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Soil CO_2 emission in 'Tifton 85' bermudagrass pasture fertilized with liquid pig slurry

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Abstract

The application of liquid pig slurry (LPS) to pastures offers potential as a fertilizer but could have a direct influence on soil CO_2 emissions. This study evaluated soil carbon dioxide emissions after successive LPS applications to soils under pasture cultivation. The experiment was carried out on 'Tifton-85' bermudagrass pasture cultivated in a red-yellow oxisol soil in the municipality of Lucas do Rio Verde-MT, Brazil. Two treatments were evaluated: the control and an application of 20 m^3 ha^{-1} of LPS after each cut of the pasture. The CO_2 emissions from the soil were determined using a high-precision infrared gas analyzer. Soil temperature and soil moisture were determined as were micrometeorological variables. The application of LPS had a significant effect on soil C-CO_2 flow. The average flow of C-CO_2 from the soil for the control treatment and with the application of LPS was 0.236 g C-CO_2 m^{-2} h^{-1} and 0.291 g C-CO_2 m^{-2} h^{-1}, respectively. The application of LPS increased the accumulated CO_2 emissions from the soil by 23.2%. Soil temperature and moisture are the main factors regulating the process of soil CO_2 emission. These factors therefore need to be considered when evaluating the impact of LPS application on greenhouse gas emissions.

Keywords: swine wastewater, soil gas fluxes, carbon dioxide, soil moisture, soil temperature.
Abbreviations: GHG_greenhouse gas; LPS_liquid pig slurry.

Introduction

Biodigestion is an important anaerobic fermentation process of organic matter carried out within a reactor (biodigester) and is one of the technological solutions used by Brazilian pig farmers in order to treat swine manure. The final products of this process can be a source of income for the producer. In addition, the use of biogas in generating electrical, thermal, and mechanical energy is highlighted, and the liquid biofertilizer (also called liquid pig slurry - LPS) can totally replace chemical fertilizers in agriculture. However, the inappropriate use of LPS can increase the risk of microbiological contamination of groundwater, accumulation of toxic elements, nutrient imbalances, and soil impermeability (Seganfredo, 2000), besides having a direct influence on the emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), and the volatilization of ammonia (NH_3) (Carvalho and Hentz, 2014).
The emission of CO_2 from the soil occurs as a function of respiration of the 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 owing to an increase in organic carbon, and consequently, an increase in microbial respiration and activity (Webb et al., 2010). 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 a study conducted in a controlled laboratory environment, CO_2 flux one day after application of LPS (200 kg N ha^{-1}) in an uncultivated clay soil was 125 mg C m^{-2} h^{-1}, while in a soil without application of LPS, the flux was 40 mg C m^{-2} h^{-1} (Jarecki et al., 2008). In a study conducted in the state of Santa Catarina, CO_2 flux rates in a no-till soil cultivated with a wheat and corn rotation varied between 60 and 208 mg m^{-2} h^{-1} in a treatment where LPS was applied at a rate of 140 kg N ha^{-1}, and these rates remained higher than those of the control treatment for the first 18 days after application

(Grave et al., 2015). The application of LPS to the soil causes an increase in the CO_2 emission in the first hours after application, with approximately 59% of the organic C added with swine manure evolving as CO_2, regardless of the way the manure was placed in the soil (Giacomini et al., 2007).

Owing to the potential of LPS as a fertilizer, its application in areas of crop and pasture areas is one of the alternatives for the use of this residue popular in the west and south of Brazil (Konzen, 2003). Because of pig production being geographically concentrated in large production centers, LPS applications in agricultural areas occur repeatedly and in close proximity to the farms, thereby constituting a problem due to the excessive use of this biofertilizer. Thus, studies are needed to assess the impacts of this practice. The objective of this study was therefore to evaluate the soil CO_2 emissions after successive LPS applications in soil under pasture planted with 'Tifton-85' bermudagrass.

Results and Discussion

Soil CO_2 emissions

LPS application had a significant effect ($p < 0.05$) on soil CO_2 emissions (FCO_2) (Table 1). The FCO_2 varied between 0.09 and 0.43 g C-CO_2 m^{-2} h^{-1} in the control and between 0.11 and 0.47 g C-CO_2 m^{-2} h^{-1} in the LPS20 treatment (Fig. 1C). The lowest FCO_2 for both treatments was observed in the first cutting cycle (C1), probably due to the low soil moisture and low precipitation (Figs 1B and 1C). The highest FCO_2 was observed in C4 and C5, for the control and LPS20, respectively, in periods with greater precipitation and soil moisture (Figs 1B and 1C).

