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Greenhouse gas emission from the soils fertilized with liquid pig slurry (LPS) in Tifton 85 bermudagrass pasture in tropical savanna

Adilson Amorim Brandão[1]*, Eduardo Guimarães Couto[2], Renato de Aragão Ribeiro Rodrigues[3], Oscarlina Lúcia Santos Weber[2], Osvaldo Borges Pinto Júnior[4]

[1]Federal Institute of Mato Grosso do Sul, Naviraí, 79950-000, Mato Grosso do Sul, Brazil
[2]Federal University of Mato Grosso, Department of Soils and Rural Engineering, Cuiabá, 78060-900, Mato Grosso, Brazil
[3]Embrapa Soils, Rio de Janeiro, 22460-000, Rio de Janeiro, Brazil
[4]University of Cuiabá, Cuiabá, 78065-900, Mato Grosso, Brazil

***Corresponding author: aabrandaojr@gmail.com**

Abstract

Soils have important roles in the global budgets of the greenhouse gases. The liquid pig slurry (LPS) in pastures has high potential as a fertilizer but could have a direct influence on emission of greenhouse gasses. This study evaluated the effects of the application of LPS and inorganic mineral fertilization during the rainy and dry seasons on the emissions of CO_2, CH_4 and N_2O in pastures planted with Tifton-85. The following treatments were tested: Control - no fertilization; LPS30 - 30 m^3 ha^{-1}; LPS60 - 60 m^3 ha^{-1}; LPS90 - 90 m^3 ha^{-1} and inorganic mineral fertilization. Gasses were sampled using static chambers first during the months of March and April, then in June and July. Fertilization with LPS caused an increase in the flux of CO_2 and CH_4 during the first hours after its application, and CO_2 emissions are greater during the rainy than in the dry season. However, the application of LPS in Tifton-85 pasture during rainy periods did not show high potential for emission of CO_2, in contrast to application during the dry season. Fertilization with LPS increases the emission of N_2O, and this varies as a function of the volume of LPS applied and the experimental conditions experimental conditions. The application of LPS in Tifton-85 pasture has a high potential for N_2O emission during the rainy season, but the magnitude is similar to that resulting from inorganic mineral fertilization.

Keywords: swine wastewater, soil gas fluxes, carbon dioxide, methane, nitrous oxide.
Abbreviations: LPS_liquid pig slurry; DAA_day after application; GHG_greenhouse gas; IC_intensive collection.

Introduction

The expansion of pasture for livestock production is the main responsible for land use change (LUC) emissions contributing for 6% of global emissions from livestock. The LUC emission from soybean is also a substantial driver of LUC emissions, covering 3.2% of global emissions from livestock (Gerber et al., 2013). The gas emission in Brazil is mostly caused by cattle, expansion of pasture for production of feed ingredients such as soybean (Karstensen et al., 2013) for pigs and poultry. In fact, pigs and poultry are mostly fed ingredients containing grain and soy products (Kebreab et al.,2016). Brazilian production of pork is increasing, with a 28.2% growth rate expected by the end of 2029 (MAPA, 2019). However, a consequence of pig farming is the generation and concentration of a large volume of excrement, which represents an environmental risk and requires measures to be taken to reduce negative impacts on the surrounding environment (Ceretta et al., 2005).

Pork farming in a confined system generates concentrated liquid slurry in specific areas on rural properties (Damasceno, 2010). For example, in the state of Mato Grosso, the estimated annual production of slurry in 2018 by pig herd amounted ~ 2.94 million, according IBGE (2018). I corresponds to a daily production of 7 liters of liquid slurry per animal (Oliveira, 2004), by which the annual slurry production is approximately 7.51 million m^3.

