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# Organic cultivation of sugarcane restores soil organic carbon and nitrogen

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**Abstract** Sugarcane cultivation in the Cerrado biome causes changes in soil attributes and affects the sustainability of agricultural production. The organic system may constitute an alternative to the conventional system. We have hypothesized that (i) the replacement of native *Cerradão* vegetation to sugarcane cultivation in a conventional system modifies the physical and chemical attributes of the soil and that (ii) organic cultivation may contribute to restoring physical and chemical properties that have been degraded by conventional cultivation. The study consisted of the following areas: (a) *Cerradão*, (b) pasture, (c) sugarcane in an organic system (organic sugarcane), (d) sugarcane in a conventional system with straw burning before harvest (burned sugarcane), and (e) sugarcane in a conventional system without burning the straw before harvest (raw sugarcane). The soil carbon and nitrogen contents and total soil density and porosity were evaluated. Six soil layers were sampled: 0–10 cm, 10–20 cm, 20–30 cm, 30–40 cm, 40–50 cm, and 50–60 cm depth. The results have showed that the sugarcane cultivation altered all the evaluated attributes when compared to *Cerradão* soil. The most significant changes, with a reduction in carbon and nitrogen contents, total porosity and soil bulk density, occurred in conventional cropping systems. In the organic system, there were few changes in the evaluated attributes when compared to the *Cerradão* ecosystem. In this paper, we show that a reduction in the total nitrogen in the 0–10 cm layer was the only observed decline. Organic sugarcane proved to be a viable alternative for production in the Cerrado biome as it restores soil attributes similar to those of the *Cerradão* ecosystem.

**Keywords** *Cerradã*o · Agroecology · Organic matter · Total porosity · Soil quality

## Introduction

The Cerrado biome accounts for approximately 23% of the Brazilian territory, occupying roughly 200 million hectares, and it is one of the main areas of agriculture expansion in Brazil (Bustamante et al.

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2006). Every year, 2.2 million hectares (5.4 million acres) of native vegetation in this ecosystem (1.1% of the total area) are replaced by agriculture (Carvalho et al. 2010), which currently occupies 80 million hectares (197 million acres), or 39.5% of the total expanse of the biome. In the area occupied by agriculture, pastures represent 26.5% and agricultural crops 10.5% (Guareschi et al. 2012).

The substitution of the native vegetation of an ecosystem causes changes in soil attributes, including density, porosity, and organic matter content, which can result in serious damage to the Cerrado ecosystem, once organic matter is one of the factors that mostly influences soil properties (Sanchez-Navarroa et al. 2013). The increase in soil density causes a reduction of the total porosity, thus reducing water infiltration into the soil (Cherubin et al. 2016), which leads to serious risks to the sustainability of the Cerrado biome. The springs of eight out of the 12 river basins in the country are located in the area, making it an important water reservoir (Ribeiro and Walter 1998).

Carbon and nitrogen are the main components of soil organic matter, and their stocks vary, depending on the rates of addition, plant and/or animal residues and losses, including those caused by erosion and oxidation of organic matter by soil microorganisms (Bayer et al. 2006). Organic matter plays an important role in nutrient and moisture retention and in the structure of tropical soils, playing an important role in the fixation of atmospheric $CO_2$, which increases carbon sequestration in the soil (Anaya and Huber-Sannwald 2015). In this context, alternative production systems seeking to conserve or increase the soil organic matter contents are fundamental, since the ecosystem imbalance affects the capacity to sustain agricultural production (Bayer et al. 2006). To conserve soil organic matter and achieve satisfactory levels of productivity, in addition to fertility control, the management of physical properties is also fundamental.

The properties of soils include maintaining environmental quality, with local, regional, and global effects. Oxisols represent more than 50% of soils in the Cerrado ecosystem and are characterized by excellent physical properties with good water permeability (Ribeiro and Walter 1998). The inadequate management of Oxisols, through soil tilling and intense traffic of agricultural machines, has favored compaction, resulting in increased density, reduction of macropores, and reduced infiltration of water in the soil. Several studies have shown that the substitution of native vegetation in the Cerrado ecosystem for crops reduced soil carbon and nitrogen stocks and increased greenhouse gas emissions into the atmosphere (Bayer et al. 2006; Franco et al. 2015).

In recent decades, the expansion of Brazilian agriculture has occurred mainly in areas of the Cerrado biome. Of the 80 million hectares (197 million acres) cultivated in this biome, 9.1 million (22 million acres) are cultivated with sugarcane (Conab 2016), which is one of the main crops produced in Brazil, making the country the largest sugarcane producer in the world, an activity that has been motivated by the depletion of oil deposits. In this context, sugarcane is considered an excellent alternative for the biofuels sector for its great potential for ethanol production. This has led to expanded cultivation of the Cerrado biome soils, replacing native vegetation and pasture areas (Conab 2016).

Organic cultivation is characterized by promoting greater biodiversity of the microbiota and soil fauna, as well as by improving fertility and maintaining biological pest control. Organic fertilizers produced with locally obtained raw materials are used to improve soil fertility (Dotaniya et al. 2016). Studies have shown that the management techniques adopted in the organic production system have promoted increases in soil organic matter, improving the functionality of the ecosystem (Mäder et al. 2002; Mondelaers et al. 2009; Borges et al. 2014).

