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#### REFERÊNCIA

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# Nitrogen oxides and CO<sub>2</sub> from an Oxisol cultivated with corn in succession to cover crops

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**Abstract** – The objective of this work was to evaluate the effect of two legumes (*Crotalaria juncea* and *Mucuna pruriens*), as cover crops, and of natural fallow, as a control treatment, on the emissions of NO<sub>x</sub>, N<sub>2</sub>O, and CO<sub>2</sub> from an Oxisol cultivated with corn, under conventional and no-tillage systems, in the Cerrado region, in Central Brazil. Variations of CO<sub>2</sub> fluxes in the soil were explained mainly by soil humidity and, in the legumes, under conventional system, by soil NH<sub>4</sub><sup>+</sup>-N concentration. Plots with legumes under no-tillage system had higher annual emissions of CO<sub>2</sub>, NO<sub>x</sub>, and N<sub>2</sub>O than natural fallow. Results show that the use of legumes as cover crops favors the emissions of NO<sub>x</sub>-N + N<sub>2</sub>O-N and CO<sub>2</sub>-C. However, when considering the potential for mitigation of CO<sub>2</sub> and nitrogen oxide emissions from the soil, it is important to evaluate changes in soil carbon and nitrogen stocks.

**Index terms:** *Crotalaria juncea*, *Mucuna pruriens*, carbon and nitrogen stocks, Cerrado, mitigating greenhouse gases.

## Óxidos de nitrogênio e CO<sub>2</sub> de Latossolo cultivado com milho em sucessão a plantas de cobertura

**Resumo** – O objetivo deste trabalho foi avaliar o efeito de duas leguminosas (*Crotalaria juncea* e *Mucuna pruriens*), usadas como plantas de cobertura, e de vegetação espontânea, como tratamento-controle, sobre as emissões de NO<sub>x</sub>, N<sub>2</sub>O e CO<sub>2</sub> de um Latossolo Vermelho cultivado com milho, em sistemas convencional e de plantio direto, na região do Cerrado, no Brasil Central. As variações dos fluxos de CO<sub>2</sub> no solo foram explicadas principalmente pela umidade do solo e, nas leguminosas, sob sistema convencional, pela concentração de N-NH<sub>4</sub><sup>+</sup>. Parcelas com leguminosas em sistema plantio direto mostraram maiores emissões anuais de CO<sub>2</sub>, NO<sub>x</sub> e N<sub>2</sub>O do que a vegetação espontânea. Os resultados mostram que o uso de leguminosas como plantas de cobertura favorece as emissões de N-NO<sub>x</sub> + N-N<sub>2</sub>O e C-CO<sub>2</sub>. Entretanto, ao se considerar o potencial de mitigação de emissões de CO<sub>2</sub> e de óxidos de nitrogênio oriundas do solo, é importante avaliar as variações nos estoques de carbono e nitrogênio no solo.

**Termos para indexação:** *Crotalaria juncea*, *Mucuna pruriens*, estoques de carbono e nitrogênio, Cerrado, mitigação de gases de efeito estufa.

### Introduction

The Cerrado (Brazilian savanna) biome originally occupied approximately 200 million hectares, but since the 1970s has been changed by an intense agricultural expansion. It is estimated that more than 50% of the area has lost its original vegetation, mainly through conversion to pastures and croplands (Beuchle et al., 2015). Currently, the Cerrado is the most important region for beef and grain production in Brazil and a potential area for the expansion of integrated crop-

livestock systems (IBGE, 2015). The dominant soils are Oxisols, and no-tillage systems were introduced in the mid-1980s, but with a rare use of cover crops to prevent soil erosion (Bayer et al., 2009). In addition, there is a demand for the selection of suitable cover crops to improve soil organic carbon and to mitigate the emissions of greenhouse gases (GHGs) from the soil to the atmosphere.

The conversion of the native vegetation of the Brazilian Cerrado to soybean (*Glycine max* L.) monoculture using conventional tillage is estimated to

reduce soil C stocks between 0.50–0.67 Mg ha<sup>-1</sup> C per year, at the 0–0.40-m layer, after 50 years of adoption (Corbeels et al., 2006). However, in the same study, these authors also predicted that the conversion of traditional soybean monoculture to cropping systems with no-tillage and direct seeding into a mulch of crop residues could result in the storage of 0.70–1.15 Mg ha<sup>-1</sup> C per year, at the same layer, during the first 12 years after the conversion. Therefore, the intensification of crop production with no-tillage practices can enhance C accumulation rates by increasing biomass production, through which greater amounts of crop residues are returned to the soil (Battle-Bayer et al., 2010; Carvalho et al., 2014b).

In Brazil, the Agriculture, Forestry and Other Land Uses (Afolu) sector contributes with approximately 46 and 95% of the total anthropogenic CO<sub>2</sub> and N<sub>2</sub>O emissions, respectively (Estimativas..., 2014). Some of the factors and management practices that might affect the emission of greenhouse gases from the soil to the atmosphere, include: soil tillage (conventional and no-tillage), deposition of crop residues, organic and inorganic N fertilization amendments, irrigation, low N use efficiency by annual crops, and cultivation of N-fixing species (Edenhofer et al., 2014). However, with the increasing establishment of no-tillage cropping practices based on direct seeding into a mulch of crop residues, an improved understanding of the relationship between cover crops and CO<sub>2</sub>, N<sub>2</sub>O, and NO<sub>x</sub> fluxes is important for the development of sustainable agricultural practices for the Cerrado region. Cover crops combined with the use of no-tillage or reduced tillage have been identified as potentially beneficial for mitigating greenhouse gas emissions (Abdalla et al., 2014; Edenhofer et al., 2014).

The application of N fertilizers is a common practice for intensive agriculture in the Brazilian Cerrado, especially in crops with high demands of this nutrient, as, for example, corn (*Zea mays* L.). The use of N-fixing legumes, such as *Crotalaria juncea* L. and *Mucuna pruriens* (L.) DC., as cover crops in agricultural systems can incorporate more than 230 kg ha<sup>-1</sup> N (Calegari et al., 2008). This practice could contribute to the reduction of the quantities of mineral N fertilizers applied, but its impacts on GHG emissions from the soil are still not widely evaluated in tropical agricultural systems (Carvalho, 2005; Carvalho et al., 2006; Metay et al., 2007; Cruvinel et al., 2011; Abdalla et al., 2014).

The objective of this work was to evaluate the effect of two legumes, as cover crops, and of natural fallow, as a control treatment, on the emissions of NO<sub>x</sub>-N, N<sub>2</sub>O-N, and CO<sub>2</sub>-C from a Oxisol cultivated with corn under conventional and no-tillage systems, in the Cerrado region, in Central Brazil.

