CROP RESIDUES ON SHORT-TERM CO_2 EMISSIONS IN SUGARCANE PRODUCTION AREAS

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ABSTRACT: The proper management of agricultural crop residues could produce benefits in a warmer, more drought-prone world. Field experiments were conducted in sugarcane production areas in the Southern Brazil to assess the influence of crop residues on the soil surface in short-term CO_2 emissions. The study was carried out over a period of 50 days after establishing 6 plots with and without crop residues applied to the soil surface. The effects of sugarcane residues on CO_2 emissions were immediate; the emissions from residue-covered plots with equivalent densities of 3 (D50) and 6 (D100) t ha^{-1} (dry mass) were less than those from non-covered plots (D0). Additionally, the covered fields had lower soil temperatures and higher soil moisture for most of the studied days, especially during the periods of drought. Total emissions were as high as 553.62 ± 47.20 g CO_2 m^{-2}, and as low as 384.69 ± 31.69 g CO_2 m^{-2} in non-covered (D0) and covered plot with an equivalent density of 3 t ha^{-1} (D50), respectively. Our results indicate a significant reduction in CO_2 emissions, indicating conservation of soil carbon over the short-term period following the application of sugarcane residues to the soil surface.

KEYWORDS: soil respiration, sugarcane management, green harvest.

RESÍDUOS DA CULTURA NA EMISSÃO DE CURTO PRAZO DE CO_2 EM ÁREAS PRODUTORAS DE CANA-DE-AÇÚCAR

RESUMO: A gestão adequada dos resíduos de culturas agrícolas pode produzir benefícios em um mundo mais quente e mais propenso à seca. Experimentos de campo foram conduzidos em áreas de produção de cana-de-açúcar no Sudeste do Brasil a fim de avaliar a influência dos resíduos de cultura na superfície do solo, em emissões de CO_2 de curto prazo. O estudo foi conduzido por um período de 50 dias após a instalação das 6 parcelas com e sem resíduos de cultura aplicados sobre a superfície do solo. Os efeitos dos resíduos da cana-de-açúcar sobre as emissões de CO_2 foram imediatos; as emissões das parcelas cobertas com restos vegetais de cultura e densidades equivalentes a 3 (D50) e 6 (D100) t ha^{-1} (massa seca) foram inferiores quando comparadas às parcelas sem cobertura vegetal (D0). Além disso, as parcelas cobertas com restos vegetais tiveram a temperatura do solo mais baixa e a umidade do solo mais elevada para a maioria dos dias de estudo, especialmente durante o período sem chuvas. As emissões totais foram tão elevadas quanto 553,62 ± 47,20 g CO_2 m^{-2}, e tão baixas quanto 384,69 ± 31,69 g CO_2 m^{-2} nas parcelas sem cobertura vegetal e com uma densidade equivalente a 3 t ha^{-1}, respectivamente. Os resultados indicam redução significativa das emissões de CO_2 do solo, indicando a conservação de carbono no solo durante o período de curto prazo após a aplicação de resíduos de cana-de-açúcar na superfície do solo.

PALAVRAS-CHAVE: respiração do solo, manejo da cana-de-açúcar, cana crua.

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INTRODUCTION

From 1750 to 2005, the anthropogenic-driven carbon dioxide (CO_2) concentration in the atmosphere increased abruptly, and according to the most recent IPCC report (IPCC 2007), the annual release of CO_2 recently peaked at 1.9 ppmv. Several studies have related the incremental increase in atmospheric greenhouse gases to global temperature, which was approximately 0.6 ^{o}C higher over the last 100 years (HOUGHTON et al., 2001). Changes in precipitation events and decreases in polar ice sheets have also been attributed to the intensification of the greenhouse gas effect (IPCC, 2007).

In Brazil, the main sector responsible for greenhouse gas emissions is not fossil fuel consumption but agriculture (CERRI et al., 2007). It is estimated that Brazilian soil carbon stocks in the first 0-30 cm of soil total 36.4 ± 3.4 Pg C, and land use changes, including agricultural practices and deforestation, are thought to be responsible for two thirds of Brazilian greenhouse gas emissions (BERNOUX et al., 2002).