The average FCO_2 during the experiment was 0.236 and 0.291 g C-CO_2 m^{-2} h^{-1} for the control and LPS20 treatments, respectively, which differed statistically (Table 1). The FCO_2 accumulated in LPS20 and at the end of the evaluated period, was 23.2% higher than the FCO_2 that accumulated in the control treatment (Fig. 1D).

FCO_2 was higher in LPS20, which indicated that the applied waste influenced the emission of greenhouse gas (GHG), an observation that corroborates the studies by Giacomini and Aita (2008), Jarecki et al. (2008), Denega (2009), Grave et al. (2015), and Friederichs et al. (2019). Jarecki et al. (2008) observed C-CO_2 flows from the soil that varied between 0.04 and 0.23 g C-CO_2 m^{-2} h^{-1} in treatments with an application of LPS equivalent to the application of 200 kg N ha^{-1} in clayey soil without cultivation (controlled environment). These values were lower than those observed in this study, but higher than emissions in soil without the application of LPS. In a study conducted in a medium texture red nitosol under wheat/corn succession (no-tillage) in Concórdia-SC, Grave et al. (2015) observed values between 0.06 and 0.208 g C-CO_2 m^{-2} h^{-1} in treatments with an application of 140 kg N ha^{-1} LPS, which are higher than those observed in the first 18 days after application in the current study.

The emission of CO_2 at the soil-atmosphere interface is linked to the decomposition of the residue of plant material, oxidation of organic matter in the soil, and respiration of microorganisms and roots (Carvalho et al., 2010; Sistani et al., 2010). As a result, the effect of LPS on the soil C-CO_2 flow is due to the addition of easily decomposable C compounds (Jarecki et al., 2008), to the greater amount of nutrients added with the application of LPS, and to changes in the edaphic environment, which can cause increases in exchanges between the soil-atmosphere system, thereby increasing GHG emissions (Sistani et al., 2010).

In cutting cycles C1, C2, C3, and C5, the FCO_2 in LPS20 was higher than in the control (Table 1), which can be attributed to the direct effect of LPS on the biological activity of the soil through the addition of N and the increase in biomass production by grass, thereby increasing the availability of C for soil biota, in addition to increasing CO_2 emissions via root respiration.

For LPS20, the average flow of C-CO_2 from the soil during C1 was lower than the flows of the other cycles (Table 1), possibly due to unfavorable edaphoclimatic conditions, such as the lower soil moisture at 5 cm and 25 cm depth (U_{5cm} and U_{25cm}), and lower precipitation in this cutting cycle (Figs 1B and 1C). For the control, the highest FCO_2 occurred during C4 due to conditions of precipitation and soil moisture (Figs 1B and 1C) being conducive to the processes linked to CO_2 emission from the soil.

According to Morell et al. (2010) and Silva-Olaya et al. (2013), precipitation events and, consequently, higher soil moisture, are factors that influence the CO_2 emission from the soil, which is why they must have potentiated the emission of this GHG in this study. Moitinho et al. (2015) observed a 70% increase in CO_2 emissions from the soil after rain (10.2 mm) under sugarcane cultivation, which suggests an effect of the crop on CO_2 emissions by increasing the release of root exudates, thereby stimulating the microbial activity of the soil (Dijkstra and Cheng, 2007), and also owing to the effect of expelling the CO_2 present in the soil profile due to the occupation of soil pores by water (Zanchi et al., 2003).

Correlation between C-CO_2 emission from soil with micrometeorological and soil variables

The variation of FCO_2 in the control treatment showed a negative linear correlation with soil temperature, indicating that 50% of the flow is owing to the soil temperature at a depth of 25 cm (T_{25cm}) (Figs 2A and 2B). For the LPS20 treatment, there was a positive and negative linear correlation with temperature at 5 cm (T_{5cm}) and at 25 cm (T_{25cm}), respectively; however, they did not explain a significant percentage of the variation in the flow data.