## Materials and Methods

The experiment was carried out in Planaltina, Brasília, DF, Brazil (15°39'S, 47°44'W, at an altitude of 1,100 m), on a plateau in the center of the Cerrado region. During the study period, from June 2002 to June 2003, monthly rainfall ranged from null, in June 2002, to 252 mm in January 2003. The monthly mean temperature oscillated between 19°C, in June 2003, and 27°C in March 2003 (Figure 1). The original vegetation, classified as Cerrado stricto sensu, was removed in 1975 and, after corrective fertilization with lime and phosphate, was subjected to different land uses, including crops, pasture, and fallow. The soil is classified as a Latossolo Vermelho distroférico, i.e., a Typic Acrustox, with clay texture (Santos et al., 2013). The experiment was set up in November 1996 when corn was cultivated, and cover crops were planted at the end of the rainy season, in April 1996, after harvesting the previous corn crop.

In 1996, before the experiment installation, the results of soil chemical and particle size analyses, at the 0.0–0.20-m layer, were: 6.2 pH in water; 3.4 mg kg<sup>-1</sup> available P; 3.4 cmol<sub>c</sub> kg<sup>-1</sup> exchangeable K<sup>+</sup>+Ca<sup>2+</sup>+Mg<sup>2+</sup>; 3.3 cmol<sub>c</sub> kg<sup>-1</sup> H+Al; 0.01 cmol<sub>c</sub> kg<sup>-1</sup> exchangeable Al<sup>3+</sup>; 23.6 g kg<sup>-1</sup> organic matter; 513 g kg<sup>-1</sup> clay; 186 g kg<sup>-1</sup> silt; and 301 g kg<sup>-1</sup> sand.

At the beginning of the experiment in January 1996, the area was fertilized with 180 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> (as single superphosphate), 60 kg ha<sup>-1</sup> K<sub>2</sub>O (as potassium chloride), 50 kg ha<sup>-1</sup> micronutrients (7% Zn, 2.5% Bo, 1% Cu, 4% Fe, 4% Mn, 0.1% Mo, and 0.1% Co), and 500 kg ha<sup>-1</sup> CaSO<sub>4</sub>.

The experimental design was a randomized complete block in a split-plot arrangement with experimental units replicated three times. Cover crops were sown into 12x30-m whole plots in March, at the end of each rainy season, following corn cultivation under conventional and no-tillage systems, both in 12x15-m subplots. Plots and subplots were separated by a 1-m border. Fertilizers were incorporated with the

plant residues before corn sowing: under conventional system, using a disk plough and harrow in subplots; and, under no-tillage system, applied on soil surface.

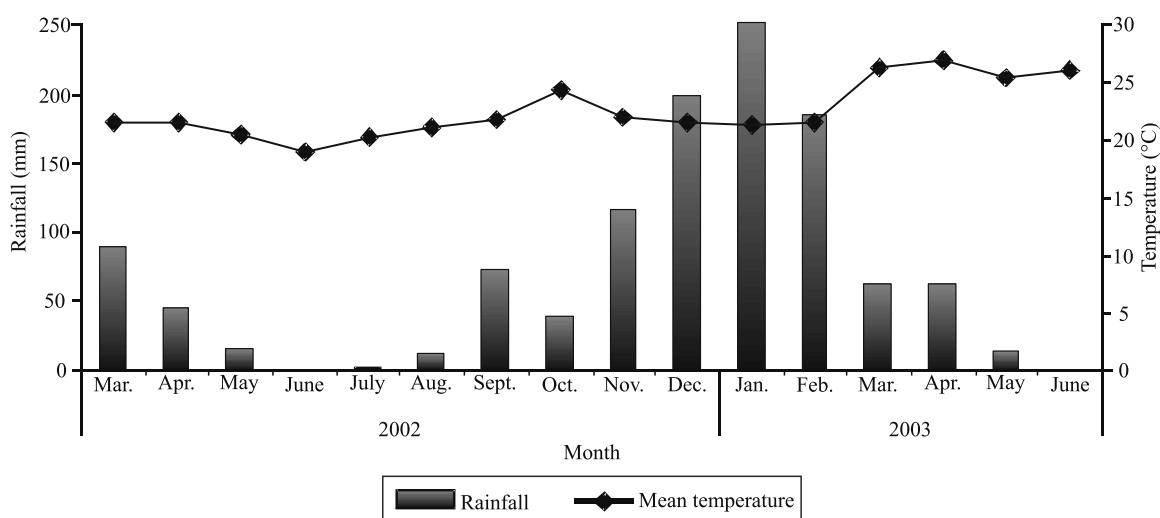
Two legumes were used as cover crops before the next corn cultivation: *Crotalaria juncea* and *Mucuna pruriens* (both Leguminosae), with seeds sown 3 cm deep in 0.5-m wide rows, using a no-tillage seeder. The control treatment consisted of natural fallow. Additional information on management practices in the experimental area is described by Carvalho et al. (2014a).

Gas measurements were performed as follows. NO<sub>x</sub>-N and CO<sub>2</sub>-C were measured using the dynamic chamber technique. For this, polyvinyl chloride (PVC) cylindrical chambers with 24 cm in diameter and 8.7 L were used. Chamber bases were inserted 2 cm into the soil 30 min before each measurement, according to Cruvinel et al. (2011) and Lessa et al. (2015). Air was circulated in a closed loop between the chamber and the analyzers. NO<sub>x</sub> was analyzed using a NO<sub>x</sub> Box LMA-3D (Drummond Technology Inc., Unisearch Associates, Inc., Bowmanville, Ontario, Canada), after first converting NO to NO<sub>2</sub> by passing the gas sample through CrO<sub>3</sub>. NO<sub>2</sub> reacts with Luminol solution to produce a luminescent reaction that is functionally related to the mixing ratio of NO<sub>2</sub>. NO concentration was recorded over a 5-min period. Fluxes were calculated from the increase rate of NO concentration, using the linear portion of the accumulation curve. Calibration was conducted in the field before and after chamber measurements using mixtures of a NO standard

(0.4 ppm) with NO<sup>-</sup> and NO<sub>2</sub><sup>-</sup> free air. CO<sub>2</sub>-C was analyzed over a 3-min period using a photosynthesis system with integrated infrared gas analyzer and data system, model LI-COR 6200 (LI-COR Biosciences, Lincoln, NE, USA). CO<sub>2</sub>-C concentrations were logged every 2 s, yielding a continuous monitoring of increasing CO<sub>2</sub> concentrations that were used to fit the most appropriate regression function.