The application of liquid pig slurry (LPS) in pastures is a viable alternative for its use because as a function of its chemical characteristics it has great potential to be used as a fertilizer (Seidel et al., 2010). Therefore, LPS could partially or totally substitute inorganic mineral fertilizer and make a significant contribution to crop production and reduce input costs (Scherer et al., 2012). The most common form of use of LPS is in application to the surface of agricultural soils due to its lower operational costs and ease of application in most cultivation systems (Friederichs et al., 2019), and also because it favors the accumulation of nutrients in the root zone of agricultural soils (Veiga et al., 2012; Friederichs, 2019). However, the inadequate use of LPS can increase the risk of microbiological contamination of groundwater, accumulation of toxic elements, nutrient imbalances and soil impermeabilization (Seganfredo, 2000), besides having a direct influence on the emissions of carbon dioxide (CO_2),

methane (CH_4) and nitrous oxide (N_2O), and on volatilization of ammonia (NH_3) (Carvalho and Hentz, 2014).

The emission of CO_2 from the soil occurs as a function of respiration of roots and organisms together with decomposition of organic residuals (Carvalho et al,, 2010). These processes are influenced by the application of LPS to the soil due to an increase in organic carbon, and consequently an increase in microbial respiration and activity (Webb et al., 2010). Furthermore, fertilization with LPS contributes to the development of agricultural crops by increasing plant root systems and the input of plant residual materials to the soil.

In research conducted in a controlled laboratory environment, CO_2 flux was 125 mg C m^{-2} h^{-1} one day after application (DAA) of LPS (200 kg N ha^{-1}) in an uncultivated clay soil, while in a soil without application of LPS the flux was 40 mg C m^{-2} h^{-1} (Jarecki et al., 2008). In a no-till soil cultivated with a wheat and corn rotation of CO_2 flux rates varied between 60 and 208 mg m^{-2} h^{-1} and after treatment of LPS at rate of 140 kg N ha^{-1}. These rates remained higher than those of the control treatment during the first 18 days after application (Grave et al., 2015).

The flux of soil CH_4 is the result of production of this gas in the soil by methanogenic bacteria under anaerobic conditions, and also the oxidation that occurs through the action of methanotrophic bacteria in the presence of oxygen (Le Mer and Roger, 2001). The oxidation of methane is generally greater than its production in well-drained and aerated soils. However, the application of different forms of nitrogen can considerably reduce the rates of oxidation of CH_4 (Suwanwaree and Robertson, 2005).

In a study conducted in New Zealand, CH_4 flux was measured during 90 days after the application of 60 m^3 ha^{-1} of LPS to a pasture. The flux of soil CH_4 was 3,933 µg C m^{-2} h^{-1} immediately after application of LPS and continued at a lower rate until the 7th DAA. From the 8th DAA onward the measured fluxes indicated absorption of atmospheric methane by the soil (Sherlock et al., 2002).

In Frederico Westphalen-RS, Brazil, treatments applying LPS were evaluated with the objective of measuring greenhouse gas emissions as a function of the method of application to no-till soil cultivated with a wheat and corn rotation (Arenhardt, 2016). The results showed that the accumulated CH_4 emissions from soil where LPS was applied on the surface were negative, meaning that methane was absorbed, although there was soil CH_4 efflux soon after LPS application.

The volatilization of ammonia (NH_3) is considered to be the principal mechanism of loss of nitrogen (N) after application of liquid residuals to the soil (Smith et al., 2009). This reduces the potential of nitrogen as a fertilizer and contributes to environmental contamination (Rochette et al., 2008). Losses of ammonia are generally high and can reach 75% of NH_4^+-N when liquid residuals, principally those from pigs, are applied with incorporation into the soil (Thompson and Meisinger, 2002). Although ammonia is not a greenhouse gas (GHG) itself, but its emission to the atmosphere and subsequent deposition on the soil can result in production of nitrous oxide (N_2O) as a by-product of the microbial nitrification process, and also as a product of microbial denitrification (Zaman and Blennerhassett, 2010). The Inter-governmental Panel on Climate Change (IPCC) estimates that, on average, 1.25% of total N from fertilizer or manure applied to soil is emitted as N_2O (IPCC, 2007).

In a study conducted in the Brazilian state of Rio Grande do Sul, the flux of soil N_2O in a no-till system using an oat mulch was increased by 160 µg N m^{-2} h^{-1} four hours after the application of 40 m^{-3} ha^{-1}, compared to the treatment without LPS. The accumulated emission of N_2O 28 days after application was 93.8 g N ha^{-1} (Giacomini et al., 2006). This dynamic of more intense N_2O flux during the first DAA after LPS application has been reported in the literature for temperate climate conditions (Rochette et al., 2008; Pelster et al., 2012) as well as for subtropical (Aita et al., 2014, Aita et al., 2015).

