Nitrogen fluxes from irrigated common-bean as affected by mulching and mineral fertilization

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Abstract – The objective of this work was to measure the fluxes of N_2O-N and NH_3-N throughout the growing season of irrigated common-bean (*Phaseolus vulgaris*), as affected by mulching and mineral fertilization. Fluxes of N_2O-N and NH_3-N were evaluated in areas with or without Congo signal grass mulching (*Urochloa ruziziensis)* or mineral fertilization. Fluxes of N were also measured in a native Cerrado area, which served as reference. Total N_2O-N and NH_3-N emissions were positively related to the increasing concentrations of moisture, ammonium, and nitrate in the crop system, within 0.5 m soil depth. Carbon content in the substrate and microbial biomass within 0.1 m soil depth were favoured by Congo signal grass and related to higher emissions of N_2O-N, regardless of N fertilization. Emission factors (N losses from the applied mineral nitrogen) for N_2O-N (0.01–0.02%) and NH_3-N (0.3–0.6%) were lower than the default value recognized by the Intergovernmental Panel on Climate Change. Mulch of Congo signal grass benefits N_2O-N emission regardless of N fertilization.

Index terms: Cerrado, climate change, greenhouse gas, N fertilization, nitrous oxide, no-tillage.

Fluxos de nitrogênio em feijoeiro irrigado influenciados pela cobertura morta e a fertilização mineral

Resumo – O objetivo deste trabalho foi medir os fluxos de N_2O-N e NH_3-N, ao longo de uma safra de feijoeiro irrigado (*Phaseolus vulgaris*), influenciados pelo uso ou não de cobertura morta e fertilização mineral. Os fluxos de N_2O-N e NH_3-N foram avaliados em áreas com ou sem cobertura de braquiária (*Urochloa ruziziensis*) ou fertilização mineral. Os fluxos de N também foram medidos em uma área nativa de Cerrado, a qual serviu como referência. As emissões de N_2O-N and NH_3-N foram positivamente relacionadas ao aumento da umidade e das concentrações de amônio e nitrato na área cultivada, na camada até 0,5 m de profundidade do solo. O conteúdo de C no substrato e a atividade microbiana na camada até 0,1 m de profundidade do solo foram favorecidos pela presença da palhada de braquiária e estiveram relacionadas com maiores emissões de N_2O-N, independentemente da fertilização nitrogenada. Os fatores de emissão (perdas de N a partir do nitrogênio mineral adicionado) para N_2O-N (0,01–0,02%) e NH_3-N (0,3–0,6%) foram menores do que o valor estabelecido pelo Painel Intergovernamental de Mudanças Climáticas. A cobertura com braquiária aumenta a emissão de N_2O-N, independentemente da fertilização com nitrogênio.

Termos para indexação: Cerrado, mudanças climáticas, gas de efeito estufa, óxido nitroso, plantio direto.

Introduction

Common-bean (*Phaseolus vulgaris* L.) is an important staple food in Brazil. During the dry season in the Brazilian Cerrado, between May and September, irrigated common-bean crop covers 182 thousand hectares (National Company of Food Supply, 2013), commonly cultivated under no-tillage system on the crop residues of maize or Congo signal grass (*Urochloa ruziziensis)*. Center pivot is the most used irrigation system, by which yields can reach up to 2.5 Mg ha^{-1}, usually 40% higher than nonirrigated ones (National Company of Food Supply, 2013). Besides irrigation, high inputs of mineral N (mainly urea, with total amounts reaching 245 kg ha^{-1}) also explain the higher yields of this crop system (Posse et al., 2011).

DOI: 10.1590/S0100-204X2013000500003

Environmental impacts of such an intensive crop system can be high, and its evaluation is a important step towards sustainable production.

Quantifying the emission of greenhouse gases (GHG) from crop systems is becoming increasingly important, considering worldwide trends towards full carbon accounting. Nitrous oxide (N_2O) is one of the GHG which contributes to climate change. In the Brazilian agriculture, emissions of N_2O-N increased in 24% from 1994 to 2005, and agricultural soils are responsible for more than 95% of N_2O-N emissions, including direct N_2O-N emission sources – mineral fertilizers, crop residues, grazing animals, animal off-field produced manure, biological fixation, etc. – and indirect ones – leaching, runoff, and atmospheric deposition (Cerri et al., 2009). Local assessment of GHG emissions from Brazilian agriculture systems have been reported (Carvalho et al., 2006; Metay et al., 2007; Jantalia et al., 2008; Zanatta et al., 2010; Cruvinel et al., 2011); however, the relative scarcity of data makes it difficult to assess the overall impact of irrigated common-bean under no-tillage on N_2O-N and NH_3-N fluxes in the Brazilian Cerrado.