N<sub>2</sub>O-N fluxes were measured using a static chamber technique. To determine N<sub>2</sub>O-N fluxes, four gas samples were collected from the headspace of a static chamber using 60 mL polypropylene syringes with siliconized polypropylene plungers. The first sample was taken immediately after chamber closure, at time point zero, whereas the other samples were removed 10, 20, and 30 min after chamber closure. At the laboratory, the samples were analyzed within 24 hours after sample collection with a gas chromatograph Shimadzu GC-14A (Shimadzu do Brasil, São Paulo, SP, Brazil) fitted with a <sup>63</sup>Ni electron capture detector. N<sub>2</sub>O-N fluxes were calculated from the increase rate of the concentration, determined by linear regression based on the four samples taken. The detection limit of 0.6 ng N<sub>2</sub>O-N cm<sup>-2</sup> h<sup>-1</sup> was adopted in the present study, since similar system and methods were used (Carvalho et al., 2006).

Measurements of CO<sub>2</sub>-C and NO<sub>x</sub> emissions were performed from June 2002 to June 2003, during a period of 367 days, while fluxes of N<sub>2</sub>O-N were measured during nine months, from September 2002 to June 2003. Gas samples were taken monthly and



**Figure 1.** Monthly rainfall distribution and air temperature from March 2002 to June 2003, measured at the meteorological station of Embrapa Cerrados in Planaltina, Brasília, DF, Brazil.

for three consecutive days after corn and cover crop management events and rainfall. Table 1 shows the sampling events and the main agricultural practices. In the case of fertilization events, gas fluxes were measured on the third day after fertilizer application and subsequently for three days, which is in alignment with previous studies under similar conditions, in which the highest emissions were detected three days after fertilizer application (Carvalho et al., 2006; Paredes et al., 2014). Annual CO<sub>2</sub>-C, NO-N, and N<sub>2</sub>O-N fluxes were estimated from the average of fluxes obtained during the 12 total measurement campaigns.

Four field-moist samples were collected at 0–0.05-m depth in every plot, in all sampling dates, in order to determine water-filled pore space (WFPS, in percentage), NO<sub>3</sub><sup>-</sup>-N, and NH<sub>4</sub><sup>+</sup>-N. Other co-variables, including water content and soil temperatures, at 0.025- and 0.050-m depth, were obtained during the gas flux measurements. Soil samples were dried to constant weight, at 105°C, for determination of soil moisture by the gravimetric method. Bulk density was determined at 0–0.05-m depth from undisturbed samples (Santos et al., 2013); the particle density value of 2.65 g cm<sup>-3</sup> was considered. The values of gravimetric water contents  $\theta_g$  (g g<sup>-1</sup>) were converted into WFPS, using the following equation: WFPS (%) =  $\{(\theta_g \times ds \times 100)/[1 - (ds/dp)]\}100$ , in which ds is soil density and dp is particle density, both expressed in g cm<sup>-3</sup>.

To measure NO<sub>3</sub><sup>-</sup>-N and NH<sub>4</sub><sup>+</sup>-N, soil samples were extracted at 0–0.05-m depth, with 2 mol L<sup>-1</sup> KCl for 1 hour, and the inorganic-N concentrations were obtained colorimetrically. Specifically, NO<sub>3</sub><sup>-</sup>-N was determined by UV absorption according to Meier (1991), and NH<sub>4</sub><sup>+</sup>-N, through reaction with Nessler reagent. The results were expressed on a 105°C oven-dry weight basis.

Multiple regression analysis was performed through the statistical method of variable selection (stepwise), at 5% probability, to determine the variable(s) that better explain the fluxes of NO<sub>x</sub>-N and CO<sub>2</sub>-C. The variables measured during sampling were subjected to analysis of correlation to avoid that those with high correlation coefficients (high collinearity) be tested together through the multiple regression model. Wilcoxon's nonparametric test was used to compare the averages of the fluxes of CO<sub>2</sub>-C, NO-N, and N<sub>2</sub>O-N obtained in the treatments, at 5% probability. Analyses were performed using SAS systems for Windows, version 9.3 (SAS Institute Inc., Cary, NC, USA).

## Results and Discussion

The WFPS values, at 0–0.05-m depth, mainly related to rainfall events, increased between July (10–20%) and November (41%) before corn sowing (Figure 2). During N fertilization, the WFPS values were 32%, on November 28, and 42% on December 19 and January 31. Soil humidity decreased again to 20% from April

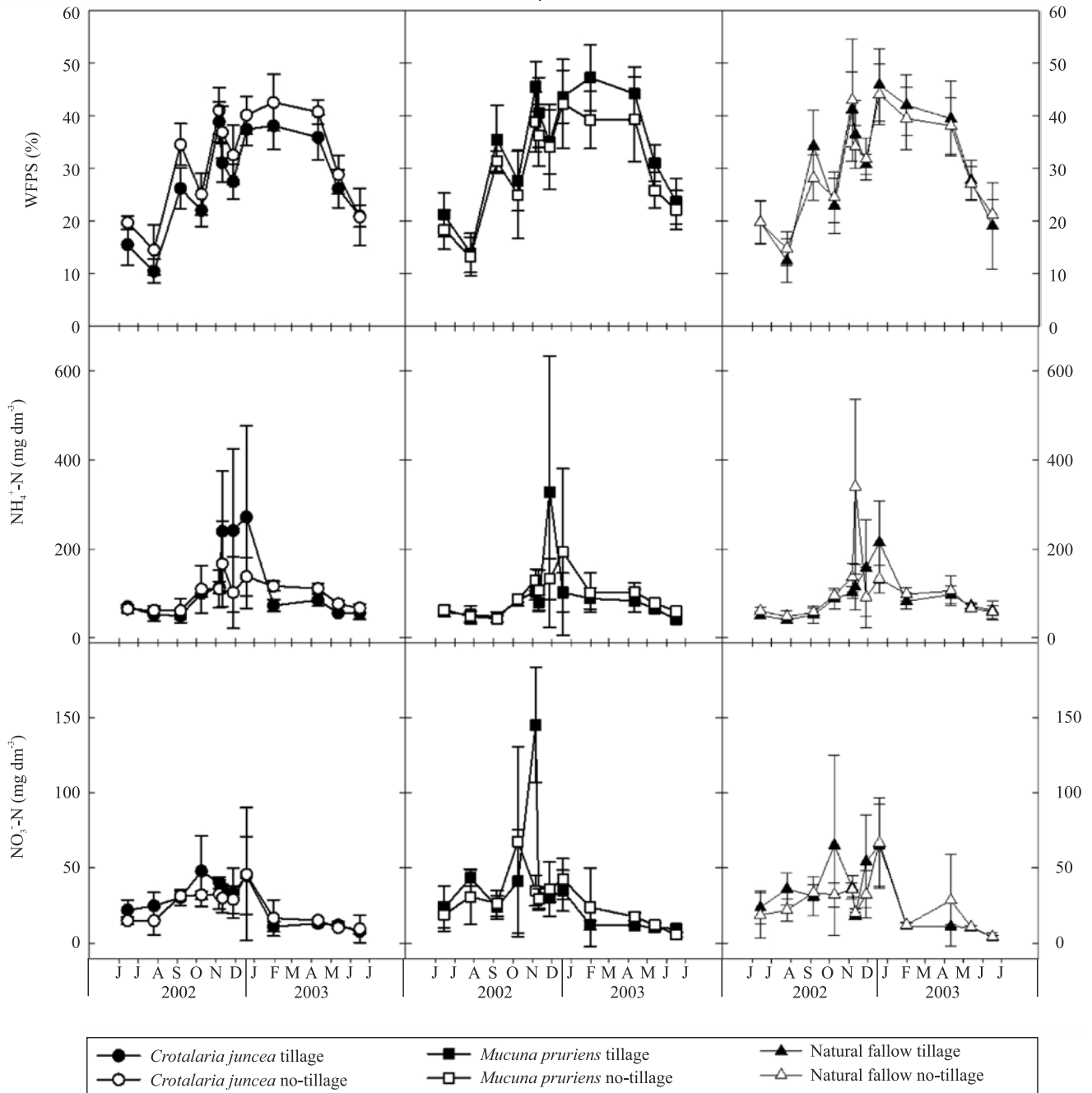
**Table 1.** Temporal distribution of gas measurements in plots with corn (*Zea mays*) planted in succession to cover crops.