The potential of LPS for the use as a substitute for inorganic mineral fertilization in agricultural production, including for forage grasses in pasture systems, is widely reported in the literature (Drumond et al., 2006; Medeiros et al., 2007; Camargo et al., 2011; Silva et al., 2015). However, it is necessary to evaluate the dimensions of the impacts of LPS application with respect to the emissions of CO_2, CH_4 and N_2O in pasture areas, especially in regions with a tropical climate. These GHG are important for atmospheric chemistry and its radiation balance as a function of their lifetimes in the atmosphere, and also because of the values for relative global warming potential (GWP) of CH_4 and N_2O which are respectively about 25 and 298 times greater than that of CO_2 (IPCC, 2007).

The objective of this study was to evaluate the effects of the application of LPS and inorganic mineral fertilization during the rainy and dry seasons on the emissions of CO_2, CH_4 and N_2O in pastures planted with Tifton-85.

Results and Discussion

Daily average flux of CO_2, CH_4 and N_2O during the intensive collection campaigns

Before application of fertilizer two intensive collection (IC) campaigns were conducted. The CO_2 fluxes were similar between the two treatments. Starting on the first day after fertilizer application (DAA), in the first IC as well as for the second IC the flux was increased in the treatments LPS30, LPS60 and LPS90 (Figs 1A and 1B). In the first IC, treatment LPS90 had a CO_2 flux above 500 mg m^{-2} h^{-1} and was statistically different from the other treatments ($F_{4;12}$= 3.506; $p<0.05$). In the second IC, treatments LPS30, LPS60 and LPS90 had similar CO_2 flux values, but differed from those for the Control and FertMin treatments ($F_{4;12}$= 4.941; $p<0.05$). In general, the greater the rate of application of LPS, the higher the emission values for CO_2 on the 1st DAA. The CO_2 flux was decreased starting from 2nd DAA until the end of the evaluation period for both the first and second ICs, with no differences between treatments.

The application of LPS to the soil stimulates an increase in CO_2 emission during the first hours after application, with about 59% of the organic carbon added in LPS being emitted as CO_2, independent of the application method to the soil (Giacomini et al., 2007). The increase in CO_2 emission during the first hours after LPS application is reported in the literature (Aita, Port and Giacomini, 2006; Giacomini et al., 2007; Giacomini and Aita, 2008; Arenhardt, 2016) and could be linked to the liberation of CO_2 dissolved in the LPS, as well as CO_2 formed from HCO_3^- and CO_3^{2-} generated during storage of this material (Carvalho and Hentz, 2014). Evidence for this shown by the fact that the CO_2 flux values on the days preceding the application of the LPS to the soil

varied between 1 and 2 kg ha^{-1} h^{-1} independent of the treatment.

During the 1st IC, several rainfall events apparently influenced the CO_2 flux in all treatments, with peaks of C-CO_2 flux on March 27 and 29, and April 1 (Fig 1A). This effect is due to the fact that precipitation increases soil biological activity, and this is reflected in greater respiration and CO_2 emission rates (Luo and Zhou, 2006a, 2006b).

The fluxes of CH_4 were equal before the application of the treatments for each IC, showing emission peaks after the application of the LPS. From the 7th DAA, the fluxes diminished and became similar between treatments (Figs 1C and 1D). In the 1st IC there were differences between treatments only on day 1 and from the 5th to the 7th DAA (Fig 1C). On the 1st DAA, treatment LPS90 had an emission of 642.7 μg m^{-2} h^{-1} and was different from the other treatments ($F_{4;12}$= 6.869; p<0.05). The FertMin treatment had a C-CH_4 flux of -7,4 μg m^{-2} h^{-1} on the 5th DAA and was different from the other treatments ($F_{4;12}$= 6.533; p<0.01), which all showed a positive flux for methane. On the 6th and 7th DAA, the treatment LPS30 had higher values than the other treatments, with a flux of 20.1 μg m^{-2} h^{-1} and 38.0 μg m^{-2} h^{-1}, respectively.

