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CO_2 EMISSIONS AND THEIR RELATION TO PHYSICAL ATTRIBUTES OF A FERTIRRIGATED LATOSOL WITH TREATED SEWAGE EFFLUENT AND TWO LEVELS OF STRAW

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ABSTRACT

Sewage Treatment Effluent (STE) is an urban waste that can be used as a source of macronutrients due to its chemical composition, reducing the use of chemical fertilizers and having a more environmentally appropriate destination. In this work we investigated the effect of the application of two levels of Brachiaria straw fertirrigated, with three effluent fractions of treated sewage (FETE - *frações de efluente de esgoto tratado*), on the emission of CO_2 (ECO_2) and its relations with the physical-chemical attributes of the soil: temperature, humidity, total porosity of the soil, pH and free porosity of water. The experiment was conducted over 23 days of November 2013, in an area of 160 m^2 of eutroferric Red Latosol, devoid of vegetation and without soil preparation. The design used was random blocks, in a 2 x 3 factorial scheme, and the treatments consisted of the combination of two levels of *Brachiaria brizantha* straw (without straw and with straw, 10 Mg ha^{-1}) and three fractions of irrigation (F1: 11% of STE, F2: 60% of STE and F3:100% of STE). The results showed that the presence of straw on the soil favored higher CO_2 emissions and smaller STE blades (F1 and F2) mitigated the environmental impact of ECO_2. The presence of straw on the soil resulted in the maintenance of higher soil moisture levels, which can benefit the cycle of various crops. The presence of straw in this short assessment period did little to increase the degradation of straw used. The intermediate fractions of STE reconcile the condition of lower ECO_2 combined with more appropriate soil physical-chemical attributes in maintaining organic matter and soil moisture.

Descriptors: Sewage Effluent; CO_2 Emission; Physical Properties of the Soil.

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1. INTRODUCTION

Domestic or sanitary sewers have their origin in homes, businesses and institutions, and the amount of sanitary sewage produced is proportional to the population involved. Sanitary sewage flow is measured in hydrograms and shows a variable rate according to the hours of the day, reaching lower flow values at dawn and higher values throughout the day (Pantoja et al., 2005). Sewage has chemical characteristics with the presence of organic compounds such as proteins, carbohydrates, fat and oils, in addition to inorganic compounds such as nitrogen in different forms, sulfur, sodium, heavy metals (Romeiro, 2012; Santin, 2012), surfactants, phenols, pesticides, and other toxic compounds (Pantoja et al., 2005; Jüschke et al., 2009; Santin, 2012).

Fonseca (2005), Khai et al. (2011) and Romeiro (2012) report the presence in wastewater (Sewage Treatment Effluent - STE) of total nitrogen, in ammoniacal, nitrate and nitrite forms. In addition, there are other elements such as phosphorus, sulfur, calcium, magnesium and potassium, which can be used by plants as nutrients. The STE presents total carbon contents in large quantities and very variable pH, according to the treatment characteristic imposed to the raw effluent, which can cause the eutrophication of the receptor bodies (Fonseca et al., 2007). Due to its chemical composition, STE can provide economic benefits, and increase in quantity and quality of fertirrigated fodder, as reported by Santin (2012) and Santos et al. (2013). They can be used in several types of crops, according to studies by Santos et al. (2014), who used STE in *Brachiaria brizantha*, and the supply of the nutrients nitrogen and potassium via STE was considerable. Furthermore, according to the reports of Santos et al. (2006), with the use of STE in coffee trees, there was a significant increase in total nitrogen in the soil.

The fodder response to the STE may provide savings in mineral formulations and mitigate the environmental impact of the disposal of this wastewater on water bodies, according to reports by Gomes (2011), who showed the economic feasibility of using wastewater. A positive contribution to soil lies in the amount of carbon and other nutrients, which can accelerate the degree of humification of organic matter in soils irrigated with STE (Santos et al., 2009). As a consequence, there may be an increase in organic matter decomposition activity, which is stimulated by increased soil moisture.

Fonseca et al. (2007), Nogueira (2008) and Simões et al. (2013) report that the use of STE allows an increase in the microbial population in the soil, which is usually proportional to the amount of STE used. Medeiros et al. (2008) stress that the application of STE should be monitored mainly in terms of soil attributes, in order to identify possible contamination from the application of wastewater.