Brito et al. (2015) reported (in a Red Latosol with a clay texture under pasture cultivation) a positive linear correlation between the CO_2 flow of the soil and the soil temperature. Bortolotto et al. (2015) reported a positive correlation between the CO_2 flow and soil temperature at a depth of 20 cm. However, Tang et al. (2003) reported that microbial decomposition and, consequently, CO_2 emissions, can be reduced by increasing soil temperature and decreasing humidity, which may have occurred in the control treatment, especially in C1, in the current study (Figs 1A and 1B). Verbug et al. (2005) reported that the CO_2 flow of the soil has an inverse relationship with soil temperatures above 20 °C. In the current study, soil temperature remained above 20 °C during the trial, reaching maximum temperatures of 29 °C and 30 °C at 5 and 25 cm depth, respectively (Fig. 1A).

Soil moisture in the control treatment, had a positive linear correlation with FCO_2 variation, with U_{5cm} and U_{25cm} explaining more than 50% of the data variation (Figs 2C and 2D). Positive linear correlations were also found for the LPS20; however, the U_{5cm} and U_{25cm} explained 45 and 25%, respectively, of the data variations (Figs 3C and 3D). La Scala

Table 1. Average and accumulated soil CO_2 emissions (FCO_2) without application of LPS (control), with application of 20 m^3 ha^{-1} of LPS in each grass cutting cycle (LPS20), and accumulated precipitation during five cutting cycles in 'Tifton-85' bermudagrass.

Cutting cycles	FCO_2 (g C-CO_2 m^{-2} h^{-1})		Accumulated FCO_2 (kg C-CO_2 ha^{-1})		Accumulated precipitation
	Control	LPS20	Control	LPS20	
C1	0.145 ± 0.011 Bd	0.177 ± 0.017 Ab	1084.39 B	1318.32 A	106.90
C2	0.210 ± 0.014 Bc	0.299 ± 0.013 Aa	1567.43 B	2227.97 A	211.20
C3	0.262 ± 0.013 Bab	0.319 ± 0.016 Aa	1447.58 B	1761.40 A	174.50
C4	0.321 ± 0.021 Aa	0.329 ± 0.014 Aa	2465.49 A	2528.12 A	103.60
C5	0.247 ± 0.024 Bbc	0.338 ± 0.020 Aa	1838.08 B	2517.70 A	238.76
General	0.236 ± 0.012 B	0.291 ± 0.012 A	8402.97 B	10353.51 A	834.96

Averages followed by the same uppercase letter in the lines do not differ statistically from each other using Student's *t*-test ($p < 0.05$), and the averages with the same lowercase letter in the columns do not differ statistically from each other using the Kruskal-Wallis test ($p < 0.05$).