Season	Management and fertilizer application	Rainfall (mm)	CO <sub>2</sub>	NO <sub>x</sub>	N <sub>2</sub> O
Dry season					
June 2002 and July 2002	Cutting of cover crops and cutting of cover crops	0	x	x	
Transition dry/wet season					
September 2002	First rainfall events	61.0	x	x	x
October 2002		39.3	x	x	
Rainy season					
November 2002	Before corn planting	37.0	x	x	x
November 2002	At corn planting (20 kg ha <sup>-1</sup> N as urea, 150 kg ha <sup>-1</sup> P <sub>2</sub> O <sub>5</sub> , and 80 kg ha <sup>-1</sup> K <sub>2</sub> O) and after corn planting	17.2	x	x	x
November 2002	N fertilization side-dressed at the V-6 stage (50 kg ha <sup>-1</sup> N as urea)	51.4	x	x	x
December 2002	N fertilization side-dressed with 50 kg ha <sup>-1</sup> N as urea at the V-8 and at the silking stage	199.0	x	x	
Transition wet/dry season					
April 2003 and May 2003	After corn maturation and Post-harvest	63.8	x	x	x
Dry season					
June 2003	Fallow	0	x	x	x

to June, which represents the transition from the wet to the dry season.

The NO<sub>x</sub>-N and CO<sub>2</sub>-C fluxes started to increase at end of the dry season, i.e., from July-August to September, after the first rainfall events of the transition from the dry to the wet season (Figures 1 and 3). Pulses

of NO<sub>x</sub>-N emissions with first rainfall events, after a long dry period, have been reported and are related to the reactiveness of the water-stressed soil decomposers and to dormant nitrifying bacteria that start to mineralize and metabolize organic and inorganic N in the soil, releasing NO as a by-product (Cruvinel et al., 2011; Hudman et

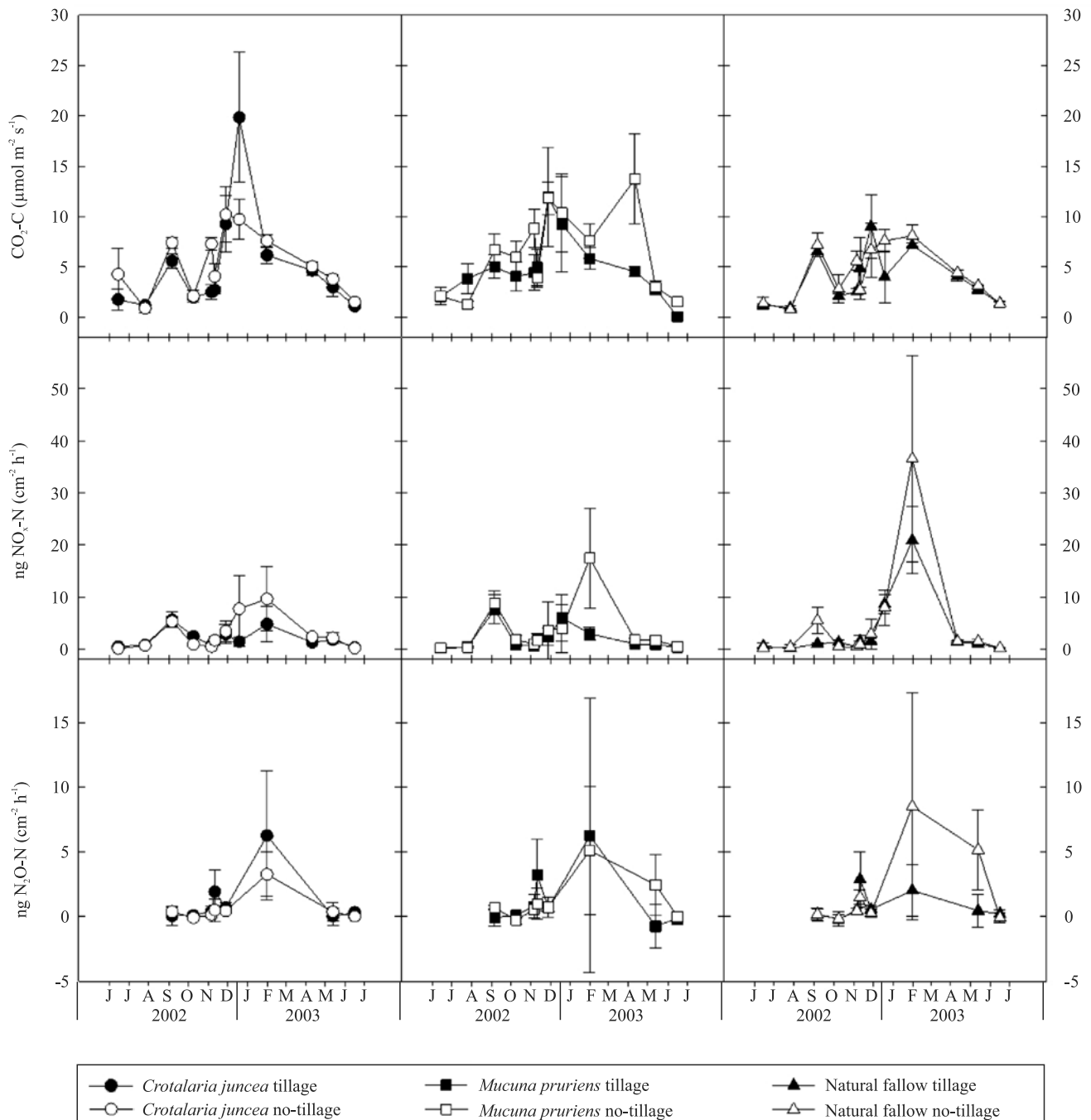


**Figure 2.** Water-filled pore space (WFPS), NH<sub>4</sub><sup>+</sup>-N, and NO<sub>3</sub><sup>-</sup>-N concentrations in an Oxisol in the Cerrado region, in Central Brazil, at 0–0.05-m depth, as affected by cover crops planted before corn (*Zea mays*) under conventional and no-tillage systems.