The effect of no-tillage on decreasing CO_2 emissions is largely known (Piva et al., 2012). There are, however, many constrains related to the exact role of this cropping system in mitigating N_2O-N/ NH_3-N emissions, especially because the impact of management on soil microbial activity (Bardgett et al., 2008) is still largely unknown. N Losses via volatilization can be high under no-tillage because the fertilizer usually has a restricted contact with the soil, due to the presence of mulch or crop residues (Da Ros et al., 2005). Additionally, large amounts of N can be lost via N_2O-N fluxes under irrigation, where denitrification is stimulated by anaerobic conditions. Rochette (2008) reported that no-tillage generally increased N_2O-N emissions in poorly-aerated soils, and Woodward et al. (2009) suggested that adopting reduced or no-tillage systems, in some cases, enhances the emissions of N_2O-N from soil, especially due to increased denitrification. However, even within presumably homogenous regions, spatial and temporal variability and range of N_2O-N emissions is large (Pérez et al., 2001); hence, local assessments of N_2O-N emissions are indispensable to estimate the overall impact of agricultural systems on GHG emissions (Reay et al., 2012).

The objective of this work was to measure fluxes of N_2O-N and NH_3-N, throughout the growing season of irrigated common-bean, as affected by mulching and mineral fertilization.

Materials and Methods

The N-fluxes measurements were made within an area cultivated with common-bean under no-tillage, irrigated via center pivot, on a clayey Rhodic Ferralsol, located at Embrapa Arroz e Feijão, in Santo Antônio de Goiás, GO, Brazil (16°29'17"S and 49°17'57"W). Manual static chambers were used to measure N_2O-N fluxes, and manual open static chambers were used to measure NH_3-N fluxes. Congo signal grass was desiccated with glifosate (0.5 kg i.a. ha^{-1}) 15 days prior to the seeding of common-bean, in order to form mulch. In the treatments without Congo signal grass mulch, common-bean was cultivated on crop residues of maize. Common-bean ('BRS Agreste') was sown in June 9th and harvested in September 20th, 2008. From June to August 2008, there was no precipitation, air temperature ranged from 13° to 34ºC, and average daily evaporation was 154 mm.

The effects of mulching with Congo signal grass (*Urochloa ruziziensis*) and of mineral fertilization (NPK) on N-fluxes were evaluated. The evaluated treatments were: common-bean cultivated with Congo signal grass mulch and fertilizer; common-bean cultivated with mulch, but not fertilized; common-bean cultivated without mulch, but fertilized; and common-bean cultivated without mulch or fertilizers. Each treatment was assessed with six manual static chambers, used to measure the N-fluxes, each chamber corresponding to a replicate. The manual static chamber used to measure N_2O-N fluxes consisted of a metal base (0.38 m wide x 0.58 m long) covering a soil area of 0.22 m^2 and a plastic cap (0.1 m height) fixed on the metal base, similar to the chamber used by Alves et al. (2012). When closed, the volume of the chamber was 19.8 L.

Soil chemical and physical properties were determined in 1 m trenches according to Silva (2009) (Table 1). Fertilized treatments received 400 kg ha^{-1} fertilizer (5-30-15 N-P-K) applied at planting. Urea, 200 kg ha^{-1} (45% N) was applied via fertigation by the center pivot system: 100 kg ha^{-1} in the 27th day after sowing (DAS), and 100 kg ha^{-1} at 41 DAS. During fertigation, the chambers and corresponding area for soil sampling were covered with plastic to prevent any chance of contamination of the treatments without N fertilization. For these treatments, the same amount of water without N was applied via irrigation. Total irrigation (via center pivot), throughout the growing period, was 419 mm (about 9 mm per event at 29 hour intervals).