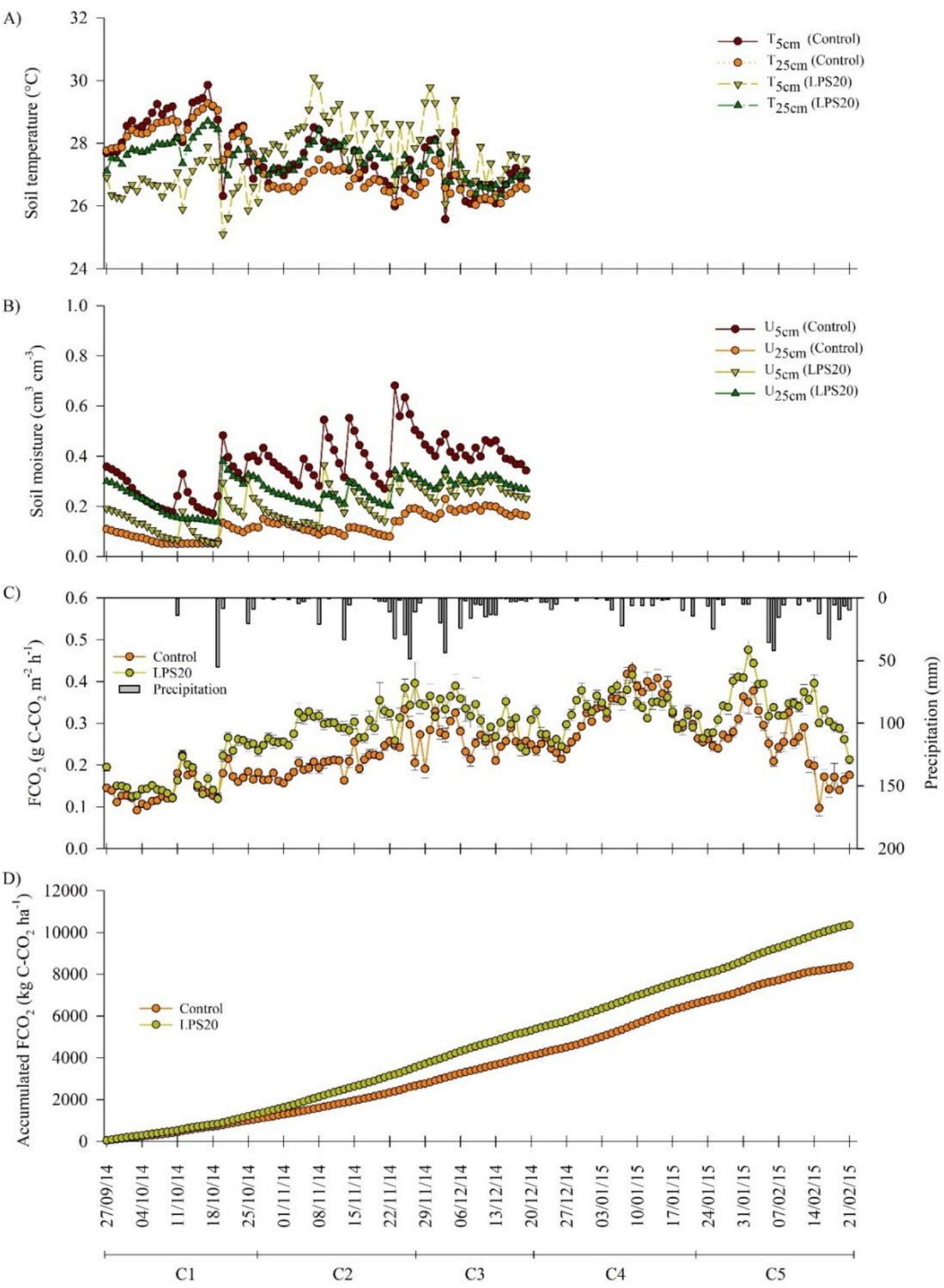

Fig 1. Soil temperature (A), soil moisture (B), average soil CO_2 emissions (FCO_2) and precipitation (C), and accumulated soil CO_2 emissions (FCO_2) (D) without application of LPS (control), and with application of 20 m^3 ha^{-1} of LPS in each grass cutting cycle (LPS20) during five cutting cycles in 'Tifton-85' bermudagrass.

Table 2. Multiple regression of soil CO_2 emissions (FCO_2) without application of LPS (control), as a function of the variables selected by the model: soil moisture at 25 cm depth (cm^3 cm^{-3}; $U_{25\ cm}$), soil temperature at 25 cm depth (°C; $T_{25\ cm}$), solar radiation (MJ m^{-2} day^{-1}; Rg), and soil moisture at 5 cm depth (cm^3 cm^{-3}; $U_{5\ cm}$).

Variable	Parameter	SD	P	R^2
Intercept	0.48722	0.23286	0.03958	
$U_{25\ cm}$	0.52242	0.15032	0.00083	0.51849
$T_{25\ cm}$	- 0.01624	0.00777	0.03975	0.56642
Rg	0.00253	0.00095	0.00895	0.59773
$U_{5\ cm}$	0.11846	0.05788	0.04397	0.61775

SD = standard deviation of the parameter estimate; R^2 = coefficient of determination.