al., 2012; Marquina et al., 2015). In addition,  $\text{CO}_2\text{-C}$  fluxes are positively correlated with  $\text{NO}_x\text{-N}$  emissions and also to microbial activity that can explain higher fluxes of  $\text{CO}_2\text{-C}$  with the first rainfall events, after a long dry period (Marquina et al., 2015). Samples collected

during the dry season show low emissions of GHGs due to soil humidity, as observed by Metay et al. (2007).

The highest value ( $8.2 \text{ ng NO}_x\text{-N cm}^{-2} \text{ h}^{-1}$ ) of  $\text{NO}_x\text{-N}$  fluxes in September was measured in the plots with *M. pruriens* under conventional tillage and no-



**Figure 3.**  $\text{CO}_2\text{-C}$ ,  $\text{NO}_x\text{-N}$ , and  $\text{N}_2\text{O-N}$  fluxes from an Oxisol in the Cerrado region, in Central Brazil, as affected by cover crops planted before corn (*Zea mays*) under conventional and no-tillage systems.

tillage systems, whereas the lowest one (1.0 ng NO-N cm<sup>-2</sup> h<sup>-1</sup>) was determined in plots with natural fallow under both systems. However, CO<sub>2</sub>-C fluxes did not differ significantly between cover crops. In the same month, considering the two legumes and natural fallow, soil CO<sub>2</sub>-C fluxes showed slightly higher value (7.1 μmol CO<sub>2</sub>-C m<sup>-2</sup> s<sup>-1</sup>) under no-tillage system than under conventional tillage (5.7 μmol CO<sub>2</sub>-C m<sup>-2</sup> s<sup>-1</sup>).

The highest peaks of CO<sub>2</sub>-C and NO<sub>x</sub>-N generally occurred after the application of N fertilizer for corn grown from November to December. In April, at the end of the wet season, a CO<sub>2</sub> peak was measured in the area cultivated with *M. pruriens* under no-tillage (Figure 3), when WFPS was still 40%; it decreased to 28 and 21% in May and July, respectively (Figure 2).

The average concentrations of NH<sub>4</sub><sup>+</sup>-N and NO<sub>3</sub><sup>-</sup>-N, considering the two management systems and cover crops, from June to September, were 52 and 30 mg kg<sup>-1</sup>, respectively (Figure 2). In October, the concentrations of NH<sub>4</sub><sup>+</sup>-N and NO<sub>3</sub><sup>-</sup>-N increased to 94 and 48 mg kg<sup>-1</sup>, respectively. Before corn sowing in November, soil concentration of NH<sub>4</sub><sup>+</sup>-N reached 116 mg kg<sup>-1</sup>, which is the mean of all treatments. For NO<sub>3</sub><sup>-</sup>-N, there was a slight increase of 40 mg kg<sup>-1</sup> from the previous months to November, with the exception of the plots with *M. pruriens*, which showed a greater average increase of 145 mg kg<sup>-1</sup> under conventional tillage. After N fertilizer applications, mean concentrations of soil NH<sub>4</sub><sup>+</sup>-N ranged from 93 to 175 mg kg<sup>-1</sup>.

Losses of N in the form of NO<sub>x</sub>-N are higher than in the form of N<sub>2</sub>O-N during the evaluated period, as also found in other studies, under different cropping systems (Cruvinel et al., 2011; Marquina et al., 2015). The incorporation of the residues before corn cultivation

promoted higher soil aeration and may have stimulated NO<sub>x</sub> emissions over N<sub>2</sub>O emissions (Carvalho et al., 2006; Metay et al., 2007). Most of soil N<sub>2</sub>O fluxes were below the detection limit, i.e., <0.6 ng N<sub>2</sub>O-N cm<sup>-2</sup> h<sup>-1</sup>. However, an increase in N<sub>2</sub>O-N fluxes was observed after corn was planted, with a mean of 1.8 ng N<sub>2</sub>O-N cm<sup>-2</sup> h<sup>-1</sup>, besides higher values under conventional tillage. Higher N<sub>2</sub>O emissions after this post-management period, specially under this system, could be related with higher N mineralization, with increases in NH<sub>4</sub><sup>+</sup>-N and NO<sub>3</sub><sup>-</sup>-N, due to the faster decomposition of the cover crop residues with the application of N fertilizer and soil plowing (Jantalia et al., 2008; Bayer et al., 2015). The highest mean flux of N<sub>2</sub>O-N, which was 5.3 ng N<sub>2</sub>O-N cm<sup>-2</sup> h<sup>-1</sup>, was measured in January, as also observed for NO fluxes. In May, peaks of 2.5 and 5.2 ng N<sub>2</sub>O-N cm<sup>-2</sup> h<sup>-1</sup> were measured in the plots with *M. pruriens* and natural fallow under no-tillage, respectively. The N<sub>2</sub>O-N peaks measured in April, even under lower rainfall, can be explained by the slow decomposition of the material from *M. pruriens*. This legume, compared to *C. juncea* and natural fallow, has the highest proportion of aromatic carbon groups highly resistant to decomposition (Carvalho et al., 2009), explaining the peaks even eight months after the deposition of its biomass.

The stepwise multiple regression model indicated that the variations of CO<sub>2</sub>-C fluxes, between 33 and 64%, were explained mostly by WFPS at 0–0.05-m depth (Table 2). However, under conventional tillage with *C. juncea* and *M. pruriens*, CO<sub>2</sub>-C fluxes were mainly explained by soil NH<sub>4</sub><sup>+</sup>-N concentrations. The multiple regression model also explained approximately 71% of the variations of CO<sub>2</sub>-C fluxes

**Table 2.** Multiple regressions used to explain the variation of CO<sub>2</sub>-C and NO<sub>x</sub>-N fluxes from an Oxisol in the Cerrado region, in Central Brazil, as affected by cover crops planted before corn (*Zea mays*), under conventional (CT) and no-tillage systems (NT).

