REVISTA TRÓPICA: Ciências Agrárias e Biológicas

Greenhouse gas fluxes from soil under different land-management in the Cerrado biome – Rio Verde (Goiás State)

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Abstract - Agricultural management is an important greenhouse gas (GHG) source. In this study, we assess the GHG fluxes from soil under different land-uses and management in the most important grains producing region in Cerrado biome (Rio Verde – Goiás State) with objective of quantifying the GHG fluxes (CO_2, CH_4 and N_2O) form soil, in order to verify the existence of relationships between these gases and obtain estimation of GHG fluxes through statistically correlation in Cerrado Biome. GHG flux was measured usittng static chambers in areas under i) native vegetation (NV), a grassy pasture (GP), a conventional-tillage (CT), and three areas under no-tillage (NT) with different crop succession. Results showed highest CO_2 emission in GP (135 mg m^{-2} h^{-1}), while in CT verified lower emission (69 mg m^{-2} h^{-1}). CH_4 emissions were found in GP (32 µg m^{-2} h^{-1}), while in other areas (NV, CT and NT) were found absorptions between -46 and -15 µg m^{-2} h^{-1}. N_2O emission was highest in NV (16 µg m^{-2} h^{-1}), while lowest in the NT with soybean (11 µg m^{-2} h^{-1}). Significates CO_2 *vs* N_2O ($r > 0.60, p < 0.01$) and CO_2 *vs* CH_4 ($r > 0.55, p < 0.05$) correlations were found to all areas, except to GP; while the CH_4 vs N_2O were found only to NV and NT ($r > 0.50, p < 0.05$). These results cannot permit to identify which processes involve in the GHG correlations, but, these statistical estimative and simple equations can provide rough estimates GHG flux through a simple field measurement.

Keywords: Greenhouse gas emission, no-tillage, conventional tillage, pasture.

Emissões de gases de efeito estufa do solo em diferentes usos e manejos da terra no bioma Cerrado (estado de Goiás)

Resumo - Os solos agrícolas correspondem a uma das mais importantes fontes de gases do efeito estufa (GEE). Neste estudo, avaliaram-se os fluxos de GEE de solo com diferentes usos e manejo na região mais importante de produção de grãos. O objetivo foi quantificar os fluxos de GEE (CO_2, CH_4 e N_2O) em sistemas de produção e verificar a existência de correlações entre esses gases estimar emissões anuais no Cerrado. Os fluxos dos GEE foram medidos em áreas de vegetação nativa (NV),

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pastagem (GP), plantio convencional (CT) e plantio direto (NT) com diferentes sucessões de culturas. Os resultados mostraram que a pastagem apresentou a média mais elevada na emissão de CO_2 (135 mg m^{-2} h^{-1}), enquanto que o cultivo convencional a mais baixa (69 mg m^{-2} h^{-1}). Foi encontrada emissão de CH_4 na GP de 32 µg m^{-2} h^{-1}, enquanto nas demais áreas foram encontradas absorção entre -46 e -15 µg m^{-2} h^{-1}. A emissão de N_2O foi mais elevada na NV (16 µg m^{-2} h^{-1}), enquanto a menor foi no NT (11 µg m^{-2} h^{-1}). As emissões de CO_2 e N_2O apresentaram correlações significativas ($r > 0,60$; $p < 0,01$), exceto para a pastagem, assim como entre CO_2 e CH_4 para NV, CT e NT ($r > 0.55$, $p < 0.05$) e, entre CH_4 e N_2O na NV e NT ($r > 0.50$, $p < 0.05$). Apesar de não podermos especificar os processos responsáveis pelos fluxos e as correlações entre os GEE, foi possível fornecer indícios da magnitude dos fluxos de cada gás, assim como, suas correlações e estimar as emissões nos diversos sistemas de produção presentes na região.

Palavras-chave: Emissão de gases de efeito estufa, plantio direto, plantio convencional, pastagem.