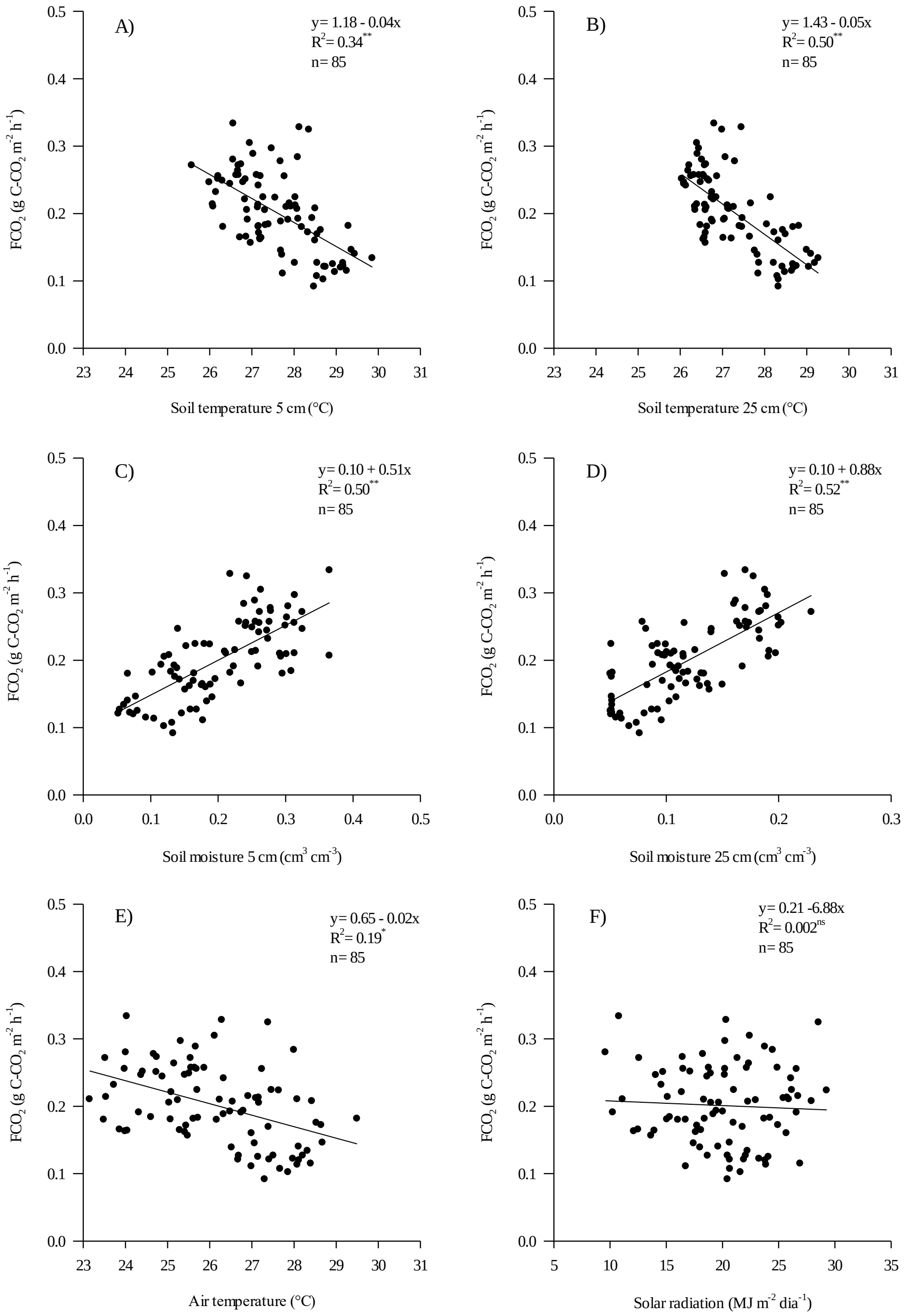

Fig 2. Correlation of soil CO_2 emissions (FCO_2) without application of LPS (control): with soil temperature at 5 cm (A) and 25 cm (B) depth, soil moisture at 5 cm (C) and 25 cm (D) depth, air temperature (E), and solar radiation (F).

Table 3. Multiple regression of soil CO_2 emissions (FCO_2) with application of 20 m³ ha⁻¹ of LPS in each grass cutting cycle (LPS20), as a function of the variables selected by the model: soil moisture 5 cm ($cm^3\ cm^{-3}$; $U_{5\ cm}$), soil temperature 5 cm (°C; $T_{5\ cm}$), air temperature (°C; T_{air}), and soil temperature 25 cm (°C; $T_{25\ cm}$).

Variable	Parameter	SD	p	R^2
Intercept	0.01692	0.28002	0.95197	
$U_{5\ cm}$	0.38824	0.07422	0.00001	0.45306
$T_{5\ cm}$	0.04211	0.00394	0.00001	0.72320
T_{air}	- 0.01034	0.00365	0.00590	0.76005
$T_{25\ cm}$	- 0.02638	0.01066	0.01542	0.77713

SD = standard deviation of the parameter estimate; R^2 = coefficient of determination.