Cover crop	CO <sub>2</sub> -C fluxes <sup>(1)</sup>			NO <sub>x</sub> -N fluxes
	WFPS	NH <sub>4</sub> <sup>+</sup> -N	Soil temperature (°C) <sup>(2)</sup>	WFPS
<i>Crotalaria juncea</i> NT	R <sub>t</sub> <sup>2</sup> = 0.528 (p<0.001)	-	-	R <sub>t</sub> <sup>2</sup> = 0.38 (p<0.032)
<i>Crotalaria juncea</i> CT	-	R <sub>t</sub> <sup>2</sup> = 0.467 (p<0.001)	-	-
<i>Mucuna pruriens</i> NT	R <sub>t</sub> <sup>2</sup> = 0.795 (p<0.001); R <sub>p</sub> <sup>2</sup> = 0.639	-	R <sub>p</sub> <sup>2</sup> = 0.156	-
<i>Mucuna pruriens</i> CT	R <sub>t</sub> <sup>2</sup> = 0.808 (p<0.001); R <sub>p</sub> <sup>2</sup> = 0.081	R <sub>p</sub> <sup>2</sup> = 0.665	R <sub>p</sub> <sup>2</sup> = 0.062	-
Natural fallow NT	R <sub>t</sub> <sup>2</sup> = 0.71 (p<0.005); R <sub>p</sub> <sup>2</sup> = 0.60	R <sub>p</sub> <sup>2</sup> = 0.11	-	-
Natural fallow CT	R <sub>t</sub> <sup>2</sup> = 0.329 (p<0.005)	-	-	R <sub>t</sub> <sup>2</sup> = 0.23 (p<0.09)

<sup>(1)</sup>R<sub>t</sub><sup>2</sup> and R<sub>p</sub><sup>2</sup>, coefficient of total determination and coefficient of partial determination, respectively. <sup>(2)</sup>At 0.0–0.05-m depth. WFPS, water-filled pore space.



measured in natural fallow plots under no-tillage, for which the explanatory variables were: WFPS, 60%; and soil  $\text{NH}_4^+\text{-N}$  concentration, 11%. In the case of *M. pruriens*, under no-tillage, 80% of the variations of  $\text{CO}_2\text{-C}$  fluxes were explained by the variables WFPS and soil temperature. Available  $\text{NH}_4^+\text{-N}$  in the soil did not significantly explain the variations of  $\text{NO}_x\text{-N}$  fluxes, contrarily to what was observed for the emissions of  $\text{CO}_2\text{-C}$  (Table 2). Alterations in WFPS values at 0–0.05-m depth explained 38% of the variations of  $\text{NO}_x\text{-N}$  fluxes in *C. juncea* plots under no-tillage and 23% in natural fallow under conventional tillage. Variations of GHG emissions due to available N ( $\text{NH}_4^+\text{-N}$  and  $\text{NO}_3^-\text{-N}$ ) and WFPS were also reported in other studies (Cruvinel et al., 2011; Marquina et al., 2015); however, in the present study,  $\text{NO}_3^-\text{-N}$  concentrations were not significant as an explanatory variable for soil emissions.

Plots with legumes under conventional tillage showed significantly higher annual N oxide emissions ( $0.9 \text{ kg ha}^{-1} \text{ N}$  per year) than those with natural fallow ( $0.5 \text{ kg ha}^{-1} \text{ N}$  per year) (Table 3). Annual emissions of  $\text{CO}_2\text{-C}$  were also higher with the use of legumes than with natural fallow under both management systems, as shown by the averages obtained for conventional tillage and no-tillage, respectively: 19 and 21  $\text{Mg CO}_2\text{-C ha}^{-1}$  per year for plots with legumes versus 15 and 16  $\text{Mg CO}_2\text{-C ha}^{-1}$  per year for plots with natural fallow. The N contents of *C. juncea* ( $91 \text{ kg ha}^{-1} \text{ N}$ ) and *M. pruriens* ( $94 \text{ kg ha}^{-1} \text{ N}$ ), when cut at the flowering stage, are significantly higher than those of natural fallow ( $59 \text{ kg ha}^{-1} \text{ N}$ ), which may explain the higher annual emissions of  $\text{NO}_x\text{-N} + \text{N}_2\text{O-N}$  and  $\text{CO}_2\text{-C}$  from plots with legumes as cover crops (Carvalho et al., 2015). Mitchell et al. (2013), while studying the effects of cover crops on  $\text{N}_2\text{O}$  emissions, found that available mineralizable C can also control  $\text{N}_2\text{O}$  emissions from

the soil and, consequently, that C from cover crop residues can increase these emissions.

However, annual emissions of  $\text{CO}_2\text{-C}$  did not differ significantly between management systems, as also reported in other studies (Abdalla et al., 2014; Carvalho, 2005). These results were attributed to the peaks of microbial respiration that do not occur simultaneously because of soil moisture, organic carbon, porosity, tortuosity, macro and mesofauna, among others. Soil  $\text{CO}_2\text{-C}$  emissions were correlated with soil water content, temperature, and available  $\text{NH}_4^+\text{-N}$ . Although the concentration of  $\text{NH}_4^+\text{-N}$  was not correlated with  $\text{NO}_x\text{-N}$  and  $\text{N}_2\text{O-N}$  emissions, higher fluxes were observed after fertilizer application, when accompanied by rainfall. The source of N (urea) and the form of application (surface coverage) of this element should have favored emissions after fertilization and greater rainfall (Carvalho et al., 2006).

Even though the obtained results show that the use of legumes as cover crops favors the emissions of  $\text{NO}_x\text{-N} + \text{N}_2\text{O-N}$  and  $\text{CO}_2\text{-C}$ , mitigating the emission of greenhouse gases also depends on the input and quality of plant residues, as well as on the magnitude of the increases in  $\text{CO}_2$  uptake by the cover crop and of the C stored in the soil (Abdalla et al., 2013). The increase in C stocks in the soil depends on C and N inputs, residue decomposition, microbial biomass growth and activity, management practices, and soil and climatic factors (Cruvinel et al., 2011); soil organic matter is higher in the surface layer due to the accumulation of plant residues there (Carvalho et al., 2014b; Boddey et al., 2010). Significant differences in soil C and N stocks were found between different cover crops grown in succession to corn in the same experimental plots evaluated in the present study (Carvalho et al., 2014b). The use of *M. pruriens* under no-tillage may enhance soil organic matter and, therefore, increase soil C and N stocks (Carvalho et al., 2014b). Moreover, the increase of the soil C/N ratio at 0–0.05-m depth, in the dry season, in plots with the addition of *M. pruriens* residues (C/N = 18), when compared to those with natural fallow (C/N = 9.4), may be another indicator of the increase in soil C, which is possibly attributed to the high concentration of aromatic compounds in the species (Carvalho et al., 2009; Talbot et al., 2012; Carvalho et al., 2014a). However, it should be noted that higher microbial biomass and activity in the soil surface layer under no-tillage system may favor higher  $\text{CO}_2$  emissions (Carvalho, 2005).