Brazil is the largest producer of sugarcane (*Saccharum* spp.) in the world, with 8.2 million hectares under cultivation; the majority of production is concentrated in the state of São Paulo, which boasts 4.4 million hectares (CONAB, 2010). Recently, conservative practices, such as leaving crop residues to the soil surface instead of burning them, have been introduced in an effort to achieve a sustainable agriculture. It has been shown that crop residue cover reduces fluctuations in soil temperature, keeping soil layers colder, and retains moisture, especially during the hotter and drier seasons (SOUZA ANDRADE et al., 2003).

Maintaining crop residues on the soil surface are thought to have great benefits in terms of soil carbon storage, a process called soil carbon sequestration (RAZAFIMBELO et al., 2006; GALDOS et al., 2009; USSIRI & LAL, 2009). Recently, to the sugarcane green harvested areas, DE FIGUEIREDO & LA SCALA JR (2011), based on the paper from RONQUIM (2007), found medium amounts of organic carbon input from 5.5 to 11 t C ha^{-1} deriving from crop residues left on soil surface every harvest year.

In addition to the benefits of soil temperature and moisture, plant residues on the soil surface have been shown to affect other soil properties, and consequently, the microbial habitat, microbial activity and soil carbon dynamics (FRANCHINI et al., 2007). However, depending on the type of residues, this could result in the immediate decay of carbon residues and the subsequent release of soil CO_2. For leguminous crop residues, the majority of carbon residues are quickly respired by the microbial biomass and released to the atmosphere as CO_2 during the initial days following residue application (ROBERTSON & THORBURN, 2007 b). Conversely, CURTIN et al., (2000) showed that the lower soil CO_2 emissions in areas with no-till practices as opposed to conventional tillage could be attributed to the lower rate of residue decay that occurs when residues are not fragmented and incorporated into the soil. DUIKER & LAL (2000) concluded that the lack of significant differences in soil CO_2 flux related to the deposition of wheat residues on the soil surface was partly attributable to the absence of residue decay. Thus, differences in the chemical composition of residues also affect the rate of residue decomposition (ROBERTSON & THORBURN, 2007 a). Depending on the C:N ratio, certain residues decay quickly and contribute to emissions.

We hypothesized that sugarcane residues applied to the soil surface would affect short-term soil CO_2 emissions, by changes in soil temperature and moisture conditions. In this study, it was investigated short-term soil CO_2 emissions, soil temperature and soil moisture and its relationship after depositing sugarcane residues onto an Oxisol surface in sugarcane production areas.

MATERIAL AND METHODS

The experiment was conducted at the São Bento farm, Guariba city in the northeast of the state of São Paulo, Brazil (21º 24' south and 48º 09' west; 550 m above sea level). The studied area has a soil type that is classified as high clay (636 g kg^{-1}), Oxisol (Eutrustox, USDA Soil

Taxonomy). Organic matter content was determined to be approximately 1.5%, and the soil pH was 4.7. The climate at the site was classified as tropical Aw (Köppen), with rainy summers and dry winters and a mean temperature of 22.2 ^{o}C. The mean amount of annual rainfall is approximately 1,425 mm, and most of it was concentrated between October and March. Over the last 15 years, the area has been under green harvest sugarcane production, a more conservative management system that involves mechanized harvests (instead of burning) and the input of approximately 12 tons of crop residues (dry mass) per hectare per year.

On October 7th, 2009, 60 (sixty) days after the crop harvest, adjacent 1 × 1 m plots were established for the following crop residue conditions on the soil surface: 0% or no crop residues (D0); 50% of crop residues (D50); and 100% of crop residues (D100), where 100% is equivalent to 6000 kg ha^{-1}. In this study, an application rate of 6 instead of 12 t ha^{-1} was used to accommodate residues inside each of the soil collars used to quantify CO_2 emissions. Crop residues were uniformly distributed on the soil surface so that it was completely covered. The experiment was located between sugarcane crop lines with small ratoon crops growing at the very beginning of the growing season.