Wastewater treatment can become a contributing factor to the accumulation of Greenhouse Gases (GHGs) in the atmosphere, so that a reduction in treatment efficiency can lead to a reduction in CO_2 emissions not only in the treatment plant, but if organic matter is not completely degraded in the treatment plant, the CO_2 (ECO_2) emissions remaining from the degradation of organic matter can occur in the receiving bodies (Silva et al., 2012).

Nogueira (2008) and Santin (2012) evaluated the ECO_2 using STE in the irrigation of bermuda grass, and found that the largest ECO_2 were related to periods of higher rainfall and/or also to irrigation. The higher soil moisture, in one of the agricultural years of the studies, provided more favorable conditions for carbon availability, directly implying microbial respiration of the soil, so that the smaller irrigation slides reduced carbon and microbial respiration. In this aspect, Castro et al. (2009) evaluated the effect of sugarcane (*Saccharum officinarum*) irrigation with STE and found that this strategy promoted a linear increase in the ECO_2 in the slides with 100% crop evapotranspiration (ETc) and 200% of ETc, increasing the ECO_2 by 33% and 146% for the soil cultivated with sugarcane.

The application of wastewater can cause changes in the soil, mainly in the elevation of electrical conductivity, pH, and exchangeable sodium content in the soil (Fonseca et al., 2007). The application of wastewater can raise the sodium content in the leaf tissue of cotton plants without harming the crop (Silva et al., 2013). More recently, Oliveira et al. (2014) evaluated the use of domestic wastewater for sewage treatment and found that the levels of copper, zinc, iron and manganese in the soil studied were not influenced by the proportions of domestic wastewater used. In addition, the pH values of the soil showed a tendency to decrease with the addition of more domestic wastewater in relation to treated well water. Santos et al. (2014) found seasonal variations in the composition of the STE used in the fertirrigation of Brachiaria grass, but did not verify the risks of contamination by heavy metals and soil salinization. Nevertheless, it presented a risk of contamination by thermotolerant faecal coliforms. However, the STE used over successive seasons resulted in a considerable amount of nitrogen and potassium being added to the soil, which may result in savings in commercial mineral formulations.

Thus, the objective of this study was to evaluate the associations of ECO_2 with the physicochemical attributes of a fertirrigated STE latosol with different levels of straw on the soil.

2. MATERIAL AND METHODS

The experiment was conducted at the FCAV-UNESP Experimental Farm, Jaboticabal, SP, at 21º15’22” S latitude,

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48º18'58" W longitude and 595 meters altitude. The soil of the experimental area is of the type Dark Red Eutroferric Latosol, clayey texture according to Embrapa's soil classification. The experimental area was initially cultivated with *Urocloa brizantha* (*Brachiaria brizantha* cv. Marandu), from November 2012 to July 2013, when the forage was desiccated with glyphosate, followed by its removal from the area with a hoe and the land kept unprepared and free of weeds. The fodder material used as mulch was harvested within the period preceding the experiment, hayed and reserved on site with plastic canvas, without direct contact with the soil. After the demarcation of the plots, which had dimensions of 1.2 x 2.40 m, the straw had its dry matter determined (15% of dry matter) and was placed in each plot the equivalent to the density of 10Mg ha^{-1}, one week before the start of the experiment. Weekly irrigations were performed with STE, according to the reference evapotranspiration accumulated in the previous week. The design used was that of randomized blocks in a 2 x 3 bifactorial scheme, with four repetitions, in which the first factor corresponded to the Brachiaria straw levels, which without straw and with straw is equal to 10Mg ha^{-1} and the second factor consisted of Treated Sewage Fractions (FETE - *Frações de Efluente de Esgoto Tratado*), in which F1 was equal to 11% of STE, F2 equal to 60% of STE and F3 equal to 100% of STE (FIGURE 1).

The irrigation slide was applied once or twice a week, calculated as a function of reference evapotranspiration (ETo) and by the FAO-56 method (Allen et al., 1998), with daily meteorological data collected at the FCAV-UNESP Agroclimatologic Station, located near the experimental area. The STE concentrations in water corresponded to: F1 equal to 0.18; F2 equal to 1.00; and F3 equal to 1.67 (FIGURE 2). The gradual distribution of STE in the irrigation blade was obtained by an in-line sprinkler system with Senninger (Model 3023-2 with double 8 x 5 mm nozzle, operated with a pressure of 300 kPa and at 6 m spacing between in-line sprinklers). The irrigation system presented Christiansen's uniformity coefficient (CUC) and water distribution uniformity coefficient (DUC) with approximately 89% and 83%, respectively.