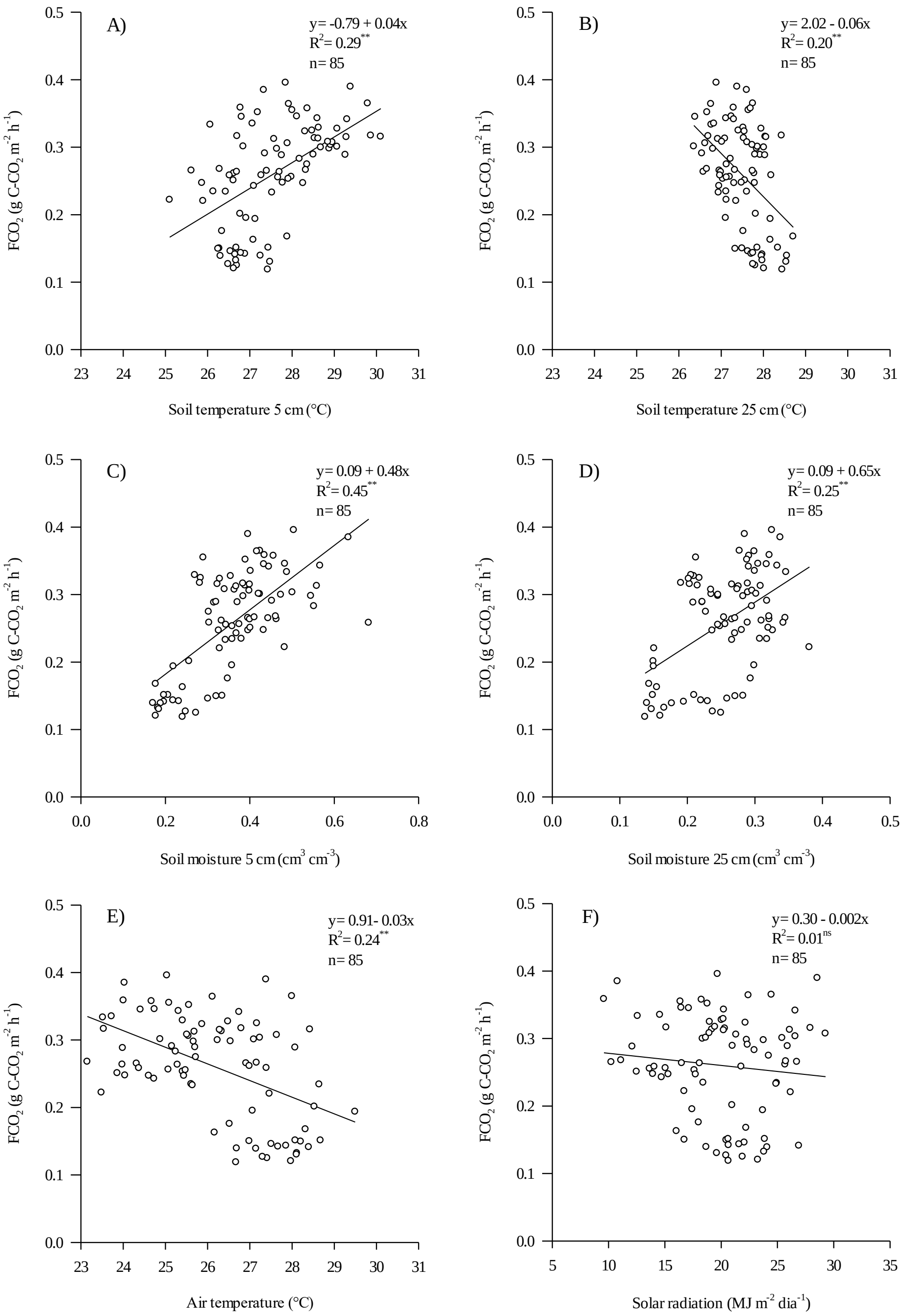

Fig 3. Correlation of soil CO_2 emissions (FCO_2) with application of 20 m³ ha⁻¹ of LPS in each grass cutting cycle (LPS20): with soil temperature at 5 cm (A) and 25 cm (B) depth, soil moisture at 5 cm (C) and 25 cm (D) depth, air temperature (E), and solar radiation (F).

Table 4. Chemical analysis of soil fertility of the experimental area at a depth of 0 to 20 cm.