INTRODUCTION

The increases of the greenhouse gas (GHG) in the atmosphere and, consequently, its association to global warming have raised discussions by authorities and the scientific community in the last decades. The IPCC (2007) related evidences that anthropogenic emissions are responsible for global warming of 0.6°C observed in the last century.

Agricultural activities increase GHG emissions from soil to atmosphere (BERNOUX et al., 2001). Globally, this activity account for about 25 % of total emissions (HOUGHTON et al., 2001), specifically in Brazil is related more than 70 % of the GHG emissions (BRASIL, 2010).

The soil is an important carbon pool, containing about 1500 Pg C (petagram = 10^{15} grams), or, twice the C content of the atmosphere (KIRCHMANN et al., 2004). The CO_2 production are associated with roots and microbial respiration, since the last uses the organic residues - animal or vegetable and/or soil organic matter (SOM) like energy source and, together, has the major role to CO_2 emissions from soils (SILVA-OLAYA et al., 2013). Soil tillage fragments soil aggregates that protected SOM fraction, favoring the oxidizing agent activity (microbial biomass), which causes highest CO_2 emissions (SIX et al., 2004).

CH_4 production in soil depends to the anaerobic microbial processes involved in the C reduction, *i.e.*, only in restricted O_2 conditions, thus the methane is largely produced under poor aeration and in saturated soils or wetlands (FERRY, 2010). However, in the well-drainage soils, as our conditions, normally, behave as a methane sink (HÜTSCH et al., 1994).

N_2O is an intermediate product that occurs mainly due microbial processes of the nitrification and denitrification (BUTTHERBACK-BAHL et al., 2013). Large quantities of N-fertilizers are identified as the main cause for N_2O emissions from croplands (SIGNOR; CERRI, 2013).

The GHG fluxes from soils present strongly variability due to its production and consumption, as well as, its emissions resulting from complex interactions between soil microbial and environmental factors such as climate seasonality, soil and conditions and, also byland use, management and crops. The intensity of each factor vary in time and space (JACINTHE; LAL, 2006), with this, are makes difficult to predict the GHG emissions using simple parameters.

This study is based in two hypotheses (1) the land management should change GHG fluxes from soil to atmosphere; (2) the rainy season should increase the GHG emission. To this, we assess the GHG fluxes from soil under different land management in the most important grains (soybean and maize) producing region in Cerrado biome. So, our objective was quantifying the GHG fluxes (CO_2, CH_4 and N_2O) in different lands management and seasons to verify the existence of relationships between these gases.

MATERIALS AND METHODS

The GHG fluxes were measured in the municipality of Rio Verde, Goiás State, Brazil (17° 47' 52"S and 50° 55' 40" W). The climate is tropical with a rainy season lasting from October to April and a dry season from May to September (Aw – Köppen classification) with a mean annual precipitation of 1550 mm and mean annual temperature of 23.3°C (Figure 1).