Fluxes of N_2O-N were measured after irrigation events at June 10, 11, 12, 13, 14, 17, 23; July 1, 7, 8, 9, 11, 12, 13, 14, 16, 21, 22, 23, 24, 25, 26, 30; August 6, 13, 20, 28; and September 3, 10, 18. Gas samples were taken between 9:00 to 11:00 a.m., as recommended by Alves et al. (2012). Gases accumulated in the static chamber in a period of 20 min were collected using a manual vacuum pump. From one chamber in each treatment, samples were taken at five-minute intervals, during the collection period of 20 min. Additionally, three air samples were taken to be used as controls. Soil temperature at 0.05 m soil depth next to the chambers was measured simultaneously with N_2O-N flux sampling. Concentration of N_2O inside each chamber was calculated as the difference between N_2O concentration in the air and N_2O concentration inside the chamber. Gas samples were analyzed by gas chromatography with an electron capture detector (ECD) auto system XL (Perkin Elmer, São Paulo, SP, Brazil), calibrated with certified N_2O standards of 350 and 1,000 ppb. Fluxes of N_2O-N were calculated according to Alves et al. (2012). When estimating total emitted N_2O-N, negative fluxes (lower than the concentration of the air), were set to zero. Total emissions were calculated by interpolating and integrating mean fluxes over time. Unfertilized treatments were used to calculate emission factor.

Fluxes of NH_3-N were quantified with manual open static chambers, each one covering 0.008 m^2 of ground. These chambers were made from 2 L plastic bottles of 0.1 m diameter, from which bottoms have been removed, according to Jantalia et al. (2012). Inside each bottle, a 70 mL plastic pot was hung and contained a polyethylene foam strip, moistened with 40 mL sulfuric acid solution (1.5 mol L^{-1} H_2SO_4 + 4% glycerol). These chambers were installed in the sowing lines, immediately after sowing, and were regularly replaced, when the foam strips were changed, allowing the soil under the chambers to receive the treatment with urea and irrigation. Foam strips were changed 19 times at June 11, 14, 18, 26; July 2, 8, 11, 14, 16, 21, 23, 25, 30; August 6, 13, 20, 28; and September 3, 10. Fluxes of NH_3-N were calculated based on N recovery of 57% for field conditions, according to Araújo et al. (2009).

Soil moisture, ammonium (NH_4^+) and nitrate (NO_3^-) concentrations were determined from 100 g soil samples collected within 0.5 m soil depth simultaneously with N_2O-N flux sampling. Around 10 g of soil was weighed, before and after drying in an oven for 24 hours at 105ºC. Soil moisture (cm^3 cm^{-3}) was calculated considering the soil bulk density (g cm^{-3}) determined for each treatment (Table 1). The available NH_4^+ and NO_3^- were determined according to Mulvaney (1996).

Table 1. Soil properties of a clayey Rhodic Ferralsol cultivated with irrigated common-bean under no-tillage with or without mulching, and in a noncultivated area (Cerrado), at 0–0.1 m, 0.1–0.3, and 0.3–0.5 soil depths.

Treatment	pH	Ca	Mg	H + Al	P	K	SOM	Clay	Silt	Sand	ρb
	water	-----------(cmol$_c$ dm^{-3})---------			----(mg dm^{-3})----		(g dm^{-3})	--------------(g kg^{-1})--------------			(g cm^{-3})
					0–0.1-m soil depth						
Mulching	5.36	0.86	0.40	7.4	46.8	156.75	22	509	80	411	1.47
Without mulching	5.45	1.05	0.41	7.7	65.2	114.75	22	554	110	336	1.48
Cerrado	5.10	0.18	0.10	8.0	1.5	0.08	40	600	100	300	0.96
					0.1–0.3-m soil depth						
Mulching	4.79	0.35	0.13	6.1	9.8	57.88	16	529	100	371	1.47
Without mulching	4.66	0.19	0.11	5.8	6.9	49.88	17	592	110	298	1.51
Cerrado	4.60	0.15	0.10	4.7	1.2	0.06	18	600	90	310	1.10
					0.3–0.5-m soil depth						
Mulching	5.06	0.43	0.15	3.6	1.3	39.38	10	549	100	351	1.25
Without mulching	5.14	0.43	0.14	3.2	0.9	54.13	11	609	110	281	1.40
Cerrado	5.10	0.10	0.10	2.5	0.8	0.03	10	650	70	280	1.09

SOM, soil organic matter; ρb, soil bulk density.

Soil microbial biomass was quantified from 200 g soil samples collected within 0.1 m soil depth, during common-bean flowering stage (56 DAS). N and C in the soil microbial biomass were determined by fumigation and extraction methods (Brookes et al., 1985; Vance et al., 1987).

Seventeen days after sowing the common-bean, maize crop residues or Congo signal grass mulch were collected in four spots of 0.08 m^2 within each treatment, in order to determine total dry matter mass, and total C and N content, using an elemental analyzer 2400 Series II CHNS/O (Perkin Elmer, São Paulo, SP, Brazil).