For the measurement of ECO_2, PVC collars of 100mm diameter, 10cm high and inserted 3 cm into the ground were implanted in each parcel. The readings were recorded using a portable system from the company LI-COR (LI-8100, Nebraska, USA). This system consists of a closed chamber, coupled on the collars previously inserted in the ground, at the points studied. In its measurement mode, the system monitors the changes in CO_2 concentration inside the chamber by means of optical absorption spectroscopy in the infrared region (IRGA, Infrared Gas Analyzer), as described by Panosso (2006) and Panosso et al. (2011). The day after the application of STE, the experiment started with the readings of ECO_2, measurement of temperature and soil moisture, taken between 8h and 10h, in the 24 plots of the experiment.

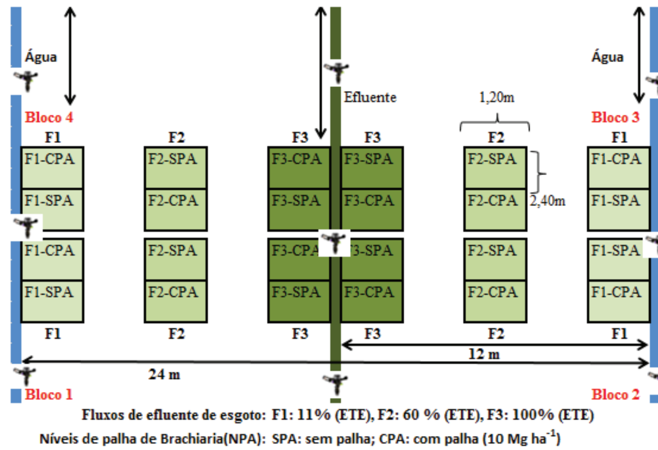
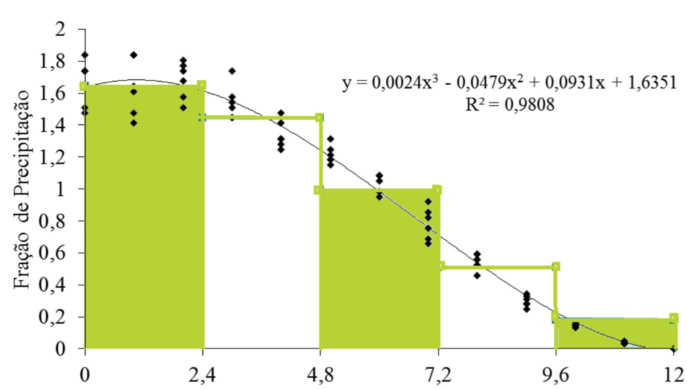


Figure 1. Experimental scheme with in-line sprinkler system and experimental units with FETE treatments (F1, F2 and F3) and straw application (without straw and with straw)

Concomitantly with the ECO_2 readings, soil temperature measurements were taken in the layer from 0 to 12 cm depth, using a thermometer (portable thermistor), which was an integral part of the system to which the soil chamber is attached. Soil moisture was measured using a portable TDR-Campbel®-type system (Hydrosense™, Campbell Scientific, Australia), which evaluates the available soil moisture (percentage by volume) in the layer from 0 to 12 cm, as described by Moitinho (2012). The deformed soil samples were collected at a depth of 0 to 20 cm, with the aid of a Dutch type auger, taken three months before the start of the experiment and at the end of the experiment, near the area of each PVC collar, for routine chemical analysis: pH, organic matter, organic carbon, Al, H + Al, P, K, S, Ca, Mg, and Na. The samples of the STE were collected from the 15,000 liter reservoir, next to the experimental area.



Distance (m)	Treatment	Rainfall distribution factor	Blades
0,0 - 2,4	F3: 100% STE	1.67	184
4,8 - 7,2	F2: 60% STE	1	110
9,6 - 12,0	F1: 11% STE	0.18	20

Figure 2. Distribution fractions of sprinkler precipitation and effluent concentration applied during the 23-day trial period as a function of the treatments.