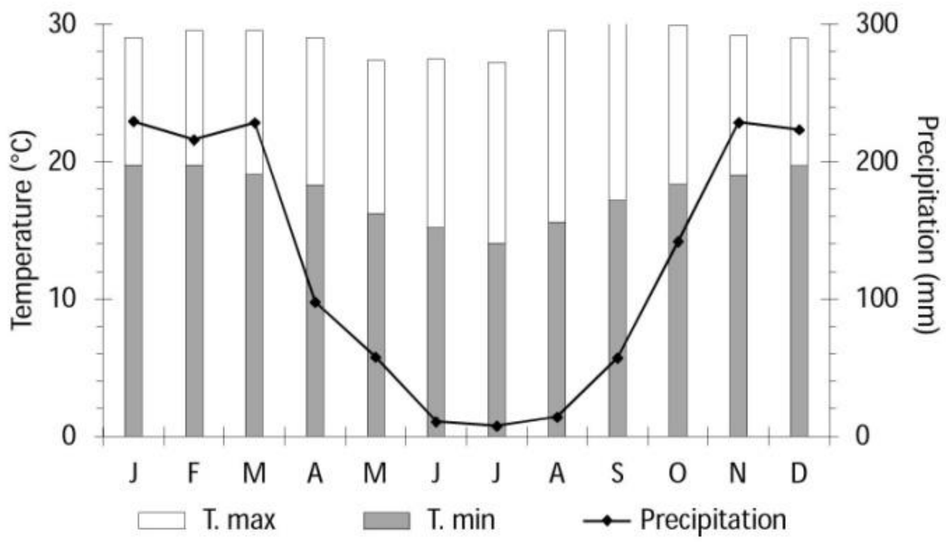

Figure 1 - Monthly temperature (maximum and minimum) and precipitation in the Brazilian Savanna: Rio Verde – Goiás State, Brazil (INMET, 2017).

The soil was classified as a Typic Acrudox (USDA, 2010) or according to Brazilian soil classification, Latossolo Vermelho Distrófico (EMBRAPA, 2006). The soil physic and chemical characterization was showed in Table 1.

Table 1 - Physicochemical characteristics of the soils (0-20 cm) under the different land uses in the Brazilian Savanna (Rio Verde – Goiás State, Brazil).

Site	pH	Clay content	Bulk density	Available-P	CEC	% BS
		%	g cm^{-3}	mg kg^{-1}	cmol$_c$ dm^{-3}	%
NV	4.7 ± 0.2	50.2 ± 2.6	1.02 ± 0.11	6.8 ± 3.7	8.3 ± 0.8	5.0± 3.3
GP	6.0 ± 0.1	65.3 ± 3.0	1.21 ± 0.09	8.3 ± 3.5	5.3 ± 0.4	43.0 ± 17.8
CT$_S$	5.6 ± 0.2	61.7 ± 3.4	1.10 ± 0.06	11.3 ± 7.6	5.1 ± 0.4	27.6 ± 12.6
NT$_{SSo}$	5.6 ± 0.3	68.1 ± 4.3	1.06 ± 0.05	16.0 ± 5.7	6.0 ± 0.7	34.5 ± 13.9
NT$_{SMi}$	5.5 ± 0.2	65.0 ± 5.3	1.06 ± 0.09	16.1 ± 5.8	6.6 ± 0.8	30.0 ± 9.7
NT$_{MSo}$	5.9 ± 0.4	64.3 ± 4.2	1.05 ± 0.04	29.3 ± 9.3	5.6 ± 1.1	27.9 ± 11.6

Mean (n = 6) ± S.D.; NV, native vegetation in Cerrado biome; GP, grassy pastures; CT, conventional tillage; NT, no-tillage; S, soybean; So, sorghum; M, maize; Mi, millet; P, phosphorus; CEC, cation exchange capacity; BS, base saturation.

The evaluated situations were: i) native vegetation (NV), called Cerradão according Eiten (1972), composed of semi deciduous tree covering with height between 15 and 25 meters; ii) nominal grazing pasture (GP); iii) conventional tillage (CT$_S$) cultivated with soybeans (*Glycine max* [L.] Merr) and, three areas under no-tillage (NT) systems with different crop succession: iv) NT$_{SSo}$ with soybean followed by sorghum (*Sorghum bicolor* [L.] Moench); v) NT$_{SMi}$ with soybeans followed by millet (*Pennisetum glaucum* [L.] R. Br) and, vi) NT$_{MSo}$ with maize (*Zea mays* L.) followed by sorghum. The history of the agricultural occupation of the areas is represented in the Figure 2.

