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Effects of sugarcane cropping on organic carbon properties of the soil

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Abstract

With the expansion of the sugarcane cropping area in Brazil, it is necessary to study the changes that this crop may affect to the soil organic matter storage (SOM). The aim of this research was to quantify the carbon management index (CMI), total organic carbon stocks (TOC), labile carbon (LC) and carbon amount in the oxidized fractions of SOM in cropping soil cultivated by sugarcane crop. The experiment was carried out in the sugarcane crop farm located in a dystroferric Red Latosol. The experimental design was completely randomized with four replications. The treatments were comprised of: reference area (RA), area cultivated with sugarcane crop for one year (AC1yr), two years (AC2yr), three years (AC3yr), and four years (AC4yr). The soil samples were collected at two depths (0-10 and 10-30 cm). The highest TOC stock was observed in the treatment AC4yr (15.32 Mg ha^{-1}), which differed from the RA (11.01 Mg ha^{-1}) at 0-10 cm depth. No significant difference was observed in LC at 0-10 cm depth. The treatment AC3yr and AC4yr showed the highest value of LC stocks differing from RA and AC1yr (10-30 cm). There was significant increasing in total organic carbon stocks and labile carbon, indicating the capacity of sugarcane crop on mitigation of greenhouse gases. It also promoted a balanced distribution in the TOC stocks in the fraction of oxidized OM (F1+F2 and F3+F4).

Keywords: Soil organic matter; labile carbon; sustainability; conservation tillage; *Saccharum officinarum* L.
Abbreviations: SOM_Soil Organic Matter; CMI_Carbon Management Index; TOC_Total Organic Carbon; LC_Labile Carbon; SOC_Soil Organic Carbon; Mg ha^{-1}_ton ha^{-1}.

Introduction

The sugarcane crop (*Saccharum* spp.) is one of the most important commercial crops for the agribusiness in Brazil. According to Conab (2014), Brazil is the biggest sugar and alcohol producer of sugarcane crop in the world. The cultivated area harvested in the 2013/2014 cropping season was 8.80 million hectares with the average yield of 74,100 kg ha^{-1}, in which the increasing showed 3.7% and 4.8% in relation to the last cropping season, respectively. Mato Grosso do Sul is one of top five producer states of sugarcane in Brazil, which represents 7.09% (624.110 mil hectares) of the whole cultivated area. In the sugarcane cropping, the mechanical harvest is increasing. This avoids the burning of the above-ground organic matter (OM), which promotes its input on the soil. This behavior is changing the soil organic matter (SOM) stocks and mitigation of greenhouse gases. As reported by Shahidi et al. (2014), the conservation agriculture has a great potential of reducing greenhouse gases emissions because of the sequestration of CO_2 into SOM. According to Luca et al. (2008), in the sugarcane harvest system without burning, the input above-ground of dry matter range between 10 to 15 Mg ha^{-1} yr^{-1}, and its decomposition affects the carbon cycle and OM dynamic. As reported by Nogueira et al. (2010), the average organic carbon (OC) stocks in traditional sugarcane cropping area were 29.66 Mg ha^{-1} at 2007/2008 cropping season and 27.80 Mg ha^{-1} in newly sugarcane area 2003/2004 cropping season. In comparison to these areas, the input of OC stocks with the sugarcane crop was 6.69% in the period from 2003 to 2007. The reason for this increase of OC stocks has been the use of mechanical harvest without pre-harvest burning.

Most studies about SOM have focused on OC and total nitrogen (TN). Nevertheless, little alteration in the total carbon and nitrogen are observed in short-time. This way, the study of LC stocks, the carbon oxidized fractions and carbon management index (CMI) must offer better comprehensive understanding about SOM dynamic. The labile carbon (LC) resolves to fractions due to the high sensibility, which mainly depends to the soil tillage system. It has important role in the soil fertility. These features are efficient to assess the modification in the SOM content (Rangel and Silva, 2007). In relation to the oxidized fraction of OC in soil, Chan et al. (2001) introduced a modification in the classical method of carbon determination by Walkley and Black (1934). With this modification, it was feasible to set apart four fractions with decreased degree of oxidation, throughout the utilization of decreased quantity of sulfur acid. The F1 and F2 fractions are associated to availability of nutrients and the formation of macro-aggregates (Blair et al., 1995; Chan et al., 2001), and F3 and F4 fractions are associated with compounds of high chemistry stability and molecular weight from decomposition and humification of SOM (Stevenson, 1994).