The soil samples, which were not formed for the physical analysis of the soil, were collected with 95 cm^3 metal cylinders at the end of the experiment in small trenches of each plot, near the PVC collar, open with a hoe, at a depth of 0 to 20 cm (Table 1). Particle density, soil density and moisture, total porosity, macroporosity, microporosity, and water-free porosity were determined. Before the beginning of the experiment, the soil had the following characteristics: pH:5.53; organic matter (OM): 33.15 gdm^{-3}; phosphorus (P): 52.18 mg dm^{-3}; sulfur (S): 6.2 mg dm^{-3}; calcium (Ca): 42.6 mmol dm^{-3}; magnesium (Mg): 13.6 mmol dm^{-3}; aluminum (Al): 0.4 mmol dm^{-3}; sodium (Na): 1.3 mmol dm^{-3}; hydrogen (H)+Al: 27.6 mmol dm^{-3}; sum of bases (SB): 58.6 mmol dm^{-3}; cation exchange capacity (CEC): 86.1 mmol dm^{-3}; base saturation (V%): 70.7%.

The data were submitted to statistical analysis using the Statistical Analysis System package. The F test ($p < 0.05$) was used in the analysis of variance, and for cases in which there was significance of the factors or interactions between the factors, the means were compared using the Tukey test ($p < 0.05$). Then, regression analysis was performed between ECO_2 and the soil physical attributes that were significant by the F test, through the PROC RSREGRE procedure. For evaluations of dependence between ECO_2 and physical-chemical variables, Pearson's correlations, whose significance was given by Student's t test ($p < 0.05$), were used.

3. RESULTS AND DISCUSSION

The application of FETE and the levels of Brachiaria straw used significantly affected ECO_2. Soil moisture and temperature, organic matter content and water free porosity (WFrP) were significantly influenced by straw levels in the soil (Table 2). The comparison of averages (Table 3) showed that treatments with straw emitted 0.25 μmol m^{-2} s^{-1} of CO_2 more than treatments without straw on the soil and it was found that the increasing fractions of STE resulted in higher ECO_2. The soil temperature was the highest on average in treatments with straw on the ground, corresponding to 0.77 ºC more (13%) than in treatments without straw, while FETE did not influence the soil temperature. Soil moisture was significantly influenced by the presence of straw on the soil, resulting in a difference of more than 5.17 (percentage by volume) in relation to the without straw soil and FETE did not affect soil moisture.

The organic matter content was not influenced by the level of straw on the soil; however, the increasing fractions of FETE resulted in higher organic matter contents on the soil, but with a significant difference only between the lowest FETE (F1) and the highest FETE (F3), which exceeded F1 by 5.3%. WFrP was significantly influenced by the presence of straw on the soil, so that the without-straw treatment had on average the highest WFrP in relation to the with-straw treatment, while the STE fractions did not influence the WFrP (TABLE 2).

In this study, higher moisture contents were associated with straw level, where the presence of straw provided

Table 1. Concentration of nutrients in the effluent and results of soil analysis at the end of the experimental period

Elements in the Effluent		STE/ha Fractions			Soil analysis				CO2 Emission		
	mg/L	F1	F2	F3	Elements	STE/ha Fractions			F1	F2	F3
		Kg/ha				F1	F2	F3	μ mol m^{-2} g^{-1}		
N	51,9	10,38	57,09	95,50	SB(mmolc dm^{-3})	58,39	62,12	68,63	2,78	2,83	3,15
P	1	0,20	1,10	1,84	P($mgdm^{-3}$)	55,81	58,07	69,82			
K	18,8	3,76	20,68	34,59	K($mgdm^{-3}$)	5,32	5,57	5,22			
Ca	15,3	3,06	16,83	28,15	Ca($mgdm^{-3}$)	13,39	11,91	11,22			
Na	47	9,40	51,70	86,48	MO($mgdm^{-3}$)	38,09	38,89	43,69			
S	20,7	4,14	22,77	38,09	S($mdgm^{-3}$)	6,69	7,93	10,67			
Fe	0,36	0,07	0,40	0,66	Al(mmol dm^{-3})	0,60	0,60	0,60			
Mn	0,1	0,02	0,11	0,18	H+Al(mmol dm^{-3})	40,19	33,65	27,78			
Zn	1	0,20	1,10	1,84	V%	58,4	62,1	68,6			
ph		7,1	7,1	7,1	pH($CaCl_2$)	5,69	5,67	5,61			

F1: 11% of STE; F2: 60% of STE; F3: 100% of STE

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higher humidity and consequently higher ECO_2, unlike Panosso et al. (2009), in whose study higher humidity conditioned lower ECO_2 in an experiment with two wetting slats, but with the soil differential being devoid of vegetation. This difference can be explained by the results of the WFrP, in which in a more humid environment, the gases from the porous spaces of the soil are almost totally occupied by water, thus expelling them.