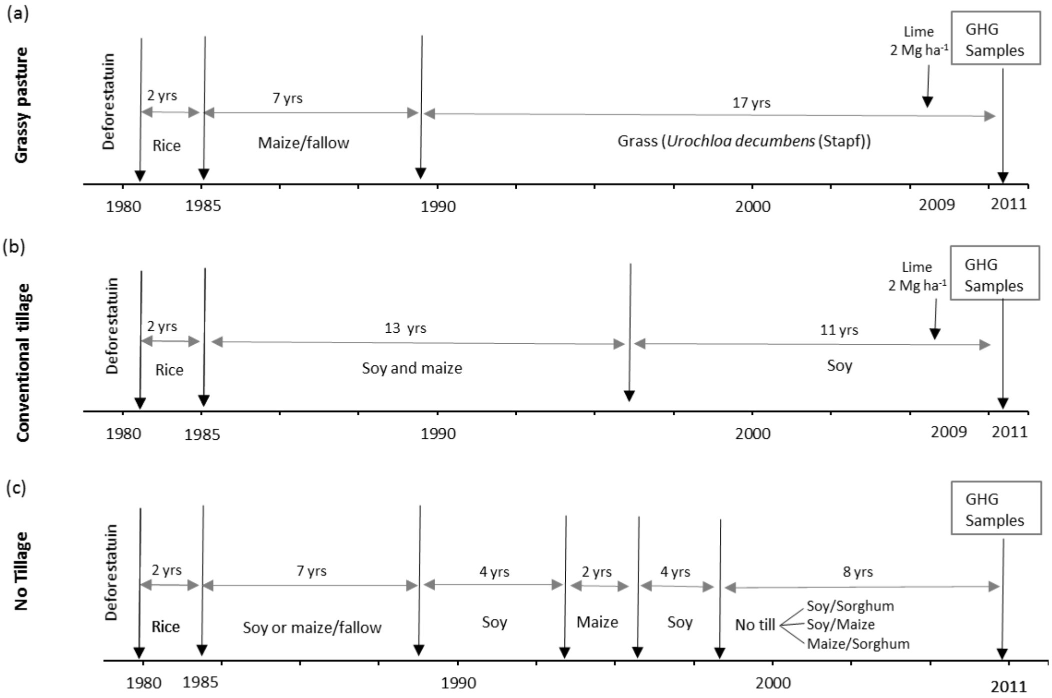

Figure 2 - Graphical representation of the history of the agricultural occupation of the areas of the experiment. No tillage areas were represented by only one history area. The change was in the last 8 years that one of the rotations was applied.

In this region the fertilizer management was similar every year in the areas under conventional and no-tillage systems. Soybean crop received 450 kg ha^{-1} of 02-20-18 NPK in the seeding and 100 kg ha^{-1} of KCl as topdressing, resulting in a productivity between 3500 and 4000 kg ha^{-1} of grain. Maize crop received 550 kg ha^{-1} of 8-20-20 (NPK) in the seeding and 200 kg ha^{-1} of urea as topdressing, resulting in a mean productivity up of 9000 kg ha^{-1} of grain for maize. Sorghum only received a just half of the topdressing fertilizer applied in maize, resulting in productivity near to 2300 kg ha^{-1} of grain. No fertilizer was applied in millet, as millet was used only as soil cover.

The GHG (CO_2, CH_4 and N_2O) fluxes were measured in six replicates (chambers) taken together six times, three on rainy season (November, December and January) and three on dry season (May, June and July). Static chambers used to collect GHG emitted by soil consist of two parts, a base and a lid. The dimensions of the base were 0.30 (ø) x 0.10 (height) m, with a total (base+lid) volume of ~5.5 L. Air samples of the chamber's headspace were sampled in a nylon syringe of 20 mL (Becton Dickinson Ind. Surgical Inc.), in four time intervals (0, 10, 20 and 30 minutes). At the same day the air samples was transferred to glass vials of 10 mL and was analyzed in 2 days. The GHG analyses were realized using a Shimadzu® GC-2014 (Kyoto, Japan) gas chromatograph, which has a packed Porapak Q® column maintained at 82°C. N_2O concentration was done by an electron capture detector (ECD) operating at 325°C and, CO_2 and CH_4 concentration were done by a flame ionization detector (FID). Meteorology data collected by using automatic weather station observations (Australian ICT Company) of experiment station and the observations (hourly) include: air temperature (maximum, minimum and daily average), relative humidity, barometric pressure, rainfall, speed and direction of wind. The soil temperature inside the chambers was analyzed with a thermometer in 5 cm deep and in soil surface.