The flux values for CH_4 during the 2nd IC was increased in the treatments with LPS a few hours after its application (Fig 1D), as also shown for the 1st IC. On the 1st DAA, CH_4 emissions for LPS60 and LPS90 were 45.7 and 47.0 μg m^{-2} h^{-1}, respectively, and were different from the other treatments ($F_{4;12}$= 4.028; p<0.05). Treatments LPS90 and FertMin had similar or greater values than those from the other treatments on the 5th DAA ($F_{4;12}$= 5.178; p<0.05).

The emission peaks of methane are most likely related to volatilization of dissolved CH_4 soon after application of LPS (Sherlock et al., 2002). Damasceno (2010) reported results that showed that methane emission is increases in the soil with addition of residuals from pork farming, with a methane emission rate of 600 μg m^{-2} h^{-1} soon after application of LPS on the soil surface. However, in the current study the increase in CH_4 flux between the 5th and 7th DAA during the 1st IC could be related to rainfall events that saturated the soil pores and formed anaerobic micro-environments that are favorable for methanogenesis.

In each IC, the majority of treatments showed negative values for CH_4 flux (influx or absorption), indicating consumption of methane. This corroborated with Piva et al. (2013) in cultivated pasture on an Oxisol in Paraná. An influx of methane is expected for an aerated and well-structured soil such as the one in the current study because this soil type is considered to be a methane sink (Saggar et al., 2008).

Before the fertilizer application, N_2O fluxes were similar between the treatments in both ICs (Figs 1E and 1F). After the application of the LPS, from the 1st to the 3rd DAA, treatment LPS90 had greater emissions than the other treatments (Fig 1E). Between the 4th and the 6th DAA, an N-N2O emission in the inorganic mineral fertilization treatment was increased, which were similar to emissions from LPS90 on the 5th DAA and greater than those from the other treatments between the 4th and the 6th DAA. Starting on the 7th DAA, average flux of N_2O was lower and there was a difference between treatments only between the 7th and 9th DAA, with greater flux in LPS90 and FertMin (Fig 1E).

In the 2nd IC, there were differences between treatments only for the 1st DAA (Fig 1F), with LPS60 and LPS90 having N_2O fluxes greater than the other treatments. In general, during this period, the emission of N_2O in the LPS treatments was greater.

The average N_2O flux values in this study were lower than those reported by Denega (2009) principally after application of LPS, where this author observed emissions above 600 μg m^{-2} h^{-1} up to 48 hours after LPS application on soil covered with a corn mulch. However, the results from the current study are within the range reported in the literature (Giacomini et al., 2006).

The increase in N_2O emission soon after LPS application to the soil has been reported in a large range of studies (Giacomini et al., 2006; Rochette et al., 2008; Denega, 2009; Arenhardt, 2016). The increase in N_2O flux due to LPS application shown during the first two periods in the current study could be attributed to three factors: 1) the organic carbon in the LPS is used by aerobic microorganisms in the soil as a carbon and energy source. This increases their activity and demand for O_2, which could create anaerobic sites. Certain types of microbes can respire using nitrate present in the soil as the final electron receptor in the respiratory chain reducing it to N_2O 2) the rapid nitrification of NH_3-N applied with the LPS could result in the production of N_2O by certain bacteria that possess the nitrite reductase enzyme 3) the liquid fraction could facilitate the occurrence of environments that are deficient in O_2 depending on soil humidity and on the dose of LPS added to the soil, where nitrate could be denitrified and emitted to the atmosphere in the form of N_2O (Giacomini et al., 2006).

The increase in the average daily fluxes in the treatment FertMin was observed in the 1st IC is in agreement with the literature (Aita et al., 2015; Arenhardt, 2016). The presence of mineral N combined with the humid soil creates a favorable environment for the denitrification process (Zanatta et al., 2010), which could explain the increase in the N_2O flux observed in this study.

The lower emissions in the 2nd IC compared to the 1st IC could be related to low soil humidity during June 22 to July 5. The elevated capacity for water infiltration into the soil may favor the greater concentration of O_2 in the soil profile, which represents and unfavorable situation for the denitrification process and consequently emission of N_2O (Jantalia et al., 2008).