Depth	pH	Al	H + Al	Ca	Mg	$T_{pH\ 7.0}$	V	OM	K	P
(cm)	(H_2O)	--------------- ($cmol_c\ dm^{-3}$) ---------------					(%)	------ ($mg\ dm^{-3}$) ------		
0-20	4.53	0.38	15.15	2.27	0.93	18.35	17.94	5.42	106.28	14.22

pH-acidity; Al-aluminum; H + Al-hydrogen plus aluminum; Ca-calcium; Mg-magnesium; $T_{pH\ 7.0}$-cationic exchange capacity at pH 7.0; V-base saturation; OM-organic matter; K-potassium; and P-phosphorus.

Fig 4. PVC collar inserted into the soil to a depth of 3 cm (A) and the chamber of the infrared gas analyzer (LI-8100A) coupled with the PVC collar (B).

Table 5. 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}--------------			
September/2014	5.6	0.7	1.0	3.0	-	8.0	40.0	20.0	150.0	11.1
October/2014	2.8	18.8	0.8	6.0	3.0	3.0	10.0	40.1	30.2	20.0
November/2014	1.4	0.1	0.7	6.0	1.5	11.0	10.0	10.0	10.0	3.9
December/2014	4.2	0.1	0.5	1.2	0.6	0.0	2.0	2.1	2.2	1.0
January/2015	4.2	0.1	0.5	1.5	0.6	0.4	14.1	4.0	48.2	4.1

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

Table 6 Cutting cycles of 'Tifton-85' bermudagrass evaluated.

Application date of liquid pig slurry (LPS)	Cutting cycle	Period	Duration (days)
27/09/2014	C1	09/27/2014 to 10/27/2014	31
28/10/2014	C2	10/28/2014 to 11/27/2014	31
28/11/2014	C3	11/28/2014 to 12/20/2014	23
21/12/2014	C4	12/21/2014 to 01/21/2015	32
22/01/2015	C5	01/22/2015 to 02/21/2015	31

Jr et al. (2006) observed a positive linear correlation between these variables when they evaluated the C-CO_2 flow in soil cultivated with sugarcane. In general, soil moisture is related to the temporal variations in the C-CO_2 flow of the soil when it becomes a limiting factor (Schwartz et al., 2010), which explains the variations in FCO_2 as a function of variations in U_{5cm} and U_{25cm} in this study.

The biotic and abiotic factors of the soil, such as microorganisms, temperature, humidity, and texture, affect the production of CO_2 in the soil by the roots and organisms and, consequently, the gas exchange at the soil-atmosphere interface (Luo & Zhou, 2006). Therefore, evaluating the isolated relationship of soil CO_2 flow with a single variable is ineffective in understanding the factors that relate to CO_2 emissions over time.

For the control treatment, the FCO_2 was estimated based on the parameters described in the multiple regression analysis (Table 2). The U_{25cm} was first the variable to enter the model, explaining approximately 52% of the FCO_2 variation. The second variable was T_{25cm}, followed by daily solar radiation (Rg) and U_{5cm}, which together accounted for about 10%. At the end of the analysis, the variables U_{25cm}, T_{25cm}, Rg, and U_{5cm} explained 62% of the total FCO_2 variation (Table 2).

For the LPS20 treatment, the U_{5cm} was the first variable to enter the model, explaining 45% of the variation in FCO_2. The second variable selected was T_{5cm}, responsible for 27%, followed by air temperature (T_{air}) and T_{25cm}, which together accounted for just over 5%. Together, these variables were responsible for approximately 78% of the total variation in FCO_2 (Table 3).

This study confirms that the water content in the soil (La Scala et al., 2006; Iqbal et al., 2009), solar radiation (Ouyang and Zheng, 2000), and the soil temperature (Wang et al., 2009; Bortolotto et al., 2015) are the main variables that affect CO_2 flow in the soil.

Materials and Methods

Study site

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 in the 0 to 0.20 m layer indicated a pH of 4.53 (H_2O); 0.38 $cmol_c\ dm^{-3}$ of Al; 15.15 $cmol_c\ dm^{-3}$ of H + Al; 2.27 $cmol_c\ dm^{-3}$ of Ca; 0.93 $cmol_c\ dm^{-3}$ of Mg; 18.35 $cmol_c\ dm^{-3}$ of cationic exchange capacity ($T_{pH\ 7.0}$); 17.94% of base saturation (V%); 5.42 mg dm^{-3} of organic matter (OM); 106.28 mg dm^{-3} of K; and 14.22 mg dm^{-3} of P (Table 4).