The analysis of variance was done using the generalized linear model procedure (Proc GLM) of SAS/STAT (SAS Institute, Cary, NC, USA). To contrast treatment effects, we used the Tukey's Studentized range test (at 5% probability). Correlations were determined between variables related to soil management and total emission of N_2O-N and NH_3-N; and a linear model was fitted to test whether the concentration of N_2O inside the chambers was dependent on the time of incubation. The magnitude of correlations and linear adjustment were assessed with the squared Pearson correlation coefficient between observed and predicted values (R^2). Parameter estimates are shown with respective nominal significance value (p-value) and standard error of estimates.

Results and Discussion

Approximately 34% of the N_2O-N measured fluxes were negative (lower than concentration of N_2O in the air). Most (54%) of the negative fluxes were measured in unfertilized areas (34% in Cerrado and 20% in unfertilized treatments). The concentration changes of N_2O over time inside the chambers were not significant for all treatments, except for the treatments fertilized with mulching and without mulching or fertilizer (Figure 1). Apart of the low fluxes itself, damping of flux diffusion control, pressure effects, and leaking – a source of error when using static chambers (Kroon et al., 2008) – are possible reasons for the observed nonsignificance. However, manual static chambers were reported to be the best method to get a direct measurement of small-scale spatial variability because it works well under all climate conditions and it has low cost, although it requires high workload (Drösler

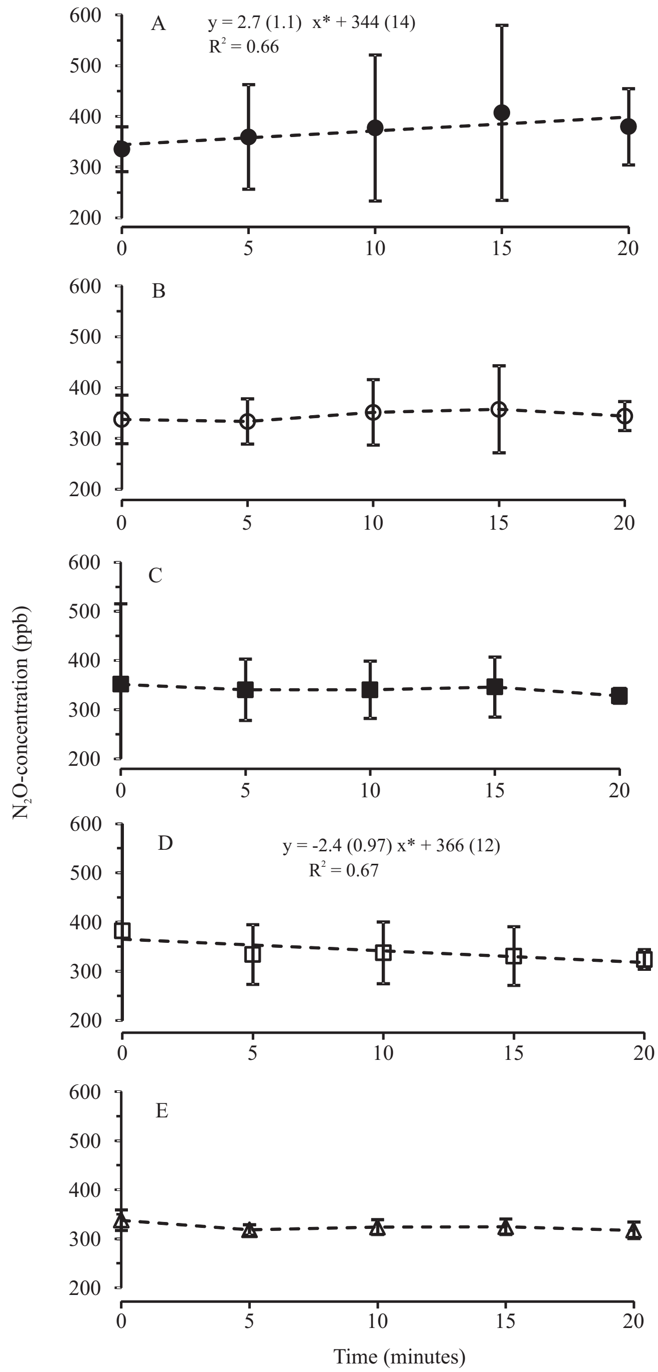

Figure 1. N_2O accumulation into manual static chambers placed in an irrigated common-bean crop system under no-tillage: A, with Congo signal grass mulch and fertilizer; B, with Congo signal grass mulch, without fertilizer; C, without Congo signal grass mulch and with fertilizer; D, without Congo signal grass mulch and without fertilizer; and E, noncultivated area (Cerrado). Black bars indicate the standard deviation of mean (n=19); dotted lines represent the fitted linear model; values between brackets represent the standard error of estimate. *Significant at 10% probability.