Accumulated emission of CO_2, CH_4 and N_2O during the intensive collection campaigns

In the 1st IC, the accumulated emissions of CO_2 did not show any differences between the treatments (Fig 2A), indicating that during a period with more rainfall the application of LPS does not cause a significant increase in the flux of CO_2. This could be explained by conditions that favor mineralization of carbon present in the soil including good levels of soil humidity and higher temperatures. However, during the 2nd IC, the application of LPS resulted in an increase in accumulated emission, with emissions from LPS90 being 3-fold greater compared to those of the Control (Fig 2A). Although the values of the accumulated emissions of CO_2 of the 2nd IC were inferior to those of the 1st IC, the use of LPS for fertilization has high potential emissions of this gas during periods with lower rainfall.

The accumulated emissions of CH_4 in the LPS treatments were greater in each IC (Fig 2B). During the 1st IC, LPS90 had greater accumulated emission of methane than the other treatments, and together with LPS30 and LPS60 were the

Table 1. Chemical composition of liquid pig slurry for each application date.

Month/year	N	P	K	Ca	Mg	S	Zn	Cu	Mn	Fe
	----------g L^{-1}----------						----------mg L^{-1}----------			
March/2015	2.10	0.70	0.40	0.15	0.09	0.41	1.20	2.10	0.60	2.60
June/2015	1.10	0.07	0.73	0.18	0.16	0.02	1.80	1.20	0.40	3.60

N=nitrogen; P=phosphorus; K=potassium; Ca=calcium; Mg=magnesium; S=sulfur; Zn=zinc; Cu=copper; Mn=manganes; and Fe=iron.