As mentioned above, the SOM is linked to soil quality. The raise of SOM fractions in sugarcane crop harvest without burning is quite important to maintain the soil quality, because of the SOM impact on chemical, physical and biological soil features (Primo et al., 2011). The SOM dynamic is influenced by climate factors. Therefore, it is important to research this issue in local conditions (Heimann and Reichstein, 2008). Although many regional studies have been done on sugar and alcohol mills yet, but there is little known about the quantification of SOM stocks in sugarcane harvested soils with no pre-harvest burning. Based on this context, the aim of this study was to quantify the carbon management index (CMI), total organic carbon (TOC) stocks, labile carbon (LC) in the fractions of oxidized SOM in areas cultivated with sugarcane crop after one, two, three and four years.

Result and Discussion

Analysis of variance (ANOVA) of the parameters

The results of labile carbon (LC) stocks did not differ ($p>0.05$) at 0-10 cm depth and neither for total organic carbon (TOC) stocks in F1+F2 fractions (Table 1). The ANOVA for LC stocks at 10-30 cm depth, TOC stocks in the fractions F3+F4 and carbon management index (CMI), showed significant difference ($p\leq0.01$) at both depths. The treatments indicated significant differences ($p\leq0.05$) in the results of TOC stocks at both depths (0-10 and 10-30 cm).

Total organic carbon (TOC) and labile carbon (LC) stocks

The highest TOC stock was observed at 0-10 cm depth (Fig. 1). It was resulted due to high above-ground dry matter input, which increases the SOM in the surface layer in sugarcane management without burning. The mechanical harvest without pre-harvest burning is quite important to increase the SOM. It is not a common practice in Brazil and other sites around the world. The common practice is to set fire in sugarcane to make the manual harvest possible. With the mechanical harvest of sugarcane, it is possible to input above-ground dry matter from 10 to 15 Mg ha^{-1} yr^{-1}, and its decomposition affects the carbon cycle and the dynamic of TOC stocks (Davidson and Janssens, 2006). According to Panosso et al. (2009), the sugarcane crop cultivation without pre-harvest burning can increase the accumulation of above-ground dry matter, which contributes the soil coverage and TOC stocks.

The results showed that the highest value of TOC stocks (15.32 Mg ha^{-1}) was obtained at 0-10 cm depth, in AC4yr. This result differed significantly ($p\leq0.05$) from the reference area, which showed 11.01 Mg ha^{-1} of TOC stocks at 0-10 cm depth (Fig. 1). On the other hand, there was no difference ($p>0.05$) among the other treatments assessed in comparison to the reference area. The same performance was observed for the TOC stocks at 10-30 cm depth (Fig. 1).

The values of TOC stocks found in this research were in agreement with Oliveira et al. (2014), who observed TOC stocks among 10-20 Mg ha^{-1} in soil cultivated with sugarcane in mechanical harvest. The results observed in this work indicated the capacity of the improvement in TOC stocks in sugarcane crop cultivated without pre-harvest burn (Fig. 1). Barros et al. (2011) demonstrated the mitigation of greenhouse gas emission in sugarcane crop, by means of plant photosynthesis, which input carbon from the air to above-ground and below-ground dry matter, if an appropriate conservation tillage is adopted.

In relation to the labile carbon (LC) stocks, the highest values were obtained at 0-10 cm depth in comparison to 10-30 cm depth. However, no significant difference ($p>0.05$) was observed among the treatments at 0-10 cm depth (Fig. 2). At 10-30 cm depth (Fig. 2), the treatments AC3yr and AC4yr showed higher LC stocks, which differed ($p\leq0.01$) from the AC1yr and reference area. These results indicate that the input of above-ground and below-ground dry matter promote the increase of LC stocks in soil deeper layer as the time pass. As reported by Rangel et al. (2008) and Silva et al. (2011), the conservation system of crop production that enables the input of above-ground and below-ground dry matter, contributes to increase the content of LC stocks in the soil. In general, the maintenance of SOC, specially the labile fraction is essential to increase the soil quality and sustainability of the conservation systems of crop production (Blair, 2000).