A PVC collar used to support the soil chamber and measure soil respiration was inserted 3 cm into the soil in the center of the plots. Ten soil collars for each of the three treatments (D0, D50 and D100 densities) were installed. The collars were inserted 24 hours before the first CO_2 measurements to avoid physical CO_2 expulsion during the first days of the study. On October 4th , 2009, three days before the start of the soil CO_2 measurements, was simulated a rain in the trial of 60 mm, during 65 minutes.

Soil CO_2 emissions were measured with a portable LI-8100 system (Li-Cor, Nebraska, USA) consisting of a closed chamber with an internal volume of 991 cm^3 and a soil contact area of 71.6 cm^2. This apparatus was coupled to the previously installed in PVC collars. During measurement, the CO_2 concentration of the air inside the chamber was continuously monitored by optical absorption spectroscopy. Changes in CO_2 concentration inside the chamber determined soil CO_2 emissions. Each point required approximately two minutes of computation time. In addition to CO_2 emissions, the soil temperature (0 – 20 cm) and moisture content (% volume, 0 – 12 cm) near the soil collars were measured daily. Soil temperature was measured by the LI-8100 system with a thermistor sensor. Soil moisture was measured with a Time Domain Reflectometry (TDR) system (Hydrosense System, Campbell Scientific, Utah, EUA). The TDR system has 12-cm probes that were inserted perpendicular to the soil surface near the PVC collars. Measurements with this system, which is based on the time required for an electromagnetic pulse wave to travel inside the soil, are dependent on the soil's dielectric constant and affected by the soil moisture content. The total soil porosity was previously determined to be 51.9%.

Soil CO_2 emissions, soil temperature and soil moisture were recorded from October 7th to November 25th, 2009. From October 7th to October 21st, measurements were recorded daily, and from October 26th to November 25th, they were recorded once a week. These measurements were taken for a total of 31 days during the 50-day period. Measurements were uniformly recorded at 7h30. During the experimental period rain precipitation occurred on studied days totalizing 222 mm (Meteorological station of FCAV / Unesp).

Data were analyzed with descriptive statistics (mean, standard error, minimum, maximum and coefficient of variation) in the SAS software (SAS version 9, SAS institute, Cary, NC, USA). Pairwise comparison of means was performed with Tukey’s procedure, and a p-value < 0.10 was considered significant. The cumulative soil CO_2 efflux during the study period was estimated by integrating the area under plots of soil CO_2 efflux versus time. Graphical analysis was conducted with the Origin 6.0 software (OriginLab Coorporation, Northampton, MA, USA).

RESULTS AND DISCUSSION

Emissions from the D0 plot (3.16 µmol m^{-2} s^{-1}) were 53% greater than those from the D50 plot (2.06 µmol m^{-2} s^{-1}) and 42% greater than those from the D100 plot (2.23 µmol m^{-2} s^{-1}) (Table 1). This is in agreement with PANOSSO et al. (2008) who demonstrated lower emissions in green plot compared to an adjacent burned plot. Conversely, mean emissions from the D0 treatment were greater than those observed by PANOSSO et al. (2009) in burned (2.87 µmol m^{-2} s^{-1}) and green (2.06 µmol m^{-2} s^{-1}) plots. BRITO et al. (2009), measuring CO_2 emissions in the same region, found emission values of 1.70 to 2.21 µmol m^{-2} s^{-1} in sugarcane areas using a green harvest system.

The presence of crop residues on the soil surface affected soil temperature in 11 of the 15 studied days (7 – 21, October). The mean values of soil temperature were 24.2, 23.7 and 23.7 ^{o}C for the D0, D50 and D100 plots, respectively. The means of soil moisture were 38.8%, 47% and 45.3% in the D0, D50 and D100 plots, respectively (Table 1). Again, the mean soil temperature and moisture from the D50 and D100 treatments differed from the D0 treatment. Thus, lower crop surface densities correspond to higher soil temperatures and lower soil moisture.