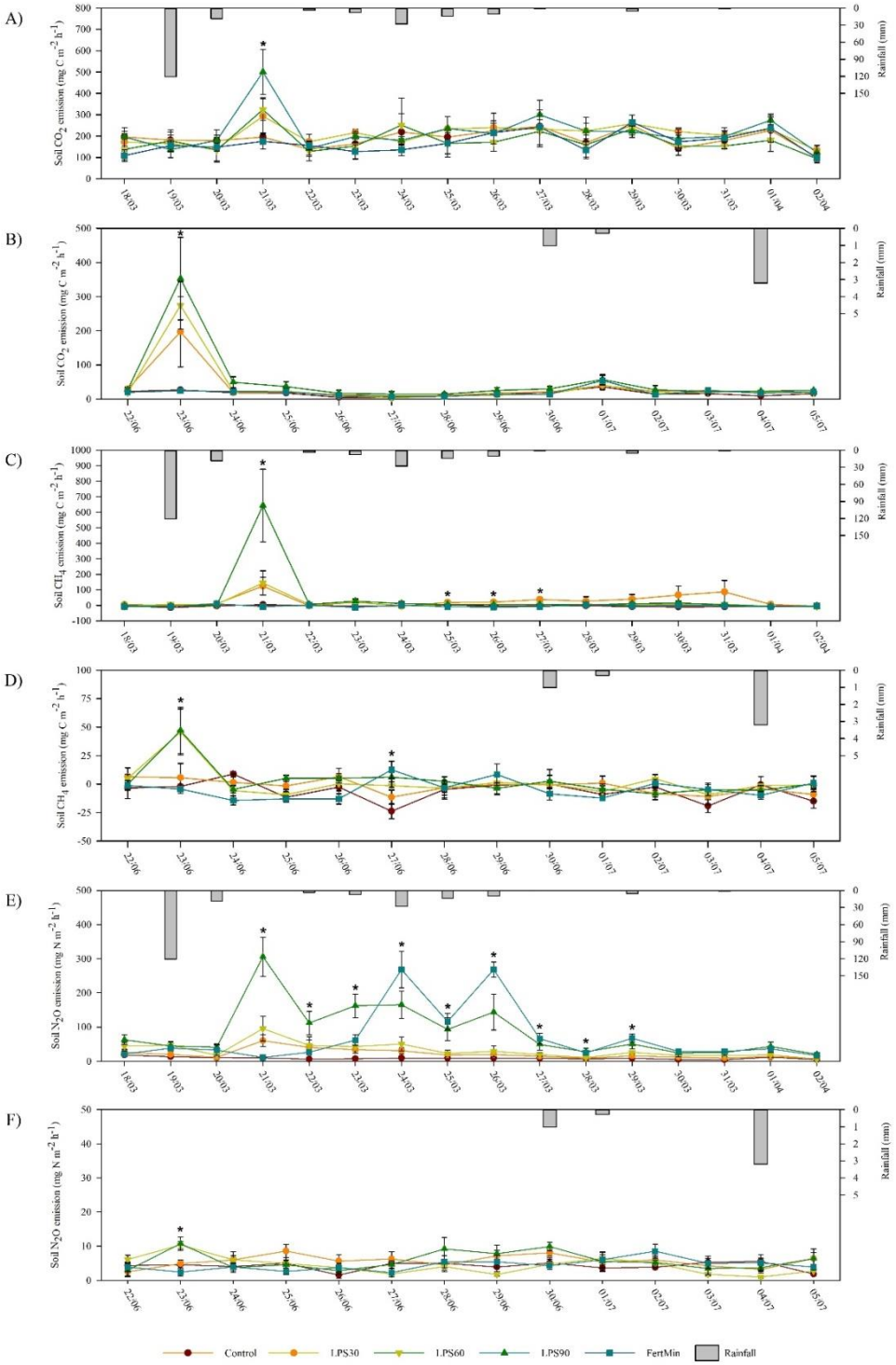

Fig 1. Average daily flux for CO_2 in the 1st IC (A) and the 2nd IC (B); CH_4 in the 1st IC (C) and the 2nd IC (D); and N_2O in the 1st IC (E) and the 2nd IC (F). Vertical bars represent the standard error of the mean (n=4). *significant difference by the Tukey's test ($p<0.05$).