GHG fluxes were calculated by linear change in the GHG concentration within the chambers as a function of incubation time. The gas flux was calculated by linear interpolation between gas concentrations and the retention time in chamber (Eq. 1).

$$Flux = \left(\frac{\delta[gas]}{\delta t}\right) * \left(\frac{Vh}{A}\right) * \left(\frac{\left(\frac{1-e}{P}\right)}{Vm}\right) \qquad \text{Eq (1)}$$

where *(δ[gas]/ δt)* is the rate of change in gas concentration as function of time (mol mol^{-1} s^{-1}), V_h is the chamber volume (m^3), A is the chamber area (m^2), P is the water pressure/air pressure in the chamber (kPa kPa^{-1}), and V_M is the molar volume of the chamber (m^3 mol^{-1}).

The two-factor factorial (land-use and season) were submitted to variance analysis by MANOVA and the means were compared by Tukey-test ($p < 0.05$). For the Pearson's correlations coefficients was applied statistical significance by Student's unpaired t-test ($p < 0.01$ and 0.05). All statistical analyses were run using the Statistical Analysis System (SAS), version 9.1.2.

RESULTS AND DISCUSSIONS

For all GHG the interaction term was not significant. It means that the effect was land use was interpreted individually. The CO_2-C emissions mean to all evaluated situations ranged from 69 to 135 mg m^{-2} h^{-1} for NT system and NV and GP, respectively. To GP the annual mean to CO_2 emissions possible occurs due the presence of active root system and soil cover more constant throughout the year. The strongest significant differentiation in CO_2-C emissions was found between rainy and dry season (Figure 3A).

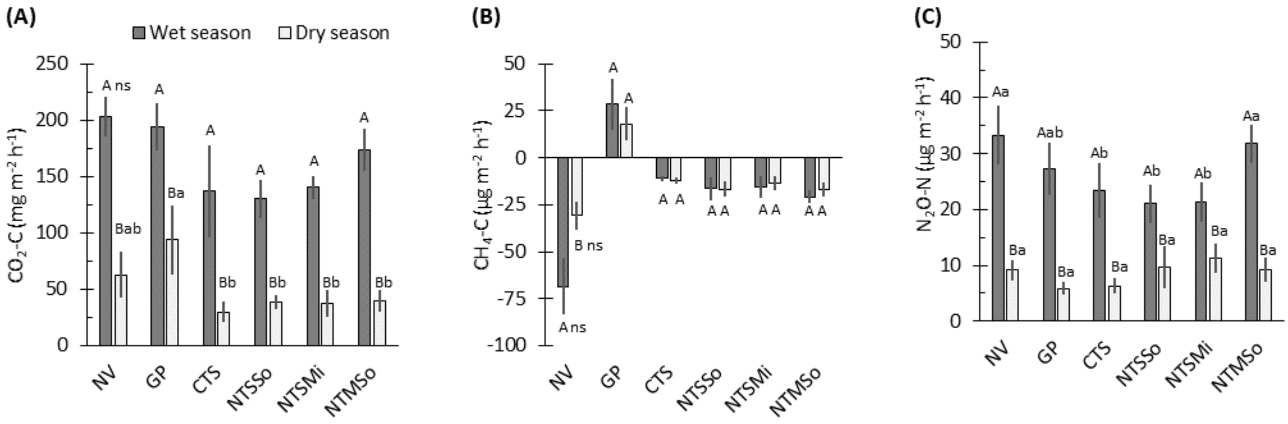

Figure 3 - Seasonal GHG fluxes: A) CO_2-C (mg m^{-2} h^{-1}), B) CH_4-C (µg m^{-2} h^{-1}) and C) N_2O-N (µg m^{-2} h^{-1}) in different land use and management in Brazilian savanna. Means (n = 18) ± SD. Capital letters refer to season and lower-case letters refer to land use; ns = not significate.