**Table 3.** Annual emissions of gases from an Oxisol in the Cerrado region, in Central Brazil, as affected by cover crops planted before corn (*Zea mays*) under conventional (CT) and no-tillage (NT) systems<sup>(1)</sup>.

Cover crop	$\text{CO}_2\text{-C}$ ( $\text{Mg ha}^{-1}$ )		$(\text{NO}_x + \text{N}_2\text{O})\text{-N}$ ( $\text{kg ha}^{-1}$ )	
	CT	NT	CT	NT
<i>Crotalaria juncea</i>	18.8a	20.1a	0.9a	0.7a
<i>Mucuna pruriens</i>	18.5a	24.2a	0.9a	1.0a
Natural fallow	14.7b	16.3b	0.5b	0.9a
Mean	17.3A	20.2A	0.8A	0.9A

<sup>(1)</sup>Means followed by equal letters, lower case in the columns and upper case in the rows, do not differ, at 5% probability.

## Conclusions

1. Emissions of NO<sub>x</sub>-N, N<sub>2</sub>O-N, and CO<sub>2</sub>-C are higher in plots with legumes, used as cover crops, than in those with natural fallow.

2. Changes in soil humidity and inorganic-N concentration are related to soil emissions during the corn (*Zea mays*) crop cycle.

3. Although legume cover crops result in higher nitrogen oxide and CO<sub>2</sub>-C emissions, it is important to evaluate changes in soil C and N stocks when considering the effectiveness in mitigating the emission of greenhouse gases.

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## References

- ABDALLA, M.; HASTINGS, A.; HELMY, M.; PRESCHER, A.; OSBORNE, B.; LANIGAN, G.; FORRISTAL, D.; KILLI, D.; MARATHA, P.; WILLIAMS, M.; RUEANGRITSARAKUL, K.; SMITH, P.; NOLAN, P.; JONES, M.B. Assessing the combined use of reduced tillage and cover crops for mitigating greenhouse gas emissions from arable ecosystem. *Geoderma*, v.223-225, p.9-20, 2014. DOI: 10.1016/j.geoderma.2014.01.030.
- ABDALLA, M.; OSBORNE, B.; LANIGAN, G.; FORRISTAL, D.; WILLIAMS, M.; SMITH, P.; JONES, M.B. Conservation tillage systems: a review of its consequences for greenhouse gas emissions. *Soil Use and Management*, v.29, p.199-209, 2013. DOI: 10.1111/sum.12030.
- BATTLE-BAYER, L.; BATJES, N.H.; BINDRABAN, P.S. Changes in organic carbon stocks upon land use conversion in the Brazilian Cerrado: a review. *Agriculture, Ecosystems and Environment*, v.137, p.47-58, 2010. DOI: 10.1016/j.agee.2010.02.003.
- BAYER, C.; DIECKOW, J.; AMADO, T.J.C.; ELTZ, F.L.F.; VIEIRA, F.C.B. Cover crop effects increasing carbon storage in a subtropical no-till sandy Acrisol. *Communications in Soil Science and Plant Analysis*, v.40, p.1499-1511, 2009. DOI: 10.1080/00103620902820365.
- BAYER, C.; GOMES, J.; ZANATTA, J.A.; VIEIRA, F.C.B.; PICCOLO, M. de C.; DIECKOW, J.; SIX, J. Soil nitrous oxide emissions as affected by long-term tillage, cropping systems and nitrogen fertilization in Southern Brazil. *Soil and Tillage Research*, v.146, p.213-222, 2015. DOI: 10.1016/j.still.2014.10.011.
- BEUCHLE, R.; GRECCHI, R.C.; SHIMABUKURO, Y.E.; SELIGER, R.; EVA, H.D.; SANO, E.; ACHARD, F. Land cover changes in the Brazilian Cerrado and Caatinga biomes from 1990 to 2010 based on a systematic remote sensing sampling approach. *Applied Geography*, v.58, p.116-127, 2015. DOI: 10.1016/j.apgeog.2015.01.017.
- BODDEY, R.M.; JANTALIA, C.P.; CONCEIÇÃO, P.C.; ZANATTA, J.A.; BAYER, C.; MIELNICZUK, J.; DIECKOW, J.; SANTOS, H.P. dos; DENARDIN, J.E.; AITA, C.; GIACOMINI, S.J.; ALVES, B.J.R.; URQUIAGA, S. Carbon accumulation at depth in Ferralsols under zero-till subtropical agriculture. *Global Change Biology*, v.16, p.784-795, 2010. DOI: 10.1111/j.1365-2486.2009.02020.x.
- CALEGARI, A.; HARGROVE, W.L.; RHEINHEIMER, D. dos S.; RALISCH, R.; TESSIER, D.; TOURDONNET, S. de; GUIMARAES, M. de F. Impact of long-term no-tillage and cropping system management on soil organic carbon in an Oxisol: a model for sustainability. *Agronomy Journal*, v.100, p.1013-1020, 2008. DOI:10.2134/agronj2007.0121.
- CARVALHO, A.M. de. **Uso de plantas condicionadoras com incorporação e sem incorporação no solo: composição química e decomposição dos resíduos vegetais; disponibilidade de fósforo e emissão de gases.** 2005. 167p. Tese (Doutorado) – Universidade de Brasília, Brasília.
- CARVALHO, A.M. de; BUSTAMANTE, M.M. da C.; KOZOVITS, A.R.; MIRANDA, L.N. de; VIVALDI, L.J.; SOUSA, D.M. de. Emissão de óxidos de nitrogênio associada à aplicação de uréia sob plantio direto e convencional. *Pesquisa Agropecuária Brasileira*, v.41, p.679-685, 2006.
- CARVALHO, A.M. de; COSER, T.R.; REIN, T.A.; DANTAS, R. de A.; SILVA, R.R.; SOUZA, K.W. Manejo de plantas de cobertura na floração e na maturação fisiológica e seu efeito na produtividade do milho. *Pesquisa Agropecuária Brasileira*, v.50, p.551-561, 2015. DOI: 10.1590/S0100-204X2015000700005.
- CARVALHO, A.M. de; MARCHÃO, R.L.; BUSTAMANTE, M.M. da C.; ALCÂNTARA, F.A. de; COSER, T.R. Characterization of cover crops by NMR spectroscopy: impacts on soil carbon, nitrogen and phosphorus under tillage regimes. *Revista Ciência Agronômica*, v.45, p.968-975, 2014a. DOI: 10.1590/S1806-66902014000500012.
- CARVALHO, A.M. de; MARCHÃO, R.L.; SOUZA, K.W.; BUSTAMANTE, M.M. da C. Soil fertility status, carbon and nitrogen stocks under cover crops and tillage regimes. *Revista Ciência Agronômica*, v.45, p.914-921, 2014b. DOI: 10.1590/S1806-66902014000500007.
- CARVALHO, A.M.; BUSTAMANTE, M.M.C.; ALCÂNTARA, F.A.; RESCK, I.S.; LEMOS, S.S. Characterization by solid-state CPMAS <sup>13</sup>C NMR spectroscopy of decomposing plant residues in conventional and no-tillage systems in Central Brazil. *Soil and Tillage Research*, v.102, p.100-107, 2009. DOI: 10.1016/j.still.2008.08.006.
- CORBEELS, M.; SCOPEL, E.; CARDOSO, A.; BERNOUX, M.; DOUZET, J.-M.; SIQUEIRA NETO, M. Soil carbon storage potential of direct seeding mulch-based cropping systems in the