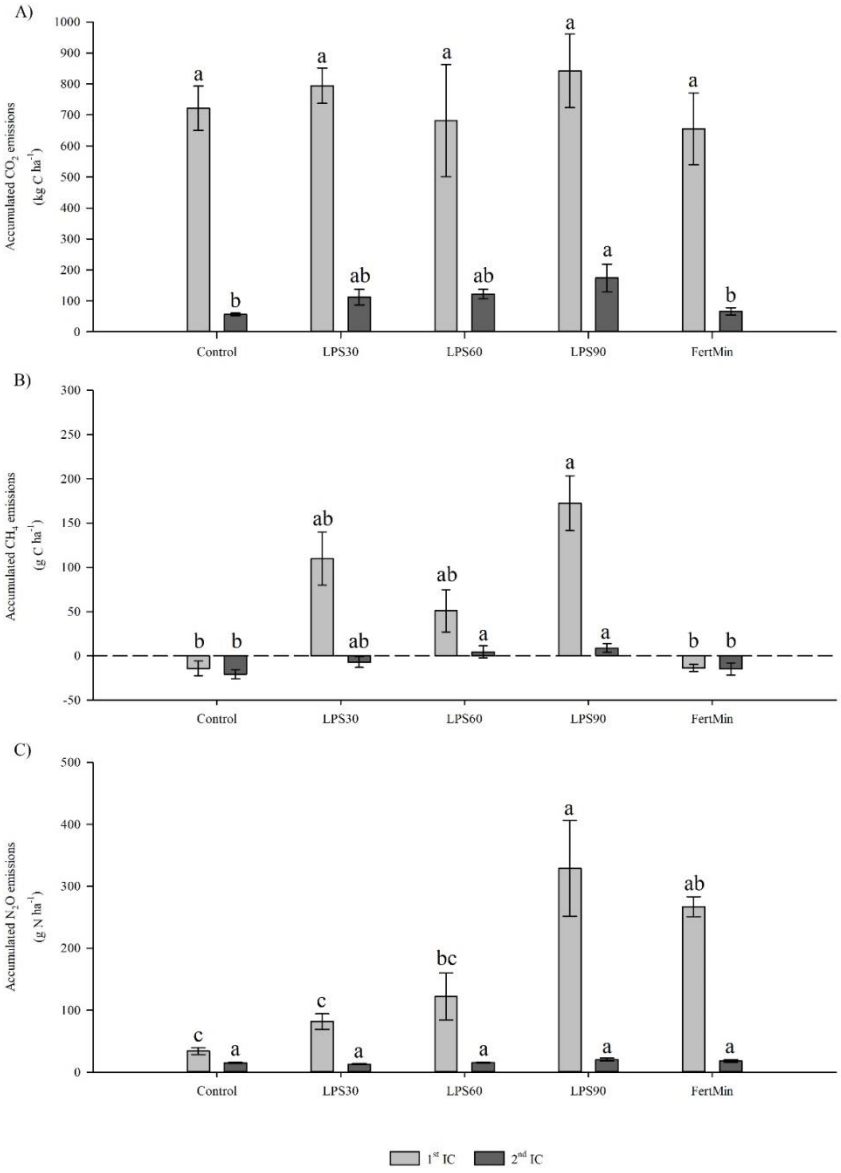

Fig 2. Accumulated emission of: (a) CO_2, (b) CH_4 and (c) N_2O in the 1st and 2nd IC. The vertical bars represent the standard error of the mean (n=4). Means followed by the same lowercase letters in to each intensive collection campaign does not differ statistically by the Tukey´s test ($p<0.05$).

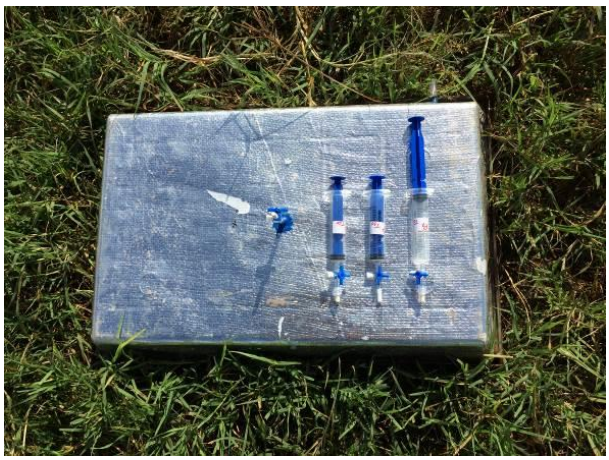

Fig 3. PVC chamber covered with a thermal insulation layer and three gas samplers (syringes) used for each collection period.

sources of this gas. In the 2nd IC, LPS60 and LPS90 had greater accumulated emissions of CH_4 and was a source of this gas to the atmosphere. In each of the intensive collection periods, the Control and FertMin treatments had negative accumulated emissions (influx), which characterized them as sinks of methane during the evaluation period (Fig 2B).

The accumulated emission of N_2O during the 1st IC showed a significant difference between treatments, with LPS90 and FertMin having greater emissions than the other treatments (Fig 2C). Greater accumulated emissions in the treatments with LPS and inorganic mineral fertilizer, but with no statistical differences, were reported by other studies (Arenhardt, 2016). In the 2nd IC, the accumulated emissions of N_2O did not differ between treatments (Fig 2C). This fact could be associated with losses of N through volatilization of NH_3 when LPS was applied to the soil surface, together with low soil humidity and a high level of oxygenation, which could have limited denitrification during this evaluation period (Aita et al., 2014).

Materials and Methods

Study area and description of experiment

The experiment was conducted under field conditions in the experimental area of the Rio Verde Foundation for Research and Technological Development, located at 13° 00' 02" S, 55° 58' 15" W and at an altitude of 387 m, in the municipality of Lucas do Rio Verde – MT, on a Red-Yellow dystrophic Oxisol of clay texture. The chemical analysis of the soil from 0 to 0.20 m layer presented pH=4.53 (H_2O); 14.22 mg dm^{-3} P; 106.28 mg dm^{-3} K; 2.27 cmolc dm^{-3} Ca; 0.93 cmolc dm^{-3} Mg; 15.15 cmolc dm^{-3} H + Al; 0.38 cmolc dm^{-3} Al and 17.94% base saturation (V%). The climate is Aw and tropical with dry winter season according to the Köppen classification system.