DOI: 10.1590/S0100-204X2013000500003

et al., 2008). Fluxes of N_2O-N (mg m^{-2} per day) ranged from -0.63±0.09 (Cerrado) to 1.74±0.84 (unfertilized mulching), and the ones of NH_3-N, from 4.66±2.44 (Cerrado) to 62.85±12.52 (fertilized mulching) (Figure 2).

Throughout the growing season, significantly higher N_2O-N fluxes occurred during 3 (1.71±1.01), 31 (0.47±0.34), and 79 (0.24±0.07) days after sowing event (DAS), in the fertilized mulching; and during 3 (1.74±0.85) and 79 (0.18±0.21) DAS in the unfertilized mulching (Figure 2). Increasing soil moisture and available mineral N were the main causes for higher N_2O-N fluxes during 3 and 31 DAS in fertilized mulching. Passianoto et al. (2003) also observed higher N_2O-N losses in a nontilled soil covered by mulch, than in tilled soil, during the first week following mineral fertilization. However, cumulative fluxes of N_2O-N during period 3, after fertilization and irrigation (42 to

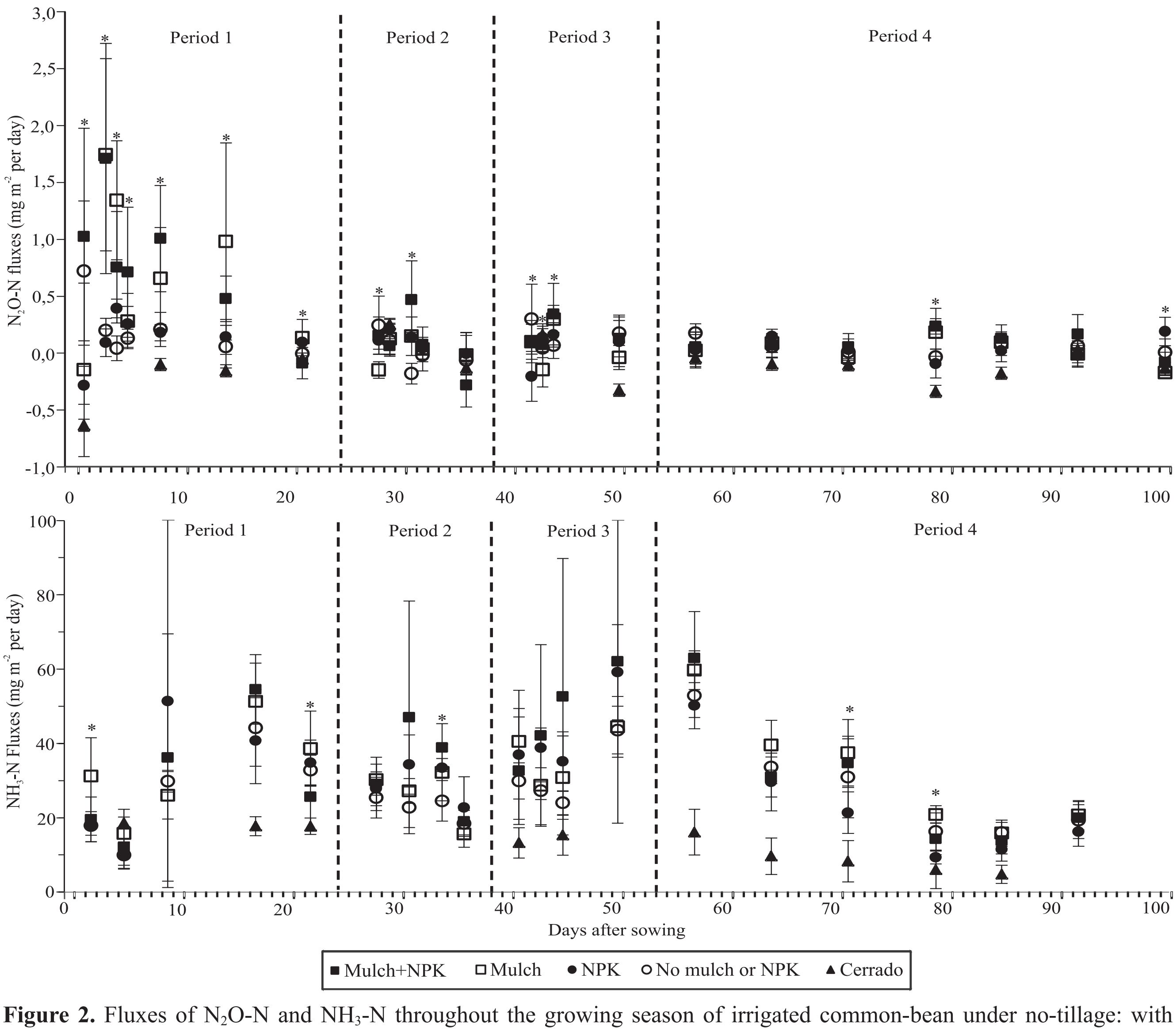

Figure 2. Fluxes of N_2O-N and NH_3-N throughout the growing season of irrigated common-bean under no-tillage: with Congo signal grass mulch and fertilizer (■Mulch+NPK); with mulch and no fertilizer (Mulch); without mulch, and with fertilizer (●NPK); without mulch of Congo signal grass, and without fertilizer (○No mulch or NPK); and from a noncultivated area (▲Cerrado). Dotted lines 1, 2, and 3 indicate the periods after mineral N fertilization; and period 4 indicates crop maturity, when no fertilization was applied. Bars represent standard deviation of means (n=6).*Significant differences among treatments, except for the noncultivated area (Cerrado), within each DAS, according to Tukey's Studentized test, at 5% probability.