The benefits of applying crop residues to tropical soils are related to soil temperature and moisture (DUIKER & LAL, 2000; SARTORI et al., 2006; PANOSSO et al., 2009), and this is especially important in a world that has experienced extended periods of higher temperatures and more severe droughts. Hence, studies of tropical soils have focused on the relation of soil CO_2 emissions to soil temperature and moisture (TEIXEIRA et al., 2010). CO_2 evolution rates were influenced by the presence or absence of residues on the soil surface, indicating an effect on both soil moisture and temperature (LA SCALA et al., 2006). The accumulation of organic material on the soil surface introduces benefits as the maximum daily temperature is reduced. For example, DOURADO-NETO et al. (1999), investigating the influence of residues on the relation between soil temperature and water content in a Oxisol in Southern Brazil, observed a strong spatial dependence of the variables, calculated an inverse relation between temperature and moisture and showed that both effects were favorable for microorganism growth and plant development (RESENDE et al., 2006; USSIRI & LAL, 2009; TEIXEIRA et al., 2010). An increase in soil temperature typically accelerates the decay of soil organic matter, increasing microbial activity and reducing soil carbon stocks (LIU et al., 2010). Soil moisture also affects soil respiration in a complex manner. While higher moisture content promotes improved conditions for microbial activity, emissions are reduced because of a decrease in gas diffusivity as the moisture level nears the level of pore saturation (FANG & MONCRIEFF, 2001).

TABLE 1. Mean CO_2 emission, soil temperature and soil moisture in the studied treatments.

Treatment	Mean	Standard Error	Minimum	Maximum	CV (%)
		CO_2 emission (µmol.m^{-2}.s^{-1})			
D0	3.16 a	0.0750	1.04	6.85	34.65
D50	2.06 b	0.0451	0.62	4.12	31.77
D100	2.23 b	0.0578	1.01	4.88	37.60
		Soil temperature (^{o}C)			
D0	24.2 a	0.1453	19.74	29.17	8.71
D50	23.7 b	0.1082	20.30	27.17	6.63
D100	23.7 b	0.1158	20.30	27.36	7.07
		Soil moisture (% volume)			
D0	38.8 b	0.9950	13.00	67	33.23
D50	47.0 a	0.6165	19.00	64	17.00
D100	45.3 a	0.7761	13.00	71	22.23

N=10. CV (%) = coefficient of variation. Mean separation procedure is presented by letters a and b. Means followed by the same letter do not differ significantly (p>0,10) by Tukey text.

Repeated one-way analysis showed a significant interaction between treatments and time, indicating that time should be considered when assessing the effects of treatment on soil CO_2 emissions, temperature and moisture. Figure 1 presents the temporal variability of daily CO_2 emissions (± standard error) for the studied treatments. In the first day of study, emissions were as low as 2.41 and 2.50 µmol m^{-2} s^{-1} in the D50 and D100 plots, respectively, and as high as 4.00 µmol m^{-2} s^{-1} in the D0 plot. Hence, our results show that within 24 hours of crop residue application, emissions inform the D0 plot was larger than those from the D50 and D100 plots. Another factor that may have influenced the higher soil CO_2 emission in the D0 plot is the simulated rainfall occurred three days before the start of the measurements, which may have affected the soil surface by breaking soil aggregates due to the impact of the water drops over the soil. Those differences remained up to four days after the beginning of the study. In days 5 and 6, emission values were more similar, and emissions did not differ statistically when treatments were compared. Between days 7 and 29, differences between emissions from the D0 and the other treatments were again significant at $p<0.10$. Emissions from the D0 treatment were always greater during this period in which drought was more intense. From day 36 to 50, a period in which rain fell, there were again no significant differences in emissions between the treatments. It can be noticed that emissions from the D0 treatment were always higher than those from the other treatments, with mean values varying from 2.5 to 4.0 µmol m^{-2} s^{-1} while were small differences between the D50 and D100 emissions, varying from 1.5 to 2.5 µmol m^{-2} s^{-1}. Also, emission values for all treatments tended to converge toward the end of the study, varying between 2.0 and 2.8 µmol m^{-2} s^{-1}.