CH_4-C fluxes mean to all evaluated situations ranged from -68 to 35 mg m^{-2} h^{-1} for the NV and GP, respectively (Fig. 3B). In GP emissions showed an annual mean of 31.5 µg m^{-2} h^{-1}, this occurs, probably, due significant high bulk density verified in this area. This behavior may reflect the macroporosity reduction due the increase in bulk density in GP, which caused minor aeration in the soil and favor anaerobia microorganisms. Soil compaction contributes to CH_4 synthesis because reduces soil air diffusion and, consequently, that increases the CO_2 accumulation in soil profile (HORN et al., 1995), contributing to the reducing sites formation in the soil.

In others land uses were observed CH_4 uptake (annual mean of ~15µg m^{-2} h^{-1}), being that the NV showed major absorption (46 µg m^{-2} h^{-1}). In forest sites, the methanotrophic activity is usually directed correlated with the organic matter content (HUTSCH, 1998). Organic matter reduced soil bulk density increasing the gas diffusivity and the Archaea activity, leading to higher CH_4 oxidize (PRICE et al., 2003). Actually, others authors suggest that savanna grasses modest contribute to the CH_4 global emission (~1%) (SANHUEZA; DONOSO 2006). It was not found significant differences in the fluxes of methane between rainy and dry season (*$p > 0.05$*).

The N_2O-N emissions ranged between 11 to 16 µg m^{-2} h^{-1} for the NT_{SSo} and NV, respectively (Fig. 3 C). However N_2O-N emissions did not presented significantly different (*$p < 0.05$*) related to land use. However, other studies have shown increased N_2O emissions under NT compared to CT (BALL et al., 1999; BAGGS et al., 2003; LIU et al., 2007).

The N_2O-N emissions showed similar behavior to the CO_2, the highest significant differentiations (72 to 78%) were found between seasons (*$p < 0.05$*) (Fig. 3C). During rainy season, the N_2O-N emissions found to the croplands with soybean were one third lower compared to NT with maize (*$p < 0.05$*). This is related to the N-fertilizer applied to the maize, beside the presence of water in the soil. Metay et al. (2007) found similar results in Goiânia (Goiás state), while in rainy season with higher temperatures were observed highest GHG fluxes.

The CO_2 and N_2O emissions showed a positive correlation to the studied areas (*$r = 0.60$, $p < 0.01$*). GP was the only area in which the relation was not significant (Table 2), however, was found high CO_2 emissions, what did not happen with the N_2O emission. The correlation was significant when considering all areas (*$r = 0.57$, $p < 0.01$*) as well as, the areas that have suffered changes in its cultivation (annual agriculture and pasture) (*$r = 0.55$, $p < 0.01$*) and, NT system (*$r = 0.62$, $p < 0.01$*). These results showed that increase in CO_2 emissions could induce N_2O emissions.

Table 2 - Pearson's correlation coefficients between GHG (CO_2, N_2O and CH_4) fluxes from soil under different land use in the Brazilian Savanna (Rio Verde – Goiás State, Brazil).

Sites[1]	CO_2 *vs.* N_2O[2]	CO_2 *vs.* CH_4	N_2O *vs.* CH_4
NV	0.69**	0.55*	0.66**
GP	0.33^{ns}	0.36^{ns}	0.12^{ns}
CTs	0.72**	0.70**	0.42^{ns}
NT_{SSo}	0.60**	0.26^{ns}	0.51*
NT_{SMi}	0.65**	-0.10^{ns}	-0.16^{ns}
NT_{MSo}	0.65**	0.63**	0.47^{ns}
Cultivate	0.55**	0.43**	0.17^{ns}
NT system	0.62**	0.28*	0.31*
All areas	0.57**	0.45**	0.33**

[1] In the studies areas under NV, GP, CT and NT (n = 30); Cultivate areas: to studies areas under GA, CT and NT (n = 150); NT system: to studies areas under NT (n = 90); All areas: to all studies areas (n = 180); [2] Correlation values followed by **: significant to *0,01*; *: significant to = *0,05* and ns: not significant.