Total organic carbon (TOC) stocks in F1+F2 fractions

In the results of TOC stocks in F1+F2 fractions, the highest TOC stocks were observed at 0-10 cm depth in comparison to 10-30 cm depth. Despite this, no significant difference ($p>0.05$) was observed among the treatments in this soil depth (0-10 cm) (Fig. 3). The F1+F2 fractions are considered the fractions that most represent the LC stocks in the soil (Loss et al., 2009; Barreto et al., 2011). Researches about SOC fractionation have pointed that the highest content of carbon in F1+F2 fractions trend can be observed in the areas with higher input of above-ground biomass (Blair et al., 1995; Chan et al., 2001; Rangel et al., 2008). This increase is related to the free fraction of SOM (Maia et al., 2007).

Total organic carbon (TOC) stocks in F3+F4 fractions

The TOC stocks in the F3+F4 fractions at 0-10 cm depth are shown in Fig. 4. The area cultivated with sugarcane crop for four year (AC4yr) showed the highest TOC stocks with 12.11 Mg ha^{-1}, which differed ($p\leq0.01$) from the treatment AC1yr (7.18 Mg ha^{-1}) and reference area (4.73 Mg ha^{-1}), even though, no significant difference was observed between the treatments AC2yr and AC3yr. At 10-30 cm depth, the highest TOC stocks in F3+F4 fractions was obtained in AC2yr treatment (11.61 Mg ha^{-1}), which differed significantly ($p\leq0.01$) from the treatments AC1yr and reference area (Fig. 4).

These results of high TOC stocks in F3+F4 fractions are related to the input of high stability chemical compounds and molecular weight from the OM decomposition and SOM humification (Stevenson, 1994; Chan et al., 2001). It is possible to note that the adoption of sugarcane crop over the years increased the TOC stocks in the fractions more

Table 1. Average soil density (g Kg^{-1}) from the experimental site.

Treatments	Soil density (g kg^{-1})	
	0-10 cm	10-30 cm
RA	1.57	1.08
AC1yr	1.54	1.48
AC2yr	1.24	1.71
AC3yr	1.57	1.71
AC4yr	1.51	1.43

RA: Reference area; AC1yr: area cultivated with sugarcane crop for one year; AC2yr: area cultivated with sugarcane crop for two years; AC3yr; area cultivated with sugarcane crop for three years; AC4yr: area cultivated with sugarcane crop for four years.

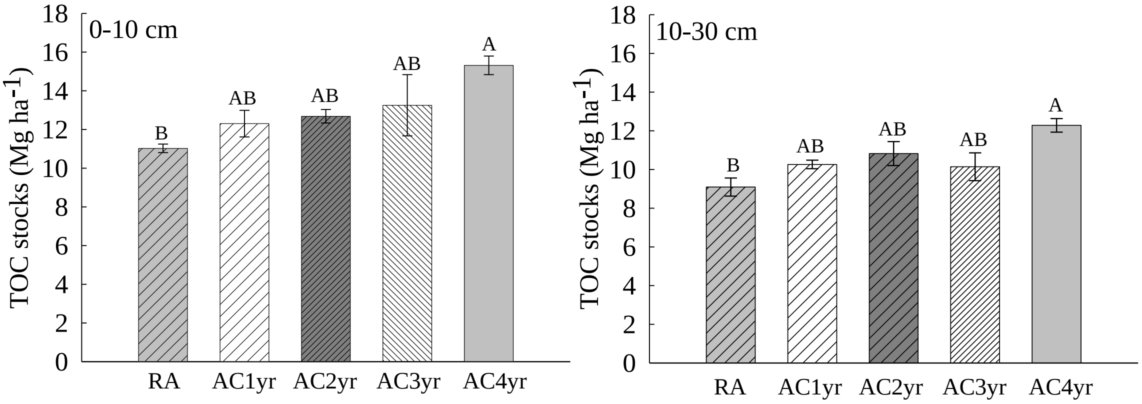

Fig 1. Total organic carbon (TOC) stocks (Mg ha^{-1}). Means followed by the same letter do not differ by the Tukey´s test at 5%. RA: Reference area; AC1yr: area cultivated with sugarcane crop for one year; AC2yr: area cultivated with sugarcane crop for two years; AC3yr; area cultivated with sugarcane crop for three years; AC4yr: area cultivated with sugarcane crop for four year.