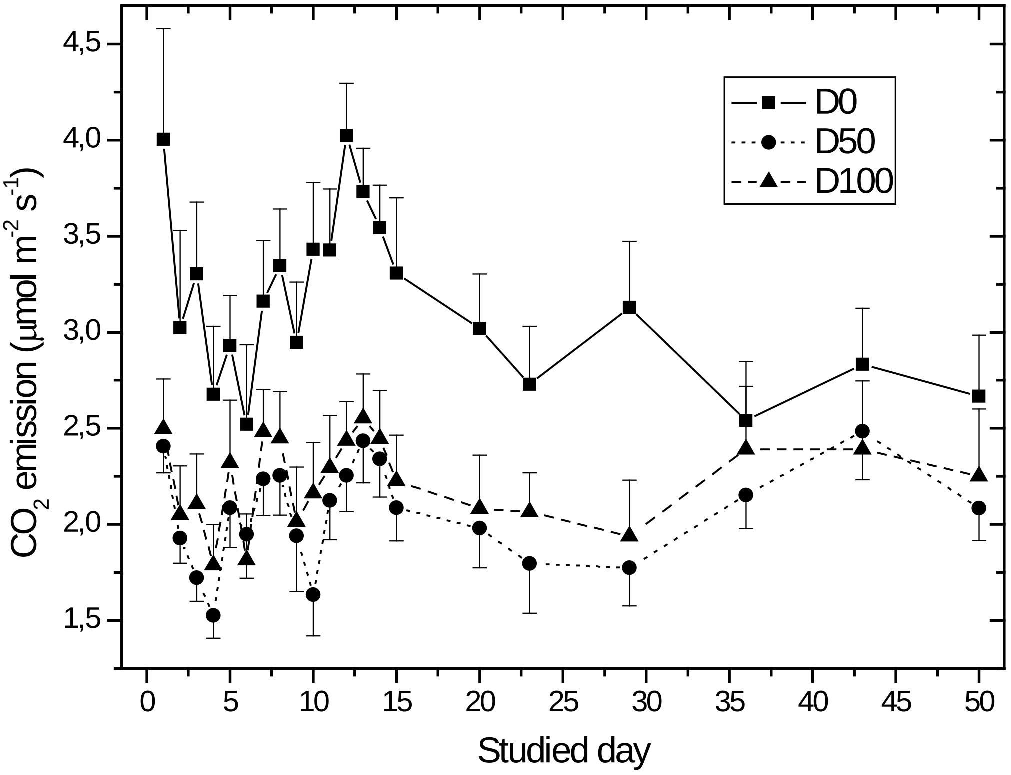

FIGURE 1. Mean (± half of standard error) of CO_2 emission in the studied days.

The highest CO_2 emissions were registered in the D0 plot on days 1 and 12, and in day 12 soil temperature reached its highest value (Figure 2). Soil temperature is one of the most important factors associated with soil respiration, especially when temporal variability is considered. Higher soil temperatures result in increases of microbial activity and organic matter decay, with a consequent increase in CO_2 emissions (LA SCALA et al., 2008). Recently, in sugarcane areas under slash-and-burn management practices, PANOSSO et al. (2008) observed a direct relationship between soil CO_2 emissions and soil temperature and an inverse relationship between emissions and volumetric soil moisture.

The lowest emissions were recorded in the D50 plot on days 4 (1.53 µmol m^{-2} s^{-1}) and 10 (1.63 µmol m^{-2} s^{-1}). This was associated with air temperature, which reached the lowest values of 19.8 and 20.4 ^{o}C on days 4 and 10, respectively. LIU et al. (2010) observed temporal variability of soil CO_2 emissions in relation to air temperature more than to soil temperature because the majority of emissions were attributed to the decay of surface residues.