Table 2. Analysis of variance of CO_2 emissions and physical-chemical attributes of an Eutroferric Red Latosol, according to straw levels and FETE factors.

Variables	F		
	Straw levels	FETE	Interaction Straw levels x FETE
ECO2 (µmol m^{-2} S^{-1})	7,143*	5,805*	1,910
Temperature (ºC)	69,192*	0,128	2,592
Humidity (%)	10,934*	2,824	0,910
Organic matter (dm^3cm^3)	29,53*	1,59	1,590
Free water porosity (cm^3cm^{-3})	7,778*	1,984	1,250
Porosity (cm^3cm^{-3})	0,019	0,057	1,592
Microporosity cm^3cm^{-3}	0,111	0,443	1,747
Macroporosity cm^3cm^{-3}	0,014	0,074	0,486
Density (g cm^{-3})	0,079	0,689	0,957
pH ($CaCl_2$)	0,537	0,361	1,297

* Significant by the F test (p <0.05)

The results of this study contrast with the results of Moitinho et al. (2012), who found that the presence of cane straw on the soil, without plowing, was associated with lower ECO_2 (Corradi, 2011), lower soil temperatures, in the morning and afternoon. In addition, the presence of straw also provided greater soil moisture, only in the morning, similar to this study.

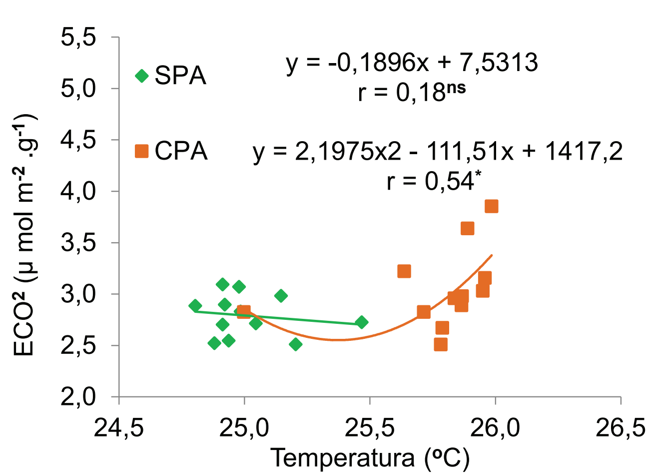
The different response in ECO_2 in this work lies mainly in the contribution of water to the soil provided by the wetting slats that were equal (184mm), but there was different contribution of nutrients in fractions F1, F2 and F3, in relation to N, P, Mg and S, elements that stimulate soil microbiota (Table 1).

Table 3. Comparison of averages of CO_2 emission and physicochemical attributes of an eutroferric red Latosol as a function of the STRAW LEVELS and FETE factors

STRAW LEVELS	FETE			Mean
	F1	F2	F3	
	CO2 emission (µmol m^{-2} s^{-1})			
without straw	2.78	2.61	2.97	2.79B
with straw	2.78	3.04	3.32	3.04A
Mean	2.78b	2.83b	3.15a	
	Soil temperature (ºC)			
without straw	24.95	25.12	24.95	25.01B
with straw	25.88	25.60	25.88	25.78A
Mean	25.41a	25.36a	25.41a	
	Soil moisture (% by volume)			
without straw	41.02	38.88	39.55	39.82B
with straw	48.02	41.10	45.85	44.99A
Mean	44.52a	39.99a	42.70a	
	Organic matter			
without straw	30.76	33.32	36.09	33.39A
with straw	32.19	35.48	37.83	35.17A
Mean	31.48 b	34.39ab	36.96a	
	Water free porosity (cm^3 cm^{-3})			
without straw	6.94	8.77	9.31	8.34A
with straw	0.72	7.65	1.42	3.26B
Mean	3.83a	8.21a	5,36a	