Table 2. Some initial soil chemical from the experimental site.

Treatments	Depth (cm)	pH $CaCl_2$	P (mg dm^{-3})	K^+	Al^{+3}	Ca^{+2}	Mg^{+2}	H+Al	SB	CEC	BS (%)
				-----------------------			mmol$_c$dm^{-3}		--------------------		
	0-10	3.9	4.20	0.8	7.0	4.1	1.8	29.4	6.7	36.1	18.6
RA	10-30	3.9	1.92	0.5	8.9	3.1	1.1	29.5	4.7	34.2	13.7
	0-10	4.9	6.93	0.9	1.2	25.2	11.6	16.2	37.7	53.9	69.9
AC1yr	10-30	4.8	4.78	0.9	2.2	19.6	9.0	16.1	29.5	45.6	64.7
	0-10	4.9	2.61	0.7	0.2	24.6	11.6	17.1	36.9	54.0	68.3
AC2yr	10-30	5.0	9.52	0.5	1.2	21.4	9.4	15.8	31.3	47.1	66.5
	0-10	4.9	3.31	0.9	0.9	19.6	9.0	16.4	29.5	45.9	64.3
AC3yr	10-30	4.8	2.08	0.4	1.8	13.0	7.4	18.6	20.8	39.4	52.8
	0-10	4.5	3.97	0.7	0.2	19.6	4.3	21.4	24.6	46.0	53.5
AC4yr	10-30	4.6	3.14	0.5	0.5	19.8	3.5	18.6	23.8	42.4	56.1

CEC: Cation Exchange Capacity; total acidity pH 7.0 (H^+ $+Al^{3+}$); Exchangeable (KCl 1 mol L^{-1}) Ca, Mg and Al; SB: Sum of Base=∑cations; BS: Base Saturation=(∑cations/CEC)x100. Reference area (RA); area cultivated with sugarcane crop for one year (AC1yr); area cultivated with sugarcane crop for two years (AC2yr); area cultivated with sugarcane crop for three years (AC3yr); area cultivated with sugarcane crop for four years (AC4yr).

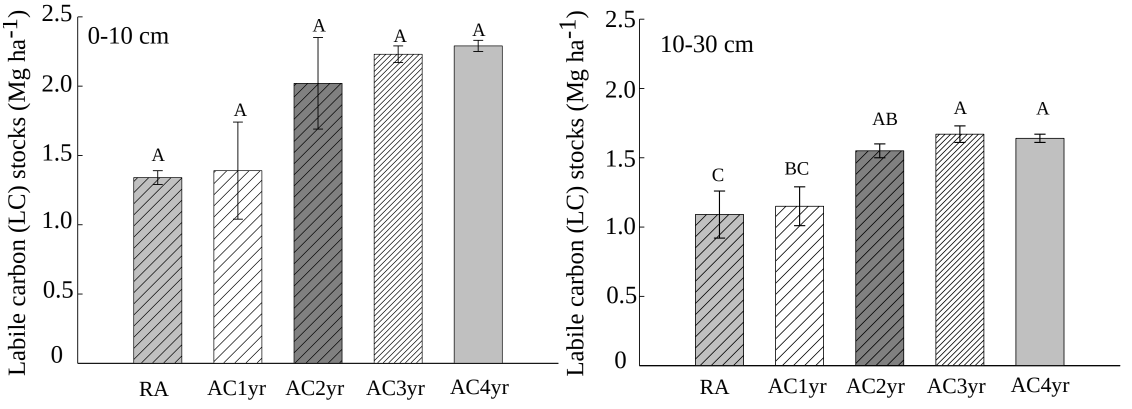

Fig 2. Labile carbon (LC) stocks (Mg ha^{-1}). Means followed by the same letter do not differ by the Tukey´s test at 5%. RA: Reference area; AC1yr: area cultivated with sugarcane crop for one year; AC2yr: area cultivated with sugarcane crop for two years; AC3yr; area cultivated with sugarcane crop for three years; AC4yr: area cultivated with sugarcane crop for four years.