Figure 2 presents the temporal variability of soil temperature for all treatments, which is characterized by a monotonic increase during the study period for all crop residue densities. The higher and lower temperatures recorded during the study period were observed in the D0 treatment, and it is also possible to examine a higher CV value (Table 1). Hence, under bare soil conditions, soil temperature fluctuates more than under covered conditions. As observed for emissions, from day 7 to 23, the soil temperature in the D50 and D100 treatments was significantly ($p<0.10$) less than the mean values of the D0 plot. Soil temperatures reached values as high as 27.5 ^{o}C and 25.2 ^{o}C for the D0 and D50 treatments, respectively, on day 14. Conversely, there were no differences in soil temperatures among treatments near the rain precipitation events (days 7, 13, 20 and 36). This effect was also observed by FANG & MONCRIEFF (2001), who attributed this phenomenon to an increase in soil moisture and its interaction with soil temperature.

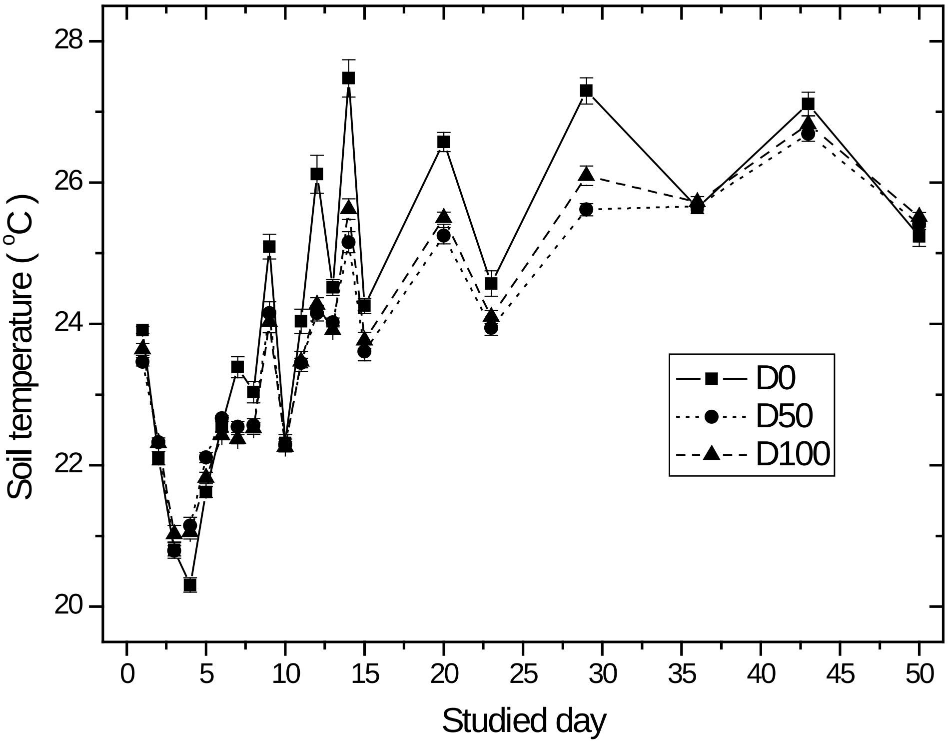

FIGURE 2. Mean (± standard error) of soil temperature in the studied days.

The soil moisture pattern was similar to the temporal variation of CO_2 emissions (Figure 3). Until day 4, there were no significant differences in soil moisture among treatments. As the experiment progressed, those differences began to increase, especially during the driest days from day 8 to 29. The sharper observed increases were associated with precipitation events, as on day 7, with a 7 mm precipitation event at the night before. Conversely, a significant reduction in soil moisture was noticed, as on day 29, the end of a 14-day drought period, when the moisture content reached 18%.

The highest values of soil moisture were recorded in the D100 treatment (Figure 3); the lowest value was equal to one recorded in the D0 plot during the drought period. The lower soil moisture value in the D100 plot compared to the D50 plot could be related to its thicker layer of crop residues that prevented water penetration into the soil (DUIKER & LAL, 2000).