The climate of the region, according to the Köppen classification, is type Aw, tropical rainy, hot, and humid, with a prolonged dry season and wet season of seven months, between October and April.

Experimental design

The experiment was conducted in two adjacent areas (5 m × 11 m) cultivated since March 2014 with a 'Tifton 85' bermudagrass cultivar (*Cynodon dactylon*). Two treatments were tested: (i) without application of LPS (control) and (ii) application of 20 $m^3\ ha^{-1}$ of LPS in each grass cutting cycle (LPS20). In each area, two sampling points were outlined in the center of the area with a minimum distance of 3 m between points. For this demarcation, PVC collars (100 mm in diameter and 5 mm in height) were inserted into the soil to a depth of 3 cm (Fig. 4).

After applying the treatments, the assessments were carried out in five cutting cycles of the 'Tifton-85' grass, over a total of 148 days. On these days, measurements of soil CO_2 emissions, soil temperature, and soil moisture were carried out every 60 minutes, totaling 48 samples (both areas) per treatment daily.

Characteristics of liquid pig slurry (LPS)

The LPS came from a finishing pig farm, 6 km away from the experimental area. This LPS was treated in a biodigester and later disposed of in a stabilization pond. LPS applications were performed immediately after arriving at the experimental area and immediately after cutting 'Tifton-85' grass. Chemical characterization was performed before each application (Table 5). The samples were frozen until the moment of the laboratory analyses, which followed the standard methods for the examination of water and effluents (Rice et al., 2012).

Assessment of soil CO_2 emission, soil temperature, and soil moisture

Soil CO_2 emissions (FCO_2) were assessed using a high-precision infrared gas analyzer (model LI-8100A, LI-COR, Lincoln, NE, USA), using two closed chambers per treatment. The closed chamber was attached to the upper part of the collar previously inserted into the soil and changes in the concentration of CO_2 inside the chamber were monitored by means of spectroscopy. The chamber has an internal volume of 991 cm^3, with an area of 71.6 cm^2 exposed to the soil. Once the chamber was closed in measurement mode, it took approximately 1.5 minutes to perform the interpolation of the changing CO_2 concentration inside the chamber. The measurements were performed after each application of LPS every 60 minutes during the period from 02/21/2015 to 21/02/2015. Therefore, five cutting cycles of 'Tifton-85' grass were evaluated for periods ranging from 23 to 32 days (Table 6).

Soil temperature and soil moisture were evaluated simultaneously with CO_2 emissions. Soil temperature (°C) and volumetric soil moisture ($cm^3\ cm^{-3}$) were evaluated using sensors based on the capacitance/frequency domain (Model GS3, Decagon Devices, Pullman, WA, USA). Such sensors were installed horizontally in the soil profile at depths of 5 and 25 cm. The data were stored at 30 minutes intervals in two microcontrollers (model Mega 2560 R3, Arduino LLC, Italy). All of this equipment was connected to a 12 V battery with a solar plate (140 W), ensuring sufficient energy for continuous and uninterrupted monitoring.

Micrometeorological variables

A meteorological station (model WatchDog 2700, Spectrum Technologies Inc., Plainfield, IL, USA) was installed in the experimental area to measure the following variables: solar radiation (W m^{-2}), air temperature (°C), relative humidity (%), air pressure (mm Hg), and average daily accumulated precipitation (mm).

Statistical analysis

A one-way ANOVA was performed in a completely randomized design, considering repeated time measures for the variables FCO_2, soil temperature, and soil moisture. Descriptive statistics were obtained from the FCO_2 data and, subsequently, the daily averages of treatments were compared per cycle using a one-tailed Student's *t*-test ($p < 0.05$). Daily averages were also compared between cycles using the Kruskal-Wallis test ($p < 0.05$). Simple linear regression and multiple regression was applied through the "stepwise" method between the C-CO_2 flow of the soil and the micrometeorological and soil variables during the period from 09/27/2014 to 12/20/2014. Statistical analyses were performed using Microsoft Excel 2013 and SPSS program.

Conclusion

Fertilization of 'Tifton 85' bermudagrass pasture with liquid pig slurry (LPS) significantly increased CO_2 emissions. More than 75% of the variation in soil CO_2 emissions was determined by the moisture soil, soil temperature, and air temperature, after applying LPS.

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