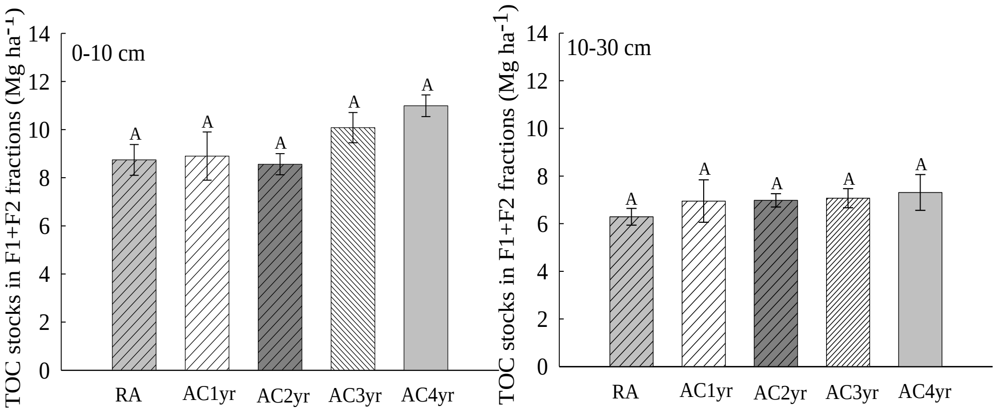

Fig 3. Total organic carbon (TOC) stocks in the F1+F2 fractions (Mg ha^{-1}). Means followed by the same letter do not differ by the Tukey´s test at 5%. RA: Reference area; AC1yr: area cultivated with sugarcane crop for one year; AC2yr: area cultivated with sugarcane crop for two years; AC3yr; area cultivated with sugarcane crop for three years; AC4yr: area cultivated with sugarcane crop for four years.

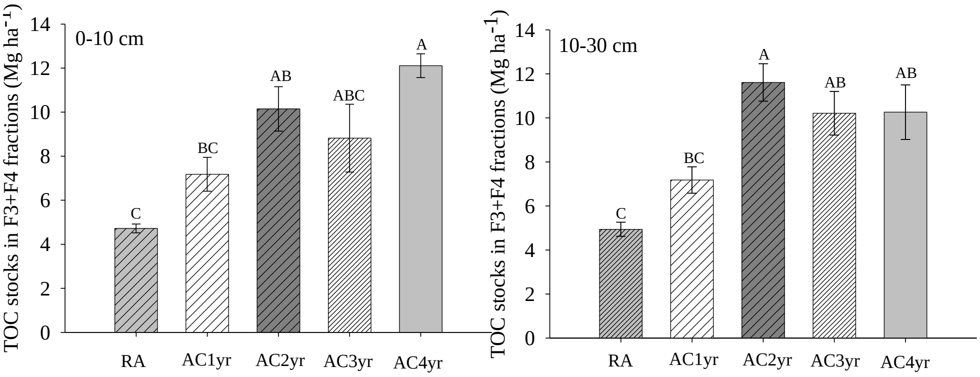

Fig 4. Total organic carbon (TOC) stocks in F3+F4 fractions (Mg ha^{-1}). Means followed by the same letter do not differ by the Tukey´s test at 5%. RA: Reference area; AC1yr: area cultivated with sugarcane crop for one year; AC2yr: area cultivated with sugarcane crop for two years; AC3yr; area cultivated with sugarcane crop for three years; AC4yr: area cultivated with sugarcane crop for four year.