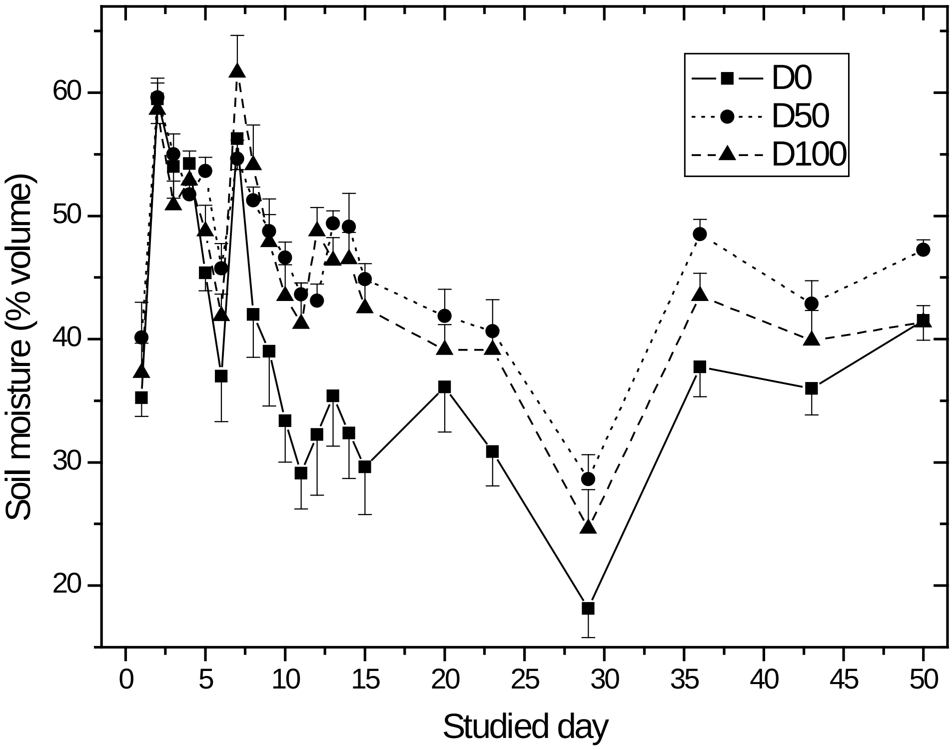

FIGURE 3. Mean (± half of standard error) of soil moisture in the studied days.

Plots under bare soil conditions had reduced mean soil moistures, showing the importance of residues in maintaining soil moisture (Table 1). The residue cover works as an insulation layer, reducing the thermal and moisture fluctuations and favoring moisture storage and other physical and chemical soil properties (NOBLE et al., 2003).

The linear correlation between soil CO_2 emissions and soil temperature and moisture indicates a significant correlation ($p<0.10$) in some of the cases. CO_2 emissions were positively related to soil temperatures throughout the study only in the D50 plot. Soil CO_2 emissions were negatively related to soil moisture in the D0 plot and positively related to soil moisture in the D100 plot.

Total emissions over the 50-day period for each treatment are presented in Figure 4. The highest total emission was observed in the D0 treatment (553.62 ± 47.20 g CO_2 m^{-2}). This is compared to emissions of 412.12 ± 48.66 and 384.69 ± 31.69 g CO_2 m^{-2} for the D100 and D50 treatments, respectively. The differences were significant ($p<0,10$) when the D0 total emission was compared to the D50 and D100 treatments. Therefore, the difference in total emissions between the D0 and the D50 plots is 168.93 g CO_2 m^{-2}, and the difference between the D0 and the D100 plots is 141.50 g CO_2 m^{-2}. These differences are equivalent to an avoided emission of as much as 460.7 and 386 kg of CO_2 - C per hectare in the D50 and D100 treatments, respectively, during the first 50 days after deposition of sugarcane residues on the soil surface. Those values are significant compared to the potential of carbon sequestration in Brazil (GALDOS et al., 2009) and Australia (ROBERTSON & THORBURN, 2007 b) according to studies in sugarcane areas where large amounts of crop residues were left on the soil surface. In addition, our experiment was conducted with D100 plot having an amount of 6 t ha^{-1}, a lower value than normally found in the field due to technical adjustments.