The experimental design was randomized blocks with five treatments and four repetitions, for a total of 20 plots with an area of 55 m^2 each, cultivated since March 2014 with a Tifton 85 bermudagrass cultivar (*Cynodon dactylon*). The following treatments were tested: Control – no fertilization; LPS30 - 30 m^3 ha^{-1} of LPS; LPS60 - 60 m^3 ha^{-1} of LPS; LPS90 - 90 m^3 ha^{-1} of LPS, and FertMin - inorganic mineral fertilization. Treatment FertMin-inorganic mineral fertilization was applied in January 2015 at a rate of 200 kg N in the form of urea, 70 kg P_2O_5 as single superphosphate, and 400 kg K_2O as potassium chloride, all on a per hectare basis. The applications of the treatments in the experimental area occurred monthly between January and June 2015. However, the application of LPS was done on March 20, 2015 and June 23, 2015, always at the end of the afternoon, and the nutrient concentrations of the LPS applied on these dates are shown in Table 1.

Sample collection

Sample collection was conducted using *in situ* closed-cover static chambers (Fig 3) based on methodology adapted from the literature (Nogueira et al., 2015).

The samples were collected during the morning between 88-10 a.m. (GMT-4) a period considered representative of average daily GHG flux (Zuchello, 2010). Immediately after coupling the chamber on the metallic base, a sample of atmospheric air was collected using a plastic syringe with a volume of 20 cm^3. Thirty minutes after coupling of chamber, the first air sample was collected from its interior, followed by another sample at 60 minutes, for a total of three samples taken at 0, 30, and 60 minutes. To facilitate sample collection, the chamber had a connecting port on its top that is regulated using a three-way plastic valve. The syringe was connected to this valve by another three-way plastic valve, which ensured proper sealing after sample collection (Rodrigues and Mello, 2012). After each collection, the samples were transferred to flasks that had their air content removed by vacuum. Additionally, air and soil temperatures were measured during sampling.

Intensive sample collection campaigns (IC) were done in two distinct periods, with the first IC done between March 18 and April 20, 2015, and the second IC between June 22 and July 23, 2015. The IC were conducted during the three days that preceded the application of the LPS, and also on the day of the application and the period afterward, with the goal of accompanying the pattern of GHG flux resulting from the fertilization treatments.

Laboratory analyses

The determination of gas concentrations was done at Embrapa Agrossilvipastoril using a gas chromatograph (model Shimadzu GC-2014) with FID and ECD detectors and an automatic injector. The calibration curves were determined using three gas standards for CO_2, CH_4 and N_2O (White Martins). These standards were: 308,700; 714,600 and 5097,000 micromol/mol, for CO_2; 1,402; 9,722 and 100,300 micromol/mol, for CH_4; and 360,000; 832,000 and 2080,000 nanomol/mol, for N_2O. The time for which the samples were analyzed was 8 minutes.

Statistical analysis

Average and accumulated flux data for CO_2, CH_4 and N_2O were processed for descriptive analysis and analyzed for normality (Shapiro-Wilk), homogeneity of variances (Levene), analysis of variance (ANOVA), and treatment means were compared using the Tukey's test ($p<0.05$). When necessary, the data were *log* transformed in order to homogenize the variances and normalize the frequency distribution. These results were transformed using the inverse operation to present the data in their original units.

Conclusion

The influence of fertilization with LPS increased the fluxes of CO_2 and CH_4 from the first hours after its application. During the period with greater precipitation, CO2 emissions were higher than in the dry season. However, the application of LPS in Tifton-85 pasture during rainy periods did not have high potential for emission of CO_2, in contrast to this application during the dry season. The soil fertilized with LPS is occasionally a source of CH_4 during periods with greater rainfall. Fertilization with LPS increases the emission of N_2O, and this varies as a function of the volume of LPS applied and the experimental conditions. The application of LPS in Tifton-85 pasture has a high potential for N_2O emission during the rainy season, but the magnitude is similar to that resulting from inorganic mineral fertilization. The emission of GHGs by the LPS treatments in this study were similar to

those observed in the area that received inorganic mineral fertilizer.

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