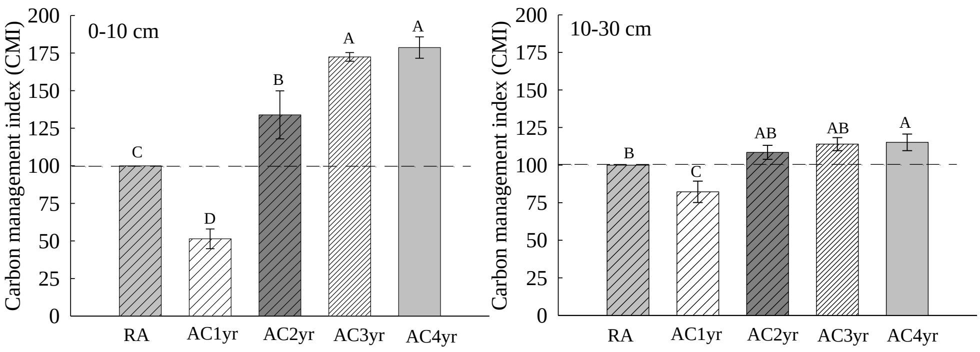

Fig 5. Carbon management index (CMI). Means followed by the same letter do not differ by the Tukey´s test at 5%. RV: Reference vegetation; AC1yr: area cultivated with sugarcane crop for one year; AC2yr: area cultivated with sugarcane crop for two years; AC3yr; area cultivated with sugarcane crop for three years; AC4yr: area cultivated with sugarcane crop for four year. The dash line means the CMI in the reference area.

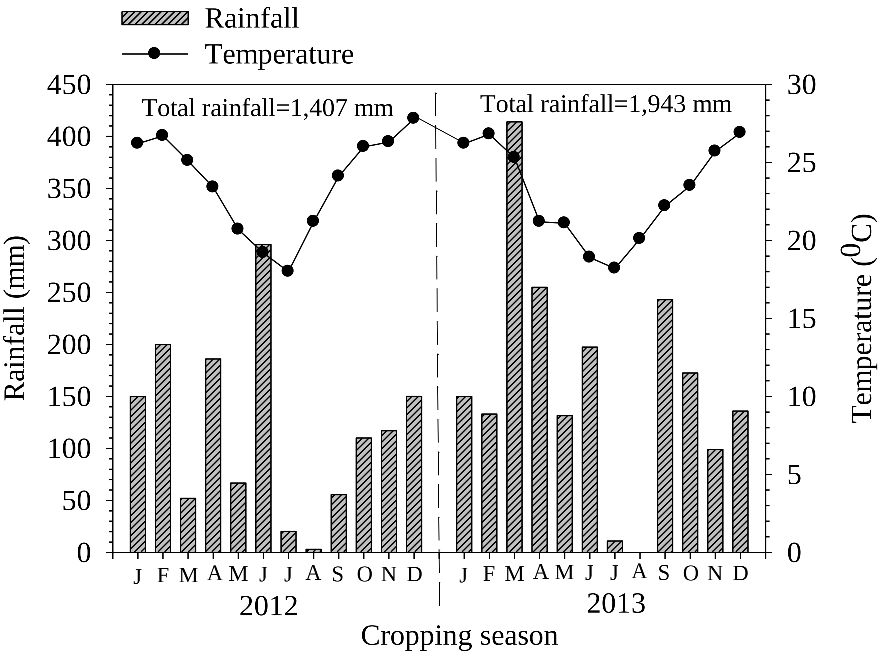

Fig 6. Monthly rainfall and temperature in 2012/2013 cropping season in the region of the experiment.

of SOM in comparison to the reference area of this work (Fig. 4). These results can be explained because of the input of above-ground dry matter from the sugarcane crop with high C:N ratio and high lignin content, which in turn associated with decomposition's slow process (Abiven et al., 2005; Zhang et al., 2008). As reported by Potrich et al. (2014), the sugarcane above-ground dry matter showed C:N ratio of 29.34 and lignin content of 221.1 g kg^{-1}, which resulted in slow process of OM decomposition.

In general, the treatments showed a balance in the TOC stocks in the oxidation fraction of SOM. According to Loss et al. (2010), this balance is quite important to have the stability among the fractions (F1+F2) of available nutrients, structure of the soil and the chemical and physical protection of fractions (F3+F4) in the soil.