* Equal lower case letters in the line and equal upper case letters in the column indicate a non-significant difference of 5% by Tukey's test (p<0.05), F1: Effluent fractions (11%), F2: Effluent fractions (60%), F3: Effluent fractions (100%), without straw and with straw.

a)



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b)

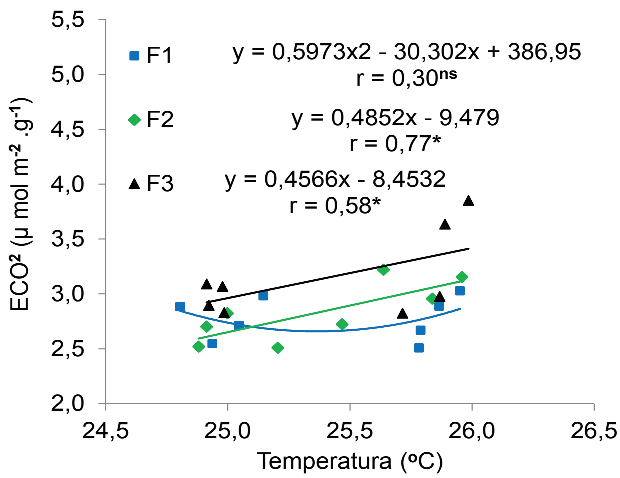


Figure 3. ECO_2 as a function of soil temperature for: a) treatments without straw and with straw and b) effluent treatment fractions (F1: 11% STE), (F2: 60% STE) and (F3: 100% STE). (Temperatura = Temperature)

b)

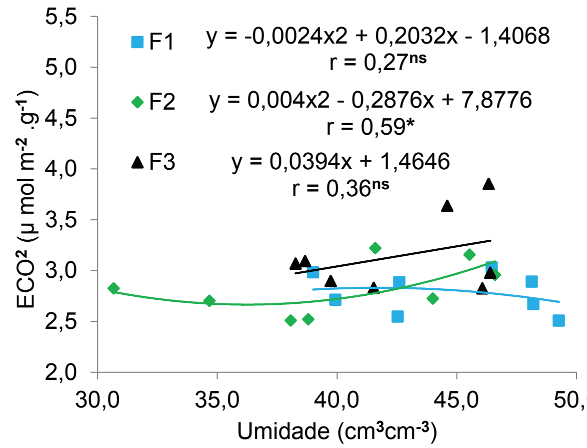
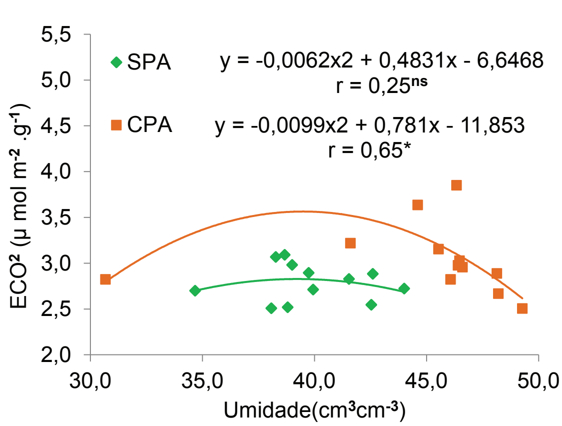


Figure 4. ECO_2 as a function of soil moisture for: a) treatments without straw and with straw and b) FETE (F1: 11% STE), (F2: 60% STE) and (F3: 100% STE). (Umidade = Humidity)

In the results of Corradi (2011), which studied different levels of straw on the ground, below the levels of this study, it was found that there was also lower CO_2 emission. However, they agree with the reports of Silva et al. (2014) that there was a positive association between ECO_2 and soil moisture, in an area changing to sugarcane crop, but only compared to the ECO_2 of FETE F2 and F3 in this study. Therefore, it seems that there is more agreement on the presence of plant residues on the soil that provides higher moisture contents.