- Cerrados of Brazil. **Global Change Biology**, v.12, p.1773-1787, 2006. DOI: 10.1111/j.1365-2486.2006.01233.x.
- CRUVINEL, Ê.B.F.; BUSTAMANTE, M.M. da C.; KOZOVITS, A.R.; ZEPP, R.G. Soil emissions of NO, N<sub>2</sub>O and CO<sub>2</sub> from croplands in the savanna region of Central Brazil. **Agriculture, Ecosystems and Environment**, v.144, p.29-40, 2011. DOI: 10.1016/j.agee.2011.07.016.
- EDENHOFER, O.; PICHES-MADRUGA, R.; SOKONA, Y.; MINUX, J.C.; FARAHANI, E.; KADNER, S.; SEYBOTH, K.; ADLER, A.; BAUM, I.; BRUNNER, S.; EICKEMEIER, P.; KRIEMANN, B.; SAVOLAINEN, J.; SCHLÖMER, S.; VON STECHOW, C.; ZWICKEL, T. (ed.). **Climate change 2014: mitigation of climate change: Working Group III contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change**. Cambridge: Cambridge University Press, 2014. 1435p.
- ESTIMATIVAS anuais de emissões de gases de efeito estufa no Brasil. 2.ed. Brasília: Ministério da Ciência, Tecnologia e Inovação, 2014. 161p.
- HUDMAN, R.C.; MOORE, N.E.; MEBUST, A.K.; MARTIN, R.V.; RUSSELL, A.R.; VALIN, L.C.; COHEN, R.C. Steps towards a mechanistic model of global soil nitric oxide emissions: implementation and space based-constraints. **Atmospheric Chemistry and Physics**, v.12, p.7779-7795, 2012. DOI: 10.5194/acp-12-7779-2012.
- IBGE. INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Indicadores: produção pecuária**. 2015. Available at: <<http://www.ibge.gov.br/home/estatistica/indicadores/agropecuaria/producaoagropecuaria/default.shtm>>. Accessed on: 30 Apr. 2016.
- JANTALIA, C.P.; SANTOS, H.P. dos; URQUIAGA, S.; BODDEY, R.M.; ALVES, B.J.R. Fluxes of nitrous oxide from soil under different crop rotations and tillage systems in the South of Brazil. **Nutrient Cycling in Agroecosystems**, v.82, p.161-173, 2008. DOI 10.1007/s10705-008-9178-y.
- LESSA, A.C.R.; SANTOS, M.A. dos; MADDOCK, J.E.L.; BEZERRA, C. dos S. Emissions of greenhouse gases in terrestrial areas pre-existing to hydroelectric plant reservoirs in the Amazon: the case of Belo Monte hydroelectric plant. **Renewable and Sustainable Energy Reviews**, v.51, p.1728-1736, 2015. DOI: 10.1016/j.rser.2015.07.067.
- MARQUINA, S.; PÉREZ, T.; DONOSO, L.; GIULIANTE, A.; RASSE, R.; HERRERA, F. NO, N<sub>2</sub>O and CO<sub>2</sub> soil emissions from Venezuelan corn fields under tillage and no-tillage agriculture. **Nutrient Cycling in Agroecosystems**, v.101, p.123-137, 2015. DOI: 10.1007/s10705-014-9659-0.
- MEIER, M. Nitratbestimmung in Boden-proben (N-min-Method). **LaborPraxis**, v.4, p.244-247, 1991.
- METAY, A.; OLIVER, R.; SCOPEL, E.; DOUZET, J.-M.; MOREIRA, J.A.A.; MARAUX, F.; FEIGL, B.J.; FELLER, C. N<sub>2</sub>O and CH<sub>4</sub> emissions from soils under conventional and no-till management practices in Goiânia (Cerrados, Brazil). **Geoderma**, v.141, p.78-88, 2007. DOI: 10.1016/j.geoderma.2007.05.010.
- MITCHELL, D.C.; CASTELLANO, M.J.; SAWYER, J.E.; PANTOJA, J. Cover crop effects on nitrous oxide emissions: role of mineralizable carbon. **Soil Science Society of America Journal**, v.77, p.1765-1773, 2013. DOI: 10.2136/sssaj2013.02.0074.
- PAREDES, D. da S.; LESSA, A.C. da R.; SANT'ANNA, S.A.C. de; BODDEY, R.M.; URQUIAGA, S.; ALVES, B.J.R. Nitrous oxide emission and ammonia volatilization induced by vinasse and N fertilizer application in a sugarcane crop at Rio de Janeiro, Brazil. **Nutrient Cycling in Agroecosystems**, v.98, p.41-55, 2014. DOI: 10.1007/s10705-013-9594-5.
- SANTOS, H.G. dos; JACOMINE, P.K.T.; ANJOS, L.H.C. dos; OLIVEIRA, V.A. de; LUMBRERAS, J.F.; COELHO, M.R.; ALMEIDA, J.A. de; CUNHA, T.J.F.; OLIVEIRA, J.B. de. **Sistema brasileiro de classificação de solos**. 3.ed. rev. e ampl. Brasília, DF: Embrapa, 2013. 353p.
- TALBOT, J.M.; YELLE, D.J.; NOWICK, J.; TRESEDER, K.K. Litter decay rates are determined by lignin chemistry. **Biogeochemistry**, v.108, p.279-295 2012. DOI: 10.1007/s10533-011-9599-6.

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