Assessment of carbon management index (CMI)

The CMI is the indicator of SOM management quality in function of soil tillage systems and adopted cropping system (Souza et al., 2009). This index allows assessing the lost or gaining of soil quality. Values of CMI equal or above 100 are suggestive of conservation system of cropping tillage. Plus, it is possible to observe that the treatment AC3yr (178.68) and AC4yr (172.44) increased the CMI in 0-10 cm depth, statistically higher than the other treatments (Fig. 5). The higher value of CMI was observed in the treatments AC3yr and AC4yr at 10-30 cm depth, different than the treatment AC1yr and the reference area. However, there was no difference (p>0.05) with the treatment AC3yr (Fig 5).

In the treatment AC1yr, the CMI was below 100, which was the smallest value of CMI (49). This result is due to the tillage system that promoted the oxidation of SOM, because in the first year of cropping, the soil was removed with disk arrow and sub-soiler. This soil tillage process is incorporated with SOM what increases its decomposition process (Fig 5). The values of CMI over than 100 observed in this work were consequence of the high input above-ground dry matter that increased the TOC and LC. It was feasible to infer that the cultivation of sugarcane crop contributes to increase the capacity of preservation and recovery the content and quality of organic fraction in the soil.

Materials and Methods

Site description

This research was carried out in 2012-2013 cropping season, in a dystroferric Red Latosol, classified according to Santos et al. (2006), located in the municipality of Naviraí, state of Mato Grosso do Sul, Brazil (approximately 23˚3'55''S, 54˚11'26''W, average altitude 364 m asl). According to Köppen (1948), the region is classified as tropical climate of type Am, with rainy summer and dry winter. The rainfall and temperature in the region of the experimental site is showed in Fig. 6.

Experimental design and treatments

Before the implementation of the experiment, the experimental site was cultivated with pasture (*Brachiaria brizantha* cv. Marandu). The experimental design was set up in a completely randomized with five treatments, which consists of the land use time with sugarcane crop cultivation (RA: Reference Area; AC1yr: area cultivated with sugarcane crop for one year; AC2yr: area cultivated with sugarcane crop for two years; AC3yr; area cultivated with sugarcane crop for three years; AC4yr: area cultivated with sugarcane crop for four years), with four repetitions. To compare the treatments, a native vegetation area (Brazilian savannah) was selected as the reference area (RA), where was 200 m distant of the studied area. The vegetation of the reference area was basically Savannah.

Plant material and measurement

The cultivar of sugarcane crop used in this experimental was *Saccharum* cv. RB86 7515. It was established the plot with the dimension of 60 × 40 m. 20 simple samples were collected to compile the compound sample in each plot, after the sugarcane harvest.

Soil tillage

The soil tillage was accomplished with the use of subsoiler at 20 cm depth, followed by twice leveling disk arrow of 22 inches until 10 cm depth. The lime and fertilizer were applied in the planting furrow (125 kg of P_2O_5, 85 kg of K_2O and 500 kg of dolomitic lime). The dolomitic lime showed calcium carbonate equivalent (CCE) of 64%. The cover fertilizer was applied in each year with 400 kg ha^{-1} of the formulation of 20-0-20 (N-P_2O_5-K_2O). The sugarcane harvest in all areas was made without the burning with automatic harvester.

Soil measurement

The soil was sampled among the sugarcane crop rows. It was used Dutch auger type to sample the soil. In each depth of evaluation (0-10 cm and 10-30 cm) four soil samples per depth in each plot were collected, but all of them mixed to form just one sample to be analyzed. The non-deformed sampling with the assistance of volumetric iron rings was collected to determine the soil density. The soil density was determined following the methodology of Claessen (1997). In Table 1, there is the average soil density of the experimental site.

After the samplings, the soil samples were stored in plastic bag and sent to soil laboratory, where the following parameters in the soil sample were measured: total acidity pH 7.0 (H^++Al^{3+}), phosphorus content, potassium exchangeable, aluminum exchangeable, calcium exchangeable, magnesium exchangeable, cation exchange capacity (CEC), base saturation (BS%), according to Claessen (1997) (Table 2).