50 DAS), were significantly higher than during period 1 (1 to 21 DAS), in the fertilized treatment without mulching, and were higher than during period 4 (57 to 100 DAS) in all treatments (Figure 3). Fluxes of NH_3-N, to the contrary, were more equally distributed over the growing season, with no significant difference for cumulative fluxes among periods for fertilized mulching. Moreover, no significant differences for NH_3-N fluxes between fertilized and unfertilized treatments were detected. Cumulative fluxes were higher in period 3 than in period 2 for the fertilized treatment without mulching (Figure 3). Cumulative fluxes of NH_3-N were significantly higher in period 4 (57 to 92 DAS), during crop maturity, than in periods 1, 2, and 3, in the unfertilized treatments.

Total emitted NH_3-N was not statistically different between fertilized and unfertilized treatments; however, it was significantly higher in the fertilized mulching than in the unfertilized treatment without mulching. Total emitted N_2O-N was significantly higher with Congo signal grass mulch than without it (Table 2). Total emission of both N_2O-N and NH_3-N and the contents of moisture and nitrate within 0.5 m soil depth were significantly lower in the Cerrado than in the crop system (Table 2). Total emission of N-N_2O and NH_3-N was positively correlated with contents of soil moisture, nitrate, and ammonium within 0.5 m soil depth. Total N_2O-N emission was positively correlated with total C added by mulch or crop residues, and with C and N in microbial biomass within 0.1 m soil depth