This result indicates the importance of retaining crop residues on the soil surface to mitigate soil carbon losses (SARTORI et al., 2006; CERRI et al., 2007). CURTIN et al., (2000) showed lower soil CO_2 emissions under different management practices and attributed this reduction to the presence of crop residues. DUIKER & LAL (2000) concluded that the lack of a significant difference in soil CO_2 emissions for treatments with varying amounts of residues was due to the negligible contribution of residues to soil CO_2 emissions. Our results points to the importance of conduction new field experiments on this in order better differentiate the effects of crop residues layer on the soil CO_2 emission in sugarcane areas.

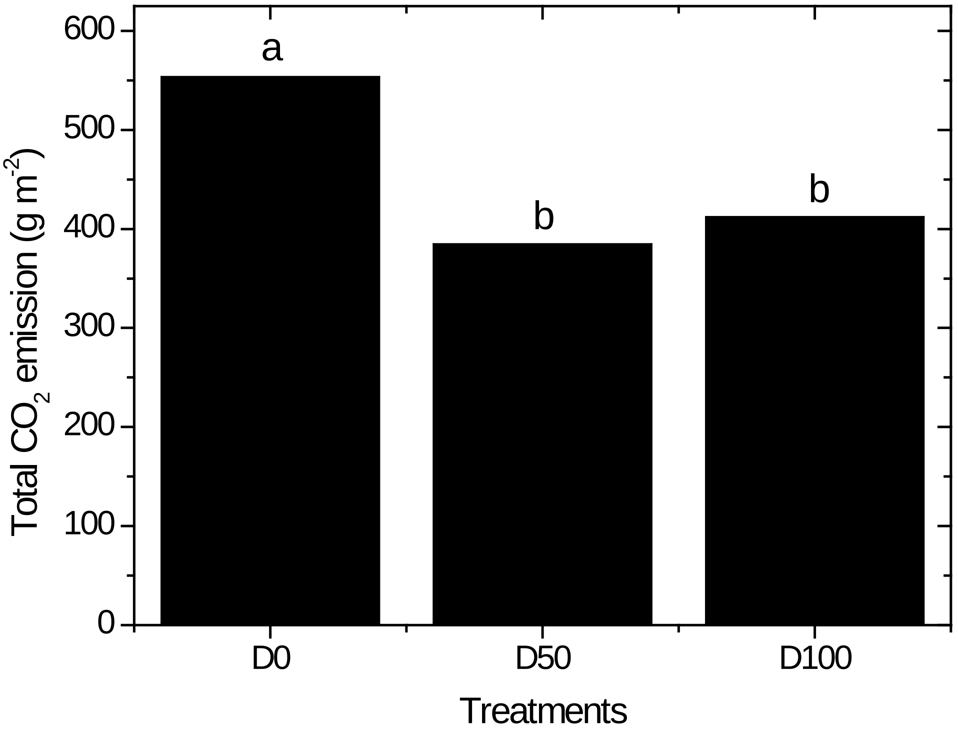

FIGURE 4. Total CO_2 emission in each treatment, distinguished by mean separation procedure (differences are signifcant at p<0.10).

CONCLUSIONS

Regardless the growth of crop ratoon crops in the experimental area, which could be a small source of carbon to atmosphere, the retaining sugarcane crop residues on the soil surface significantly, mitigates soil CO_2 emissions, suggesting its role on the preservation of soil carbon after harvest. Soil temperature and moisture were also affected by the presence of crop residues on the soil surface, but additional research should be conducted to determine if changes in soil moisture and consequently soil gas diffusion affects emissions.

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