To measure the quantitative values of organic matter (OM), the soil samples were crushed, ground and sifted into the sieve with mesh of 0.210 mm. The total organic carbon (TOC) was determined following the methodology of oxidation via dampening, with external warming, as described by Yeomans and Bremner (1988). To determine the content of oxidized carbon by $KMnO_4$ [from now on called labile carbon (LC)], we weighted 1g of the crushed soil and sifted into the sieve of 0.210 mm mesh, right after the solution was stored in tube of 50 ml mixed with 25 ml of $KMnO_4$ (0.033 mol L^{-1}) solution (Shang and Tiessen, 1997).
This solution was shaken in horizontal shaker to 130 rpm (rotation per minute) for one hour, and centrifuged to 2500 rpm. Right after the centrifugation, 100 μL of supernatant pipetted into the test tube and the volume was completed to 10 mL with distilled water. The readings were done in spectrophotometer of wavelength of 565 nm, and the labile carbon (LC) was measured from the standard curve equation. The standard curve was obtained from the concentration of 0, 0.2, 0.4, 0.6, 0.8 and 1 mL of $KMnO_4$ (0.033 mol L^{-1}) solution that was stored in volumetric flask of 100 mL, filling the rest of volume with distilled water.

To determine the oxidized carbon the method of Chan et al. (2001) was applied, where 0.5 g of soil was weighted and stored in 10 mL of $K_2Cr_2O_7$ 0.167 mol L^{-1}. From this step, we set apart the solution of four fractions of oxidized carbon based on increasing solution of H_2SO_4 concentration. First fraction (F1) – was obtained by means of oxidation with H_2SO_4 3 mol L^{-1}. Second fraction (F2) –was obtained by difference between the oxidized carbon with H_2SO_4 between 6 and 3 mol L^{-1} of H_2SO_4, that corresponds to labile carbon (LC) fraction (F1+F2). Third fraction (F3) –was obtained by the difference between oxidized carbon with H_2SO_4 between 9 and 6 mol L^{-1}, and the fourth fraction (F4) –was obtained by the difference between oxidized carbon with 12 and 9 mol L^{-1} of H_2SO_4. This solution corresponded to the recalcitrant carbon (F3+F4 fractions). For all concentrations 50 mL of distillate water was added, and after cooling it was added 5 droplet of ferroin was added, titrating the excess of $K_2Cr_2O_7$ 0,167 mol L^{-1} $(NH_4)_2Fe(SO_4)_2 6H_2O$ 0.5 mol L^{-1}.
Based on the total organic carbon (TOC) changes, between the reference area (RA) and cultivated area (sugarcane crop), it was calculated the carbon compartment index (CCI) was calculated as equation below.

$$CCI = \frac{TOC\ in\ cultivated\ area}{TOC\ in\ no\ cultivated\ area\ (reference\ area)}$$

(LI): LI=L cultivated area/reference area L. These two indices were used to calculate the carbon management index (CMI), obtained by the following equation (CMI= CCIxLIx100), according to Blair et al. (1995).

The total organic carbon (TOC) stocks, labile carbon (LC) and oxidized carbon were obtained by the multiplication of the carbon content (g kg^{-1}) and soil mass, in each studied depth (kg ha^{-1}) (0-10 and 10-30 cm). The soil mass was obtained by the multiplication of width of each depth (cm), for its soil density (kg dm^{-3}), and the soil volume (dm^3).

Statistical analysis

The variables evaluated in this experiment were subjected to the analysis of variance (ANOVA) by the F-test. The mean was compared by the Tukey's test ($P \leq 0.05$). These tests were carried out with the use of SAEG software (Ribeiro and Melo, 2008).

Conclusions

The soil cultivated with sugarcane crop showed increased TOC and LC stocks, which indicate the capacity of sugarcane crop to act in the mitigation of greenhouse gas. It promoted the unbiased TOC stocks in the oxidized organic matter. The treatments promoted the CMI as the time passed under sugarcane crop cultivation. This suggested that the conservation tillage system improves the SOM as well as the native vegetation of Brazilian savannah. The results showed that sugarcane crop cultivated without pre-harvest burning is quite capable to increase the fixation of atmosphere CO_2 carbon into the SOM.

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