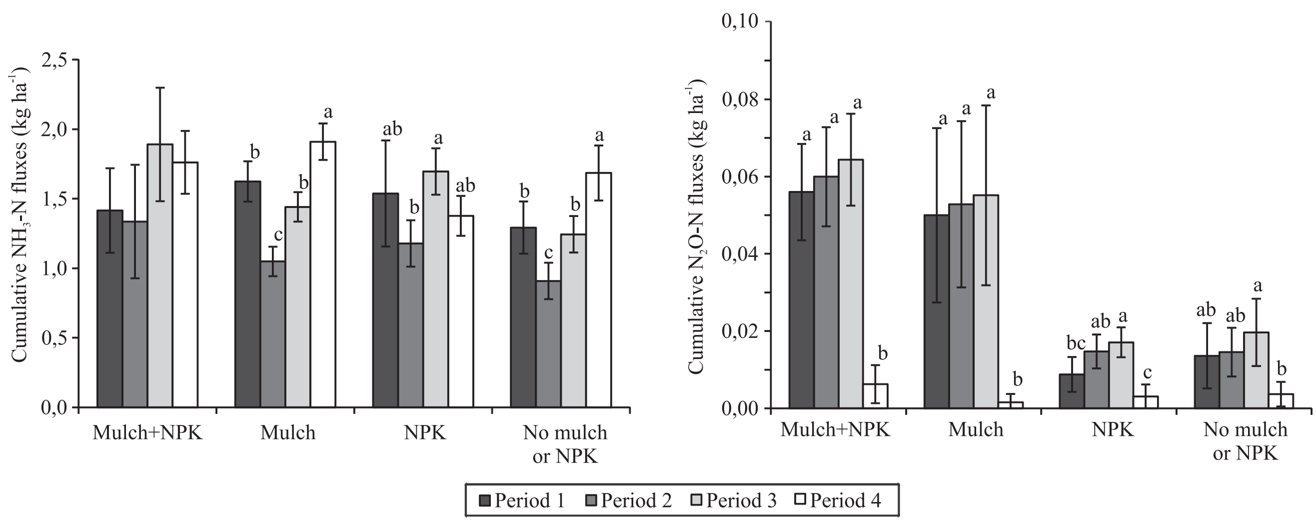

Figure 3. Cumulative N_2O-N and NH_3-N fluxes within four periods over growing season of irrigated common-bean under no-tillage, with or without mulching and mineral fertilization (NPK). Periods after fertilization and irrigation are represented by the periods 1, 2 and 3; and crop maturity, by period 4, when no fertilization was applied. Bars represent standard deviation of mean (n=6). Values followed by the same letter are not significantly different, according to Tukey's Studentized test, at 5% probability.

Table 2. Total N_2O-N and NH_3-N emissions, soil moisture within 0.5 m soil depth, concentration of soil nitrate (N-NO_3^-) and ammonium (N-NH_4^+) within 0.5 m depth, carbon (CMB) and nitrogen (NMB) in soil microbial biomass within 0.1 m depth, and total carbon and nitrogen in mulch and crop residues, in an irrigated common-bean crop system under no-tillage[(1)].

Treatment	Emitted		Soil moisture	N-NO_3^-	N-NH_4^+	CMB	NMB	Mulch or residues	
	N_2O-N	NH_3-N						Total C	Total N
	--(kg ha^{-1} per season)--		(cm^3 cm^{-3})	------------------------(mg kg^{-1})-----------------------				-------(Mg ha^{-1})--------	
Mulch+NPK	0.229a	6.40a	0.98b	329b	115ab	413ab	45b	0.9b	0.014b
Mulch	0.213a	6.03ab	0.99b	244c	120a	377abc	41b	1.1b	0.020b
NPK	0.107b	5.79ab	1.00b	383a	119a	288bc	39b	0.8b	0.026b
No Mulch or NPK	0.094b	5.13b	1.04a	291b	119a	239c	38b	0.6b	0.007b
Cerrado	0.001c	1.22c	0.62c	62d	105b	482a	76a	4.9a	0.104a
CV (%)	34	21	0.97	5	3	21	15	51	48

[(1)]Values followed by the equal letters are not significantly different, according to Tukey's Studentized test, at 5% probability.

(Table 3). Carbon in microbial biomass for treatments with mulch was equivalent to that observed in the Cerrado (Table 2), meaning that the soil under this mulch was as biologically active as the Cerrado soil. Because of the irrigation, however, soil moisture was higher in the crop system.

In an irrigated crop system, the amount of water applied can be associated with the magnitude of N_2O-N emission (Scheer et al., 2012). In the same Ferralsol of the present study, Metay et al. (2007) observed that N_2O-N fluxes were positively related to increasing water-filled pore space. Zanatta et al. (2010) found the highest fluxes of N_2O-N during 45 days after soil management associated with high water-filled pore space and increased organic C and mineral N, which accounted for 30% of N_2O-N emissions in a year. During two years of field experiment, Jantalia et al. (2008) observed the highest fluxes of N_2O-N after periods of high rainfall associated with mineral fertilization. However, the C content in the mulch and microbial activity, favoured by the Congo signal grass, induced a higher emission of N_2O-N in treatments with mulching, regardless of N fertilization. The presence of mulch has been considered important for high N_2O-N emissions in no tillage systems (Gomes et al., 2009). Baggs et al. (2003) reported that surface-mulching residues of rye resulted in higher N_2O-N losses than with the incorporation of residues. They attributed this result to the degradable C of rye in the presence of anaerobic conditions under mulch. Available organic C, associated with increasing water-filled pore space, can induce anaerobic sites, which can enhance denitrification of the available nitrate in soil, resulting in high N_2O-N fluxes in no tillage system (Giacomini et al., 2006).