In NV it was found a highly significant correlation (*$r = 0.83$, $p < 0.01$*) between CO_2 and N_2O emissions. However, the mechanism that causes these antagonic processes is still unknown. Probably the increase in CO_2 concentration during the organic material decomposition can form micro-sites in the soil with low O_2 availability that favors denitrifies (GARCIA-MONTIEL et al., 2002).

The correlations between CO_2 and CH_4 fluxes were significant for the areas under NV, CT and NT with maize (Table 2). When considering all areas, cultivated areas and NT system, the relations between CO_2 and CH_4 showed low correlation's coefficient ($r < 0.50$), however, were significant ($p < 0.01, p < 0.05$).

The NV and NT with maize showed increase in the SOM, keeping the crop residues on the soil surface propitiating a wider variety of microorganism's functional groups, in this way, these processes could co-exist in the same environment. In the Amazon rainforest larger soil microbial diversity was found, with approximately 20 % still unknown in the scientific world (BORNEMAN; TRIPLETT, 1997). The link between microbial diversity and function is unknown, but biodiversity can influence the system stability, productivity and resilience to stress and disturbance in the system (TORSVIK; ØVREÅS, 2002).

N_2O and CH_4 fluxes showed significant correlation to NV and NT with soybean and sorghum (Table 2). Just as native vegetation, NT system has presented significant correlations between these gases fluxes, indicating that the land management changes from CT to NT improved soil condition, increasing SOM and, consequently, the quantity of soil with increases in microorganism biodiversity (KENNEDY, 1999).

Since were verified correlation between GHG fluxes, it is possible, very simplistically, to predict their emissions in systems with estimated equations (Table 3).

Table 3 - Estimated linear equations to GHG (CO_2, N_2O and CH_4) fluxes from soil under different land use in the Brazilian Savanna (Rio Verde – Goiás State, Brazil).

Sites	CO_2 *vs* N_2O	CO_2 *vs* CH_4	N_2O *vs* CH_4
NV	$N_2O = 0.06\ CO_2 + 3.2$	$CH_4 = -0.09\ CO_2 – 22.2$	$CH_4 = -1.46\ N_2O – 21.4$
CT	$N_2O = 0.05\ CO_2 + 5.9$	$CH_4 = 0.10\ CO_2 – 21.1$	*ns*
NT system	$N_2O = 0.08\ CO_2 + 5.1$	$CH_4 = -0.04\ CO_2 – 13.1$	$CH_4 = -0.37\ N_2O – 12.1$
All areas	$N_2O = 0.04\ CO_2 + 5.8$	$CH_4 = 0.16\ CO_2 – 16.0$	$CH_4 = -0.36\ N_2O – 6.9$

All areas: to all studies areas; ns: not significant. The equations were applied only in situations that were statistically significant in the Pearson's correlations coefficients.

The slope coefficients to CO_2 *vs* N_2O correlations for all areas were three times lower comparing to data presented by Garcia-Montiel et al. (2002) under rain forest in Rondônia State. This occurs, probably, due differences in the climate, mainly rainfall, since N_2O emissions are influenced directly by soil moisture (DALAL et al., 2003).

The linear equations involving the correlations between CH_4; CO_2 and N_2O had a slope coefficient practically insignificant (Table 3). These results showed that the CH_4 flux can be linked to specific processes that are independent to CO_2 and N_2O emission patterns, as well as, the concentration and distribution of such gas within the soil.

CONCLUSION

Based on results one cannot clearly identify which processes were responsible for the relation of the GHG fluxes from soil, especially when associated with the cropping systems with different fertilizers inputs and crop residues. However, since this is not a model with multiple variables, some criteria should be considered due to the reservations and local specialties such as, climate, soil type, land use and management. These statistical estimative and correlations may provide evidence of the magnitude of the main gases fluxes with the application of few and simple field's measures.

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