The results of ECO_2 in this study agree with the reports of Zotelli (2012), who used industrial waste from the sugar-energy sector (vinasse) and evaluated ECO_2, noting that the maintenance of increasing straw levels of 7, 14 and 21Mg ha^{-1} on the soil increased CO_2 emissions, fertirrigated or not. The soil without straw cover, but fertirrigated with vinasse, emitted more CO_2 than the soil without non-fertirrigated straw.

a)



The soil temperature tended to increase in treatments with straw (FIGURE 3a), while higher FETE, F2 and F3, ECO_2 were increasing (FIGURE 3b). Larger FETE probably provided more nutrients, especially phosphorus and carbon contents, which reflected in microbial growth stimulus, decomposing the straw on the soil. The results agree with Zanini et al. (2005), who obtained a positive relationship between ECO_2 and soil temperature and disagree with Panosso et al. (2009), where soil temperature had a low association with ECO_2.

The association between soil moisture and ECO_2 was influenced by the presence of straw on the ground (FIGURE 4a) and only fraction F3 (100% ETE) exhibited consistent association with larger ECO_2 (FIGURE 4b). Panosso et al. (2009) reported that larger ECO_2 were associated with larger wetting sheets. These results also agree with Zotelli (2012), where higher soil moistures provided a positive relationship between CO_2 and soil moisture. Differently, Moitinho et al. (2012) found that the presence of straw on the soil implied lower ECO_2, lower temperatures and higher humidity levels. D'Andrea (2004) found no association of ECO_2 with soil moisture, either in the natural environment or in a reforested area. Fernandes (2008) explains that the seasonal distribution of soil moisture largely explains the ECO_2.

The association between organic matter and ECO_2 as a function of the treatment with straw on the soil showed no average effect of straw in relation to the treatment without straw (FIGURE 5a). However, in the association of ECO_2 and different fractions F1, F2 and F3 (Table 3), increasing values of OM were observed with the increase of the STE fractions, where the greatest difference is in favor of fraction F3 (100% STE), in relation to fraction F1 alone, which has a concentration of nutrients lower than the others and emitted less CO_2. The higher OM content

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in the F3 fraction may be justified by the higher contribution of nutrients P, N, Mg and S, present in the STE. Simões et al. (2013) and Sparling et al. (2006) found higher microbial activity in soils that had higher FETE applications, a fact that probably explains the results of higher ECO_2 with higher FETE in this study, and the probable higher electrical conductivity of treatments with F3 (Hanko; Summes, 2006).

D'Andrea (2004) reports that they did not verify a satisfactory association of soil organic matter, total microbial carbon and physical attributes of temperature and humidity to explain the ECO_2 in natural forest and reforested environments. This information was corroborated in a similar study, reported by Fernandes (2008), only in relation to nitrous oxide emission ($N-N_2O$).