Table 3. Pearson correlation coefficients representing the relationship between total emission of N (N_2O-N + NH_3-N) and soil management variables in an irrigated common-bean crop system under no-tillage[(1)].

Variable	Including the Cerrado		Excluding the Cerrado	
	N_2O-N	NH_3-N	N_2O-N	NH_3-N
Soil moisture (cm^3 cm^{-3})	0.5795^{**}	0.9339^{***}	-0.4854^{ns}	-0.4552^{ns}
Soil N-NO^{-3} (mg kg^{-1})	0.5279^{**}	0.8990^{***}	-0.1402^{ns}	0.2768^{ns}
Soil N-NH_4^+ (mg kg^{-1})	0.4553^{*}	0.7797^{***}	-0.1643^{ns}	-0.1084^{ns}
CBM (mg kg^{-1})	-0.0633^{ns}	-0.4528^{**}	0.5924^{***}	0.2880^{ns}
NBM (mg kg^{-1})	-0.4992^{**}	-0.8100^{***}	0.3997^{*}	0.2819^{ns}
Total C (Mg ha^{-1})	-0.5021^{**}	-0.8368^{***}	0.4620^{*}	0.1815^{ns}
Total N (Mg ha^{-1})	-0.5301^{**}	-0.8465^{***}	0.2375^{ns}	0.2914^{ns}

[(1)]CBM and NBM, C and N in microbial biomass measured within 0.1 m soil depth; total C and N, measured from Congo signal grass mulch and crop residues, after 17 days from sowing. ^{ns}Nonsignificant. ***, ** and *Significant at 1, 5, and 10% probability, respectively.

Nitrogen losses (N_2O-N + NH_3-N) from the applied mineral N (emission factor) varied from 0.01% (fertilized without mulching) to 0.02% (fertilized mulching) for N_2O-N, and from 0.3% (fertilized mulching) to 0.6% (fertilized without mulching) for NH_3-N. These values were much lower than the default value proposed by the Intergovernmental Panel on Climate Change (IPCC), which is 1% for N_2O-N, ranging from 0.3% to 3%; and 10% for NH_3-N, ranging from 3 to 30%. In an irrigated common-bean crop system in the Brazilian Cerrado, with broadcasted urea, Cruvinel et al. (2011) found an emission factor for N_2O-N of 0.20%. The emission of N_2O-N found in the present study was equivalent to that measured by Metay et al. (2007) of 0.03%, in a rainfed rice crop system under no tillage, with Congo signal grass mulch, in a Cerrado Ferralsol. Literature information on NH_3-N fluxes is rather variable, since they are often obtained through different methodologies. Using semi open static chambers, Da Ros et al. (2005) observed 17% NH_3-N losses of the urea broadcasted on crop residues, in a subtropical Acrisol, in Southern Brazil. Using open chambers, Jantalia et al. (2012) observed 1.9% to 2.4% NH_3-N losses of the urea broadcasted in an irrigated system. Turner et al. (2012) found NH_3-N losses ranging from 1.8 to 23% of the added N fertilizers in different cropping systems. They attributed the variability of these results to soil-climate conditions, such as soil moisture, temperatures, and wind speed. Due to the wide range of values that can be obtained, estimation of N losses from fertilizer application in crop systems is challenging.

Conclusions

1. Carbon content of the mulch and soil microbial activity, both favoured by *Urochloa ruziziensis*, enhances the emissions of N_2O-N in treatments with mulching, regardless of N fertilization.

2. Total N_2O-N and NH_3-N emissions are positively related to the concentrations of moisture, ammonium, and nitrate within 0.5 m soil depth, when mineral fertilization is used.

3. Emission factors for N_2O-N and NH_3-N under the conditions of this study were lower than the default value recognized by the Intergovernmental Panel on Climate Change.

Acknowledgments

To Challenge Program on Climate Change (CGIAR), to Agriculture and Food Security (CCAFS), and to the Faculty of Life Sciences, University of Copenhagen, for providing funds; to Bruno José Rodrigues Alves and João Eudes Santana Lima, whose advices were important to enable this study; to Jaison Pereira Oliveira and Aline de Holanda Nunes Maia, for guidance on data analysis; and to Prof. Holger Meinke and Pepijn A.J. van Oort, who kindly revised the scientific content.

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Received on Dezember 26, 2012 and accepted on April 17, 2013