shown in Tables 2 and 3 coincides with Perdomo et al. (2009) findings in Mollisols of the Pampa biome and contrasts with those of Smith and Conen (2004) and Smith (1999).

The regression tree for the fallow period (Fig. 5a) prioritizes NO_3^-–N content as an explanatory variable, evidence that this process occurred mainly in a period of low leaching. WFPS appears as the second priority item although with values below the threshold given by Linn and Doran (1984) to justify denitrification.

For the growing period, the model gives WFPS as the most important explanatory variable of N_2O emissions (Fig. 5b). This was to be expected, considering the relationship between N_2O emission and WFPS (Saggar et al. 2004; Metay et al. 2007) but also as 80 % of annual precipitation occurred during this period (INTA 1987; Casagrande and Vergara 1996). In addition, Rochette (2008) found a strong association between increases in N_2O emissions and low aeration conditions in soils under no-till, suggesting that it is caused by denitrification. The second level of priority is the tillage system, although no significant differences were found (ANOVA, Tables 2, 3). However, the regression tree data are consistent with increased N_2O emissions under RT as reported by Six et al. (2004) and Zanatta et al. (2010).

Annual N_2O emissions measured and estimated on the basis of IPCC guidelines

No-till is often suggested as a practice to reduce greenhouse gases net emissions. We found that, although not significant, N_2O emissions are on average 0.78 kg N_2O–N ha^{-1} $year^{-1}$ greater under reduced tillage than under no-tillage in the sequence sy–mz and 0.13 kg N_2O–N ha^{-1} $year^{-1}$ greater under NT than under RT in the sy–sy sequence. Considering the global warming potential of N_2O this is equivalent to a soil carbon loss of approximately 104 kg C ha^{-1} $year^{-1}$ (RT > NT) under sy–mz and 16 kg C ha^{-1} $year^{-1}$ (RT < NT) under sy–sy.

In NT sy–mz, NT sy–sy and RT sy–sy, IPCC estimated emissions were higher than the measured ones (Fig. 6). This same trend was observed by Jantalia et al. (2008) when carrying out estimates with the EF1default value while Parkin and Kaspar (2006) obtained lower N_2O estimates than those measured. In the semi-arid Pampa region 94 % of agricultural land is managed under NT (Aapresid 2009) and 73 % is cultivated with soybean (MINAGRI 2012). Therefore, we recommend more evaluations, as if this trend is maintained the use of the IPCC methodology (2006) generates a significant overestimation of N_2O emissions.

Conclusions

Nitrogen fertilization increased N_2O–N soil emissions. No significant differences were found due to tillage system. Measured annual N_2O–N emissions were generally lower than those calculated using the methodology proposed by the Intergovernmental Panel on Climate Change. Notably lower emissions were measured in the soybean NT crop than those calculated by the IPCC.

Acknowledgments We are grateful to *Centros Asociados* Program (CAPES, Brazil-SPU, Argentina). This work was granted by National Institute of Agricultural Technologic Regional Project (CORDO-62041), National Institute of Agricultural Technologic National Project (PNCER-022411) and the University of Buenos Aires (UBACYT 20020100 100257, 2011–2014).

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