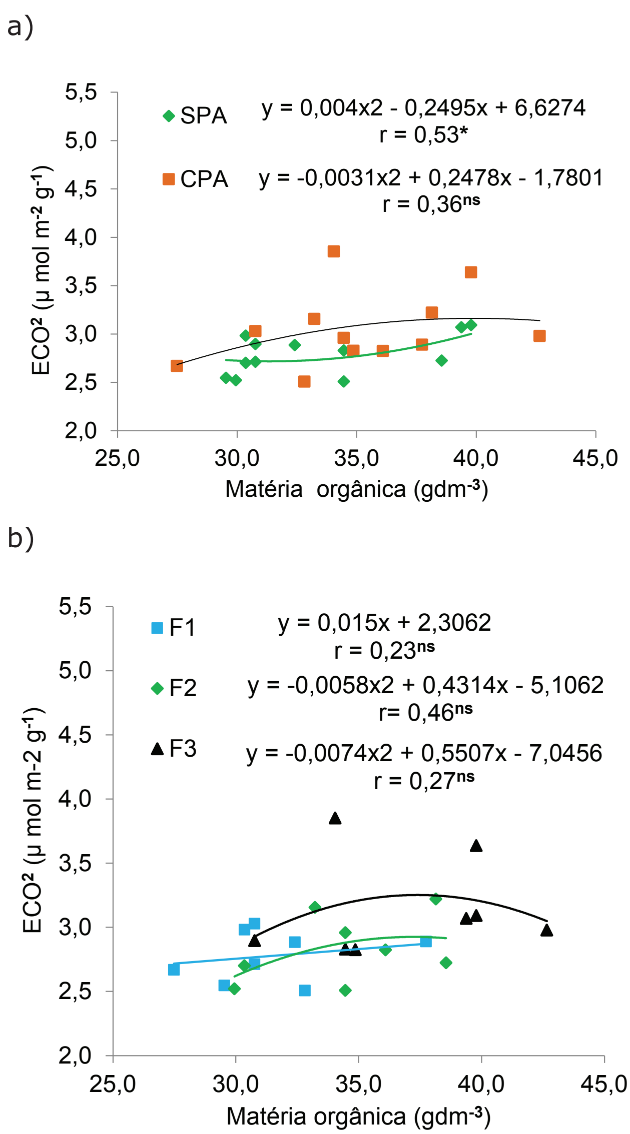

Figure 5. Emission of CO_2 (ECO_2) as a function of soil organic matter for: a) treatments without straw and with straw and b) fractions of effluent (F1: 11% STE), (F2: 60% STE) and (F3: 100% STE). (Matéria orgânica = Organic matter)

The relationship between WFrP and ECO_2 was consistent in straw treatments (FIGURE 6a) and in the application of fraction F3 (FIGURE 6b). The straw on the soil provided greater maintenance of moisture (Corradi, 2011; Moitinho, et al., 2012), which occupies the porous spaces of the soil. The WFrP verified in this study may partly explain the variations of ECO_2, different from that found in the study by Zotelli (2012).

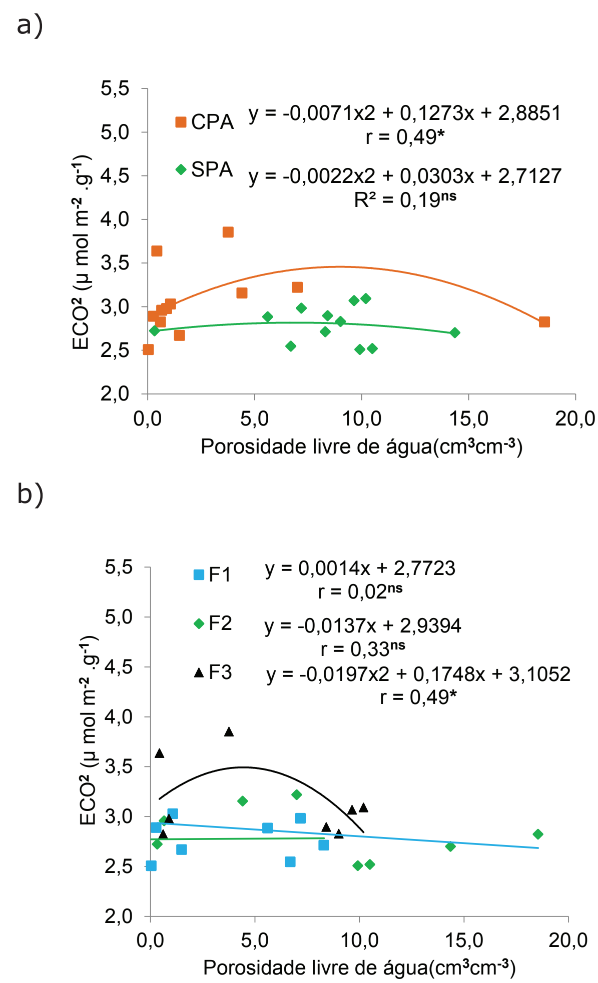

Figure 6. ECO_2 according to WFrP for: a) treatments without straw and with straw and b) FETE (F1: 11% STE), (F2: 60% STE) e (F3: 100% STE). (Porosidade livre de água = Water free porosity)

The association between WFrP and ECO_2 for the F3 fraction of this study was significant. Fernandes (2008) states that the ECO_2 is explained by the seasonal variation of humidity in several environments (forest, soybean and cotton). However, it was noted that even in rainy seasons, microbial soil respiration in the environments assessed, water-filled porosity was high and the number of soil bacteria in native forest environments was much higher than in other environments (soybean, cotton). In the integration system of livestock farming, the EPPA in the rainy period reached values of 55%, while in the dry period the values were close to 15%.

4. CONCLUSIONS

The presence of straw and a high dose of STE applied to the soil favored ECO_2.

The presence of straw on the soil keeps the soil humidity high.

The presence of straw on the soil contributed to a higher soil temperature.

In this study the two smallest FETE, by the smallest ECO_2, mitigate environmental impact through the use of STE.

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