In view of this scenario, the organic cultivation system may be an alternative to the conventional system, as it does not use chemical fertilizers and agrochemicals and has the ability to increase soil fertility and nutrient content in plants. Borges et al. (2015) compared the organic cultivation of sugarcane with conventional farming and found that after 10 years of organic cultivation, the contents of N, P, and K in the soil in the 0–20 cm and 20–40 cm layers were higher than in conventional cultivation. The findings showed higher contents of these nutrients in the sugarcane leaves under organic cultivation and higher productivity under this production system. In addition, Bullock III et al. (2002) found that calcium, potassium, magnesium, and manganese levels have increased in the soil that had received organic amendments, compared to soils receiving synthetic fertilizers. Despite these finds, Rahmann et al. (2017) stated in a literature review that productivity in organic agriculture, in general, is relatively low because its principles and standards are not adopted by all farms. Little is known regarding the effect of the sugarcane organic cultivation system on soil attributes in the Cerrado biome, which highlights the importance of this study.

The hypotheses of this study are as follows: (i) the substitution of native *Cerradão* vegetation by sugarcane cultivation in a conventional system alters the physical and chemical attributes of the soil; (ii) the cultivation system may contribute to restoring physical and chemical properties degraded by conventional cultivation. To test these hypotheses, the levels and stocks of carbon and nitrogen in the soil and total density and porosity were calculated for soils cultivated with sugarcane in organic and conventional systems, in an area with native *Cerradão* vegetation and in another area with pasture, which was included because, in this region, the sugarcane crop is introduced in areas previously occupied by pasture.

The objective of this study is to evaluate the effect of organic and conventional sugarcane production systems on the physical and chemical attributes of a clayey Oxisol in the Cerrado Biome. In this study, we have investigated the effect of sugarcane production systems on the physical and chemical properties of the soil, using the native *Cerradão* as a reference. A pasture area was included, as in this region, sugarcane is introduced in pasture areas.

## Material and methods

### Study location

The study was performed in commercial farms with sugarcane cultivation in Goianesia, Goiás, Brazil (15°19′ S, 49°08′ W, altitude of 649 m). The native *Cerradão* vegetation of the region is classified as Cerrado, under the *Cerradão* subgroup (Ribeiro and Walter 1998). The climate of the region is classified as Aw in the Köppen classification—tropical with rainy summers and dry winters (Kottek et al. 2006). The annual precipitation and temperature averages are 1602 mm and 24.3 °C, respectively.

The treatments and their respective coordinates were as follows: (i) organic sugarcane (− 15°22′ S and 48°98′ W), (ii) raw sugarcane grown in a conventional system without burning of straw (15°30′ S and 49°02′ W), (iii) sugarcane in a conventional system with burning of the straw 1 day before harvest (− 15°14′ S and 48°90′ W), (iv) *Brachiaria* spp. pasture (− 15°28′ S and 49°00′ W) and native *Cerradão* vegetation ecosystem, type *Cerradão* (− 15°23′ S and 48°99′ W). The organic sugarcane area is certified as organic by the Instituto Bidinâmico de Certificações (IBD). The yield of organic sugarcane, burned sugarcane, and raw sugarcane areas were 90.58 Mg ha$^{-1}$, 73.49 Mg ha$^{-1}$, and 74.71 Mg ha$^{-1}$, respectively. The location of the studied areas is presented in Fig. 1.

The soil of the study areas was classified as Oxisol, with the clay percentages of 53, 34, 45, 37, and 48. The altitude of the experiment area is 660 m and the relief is flat to smooth wavy. The study areas are relatively close to each other and are under the same climatic conditions, so that differences observed in the soils in the present study can be attributed to the different systems of land use and management.

Before being cultivated, all areas of the study were occupied with native Cerrado vegetation, type *Cerradão*. In the 1930s, part of the native *Cerradão* vegetation was removed, and the areas were occupied by *Brachiaria* spp. In the 1980s, a portion of the areas that were occupied with pasture was replaced with sugarcane. The areas used in this study were cultivated with sugarcane for approximately 28 years. For the study, three areas cultivated with sugarcane under different management systems were chosen. They included one area managed in a conventional production system without burning of the straw before harvest (raw sugarcane), a second area also managed in a conventional production system, but with burning of the straw before harvest (burned sugarcane), and a third area managed under the organic production system. The organic-cultivated area was managed under this production system for 10 years. Before that, the area had a conventional production system without burning of the straw.

### Fertilizer management in organic and conventional systems

Soil operations and sugarcane harvest in the organic system did not differ from the conventional system, but diverged in relation to fertilizer source. In both systems, organic and conventional harvest were mechanized and managed without pre-harvest straw burning. The cycle of sugarcane fields is of 5 years, at the end of which the sugarcane fields were reformed. In the renovation of fields, the crop residues were removed, and the soil was prepared for a new crop cycle. Table 1 presents the sugarcane field fertilization per 5-year cycle.

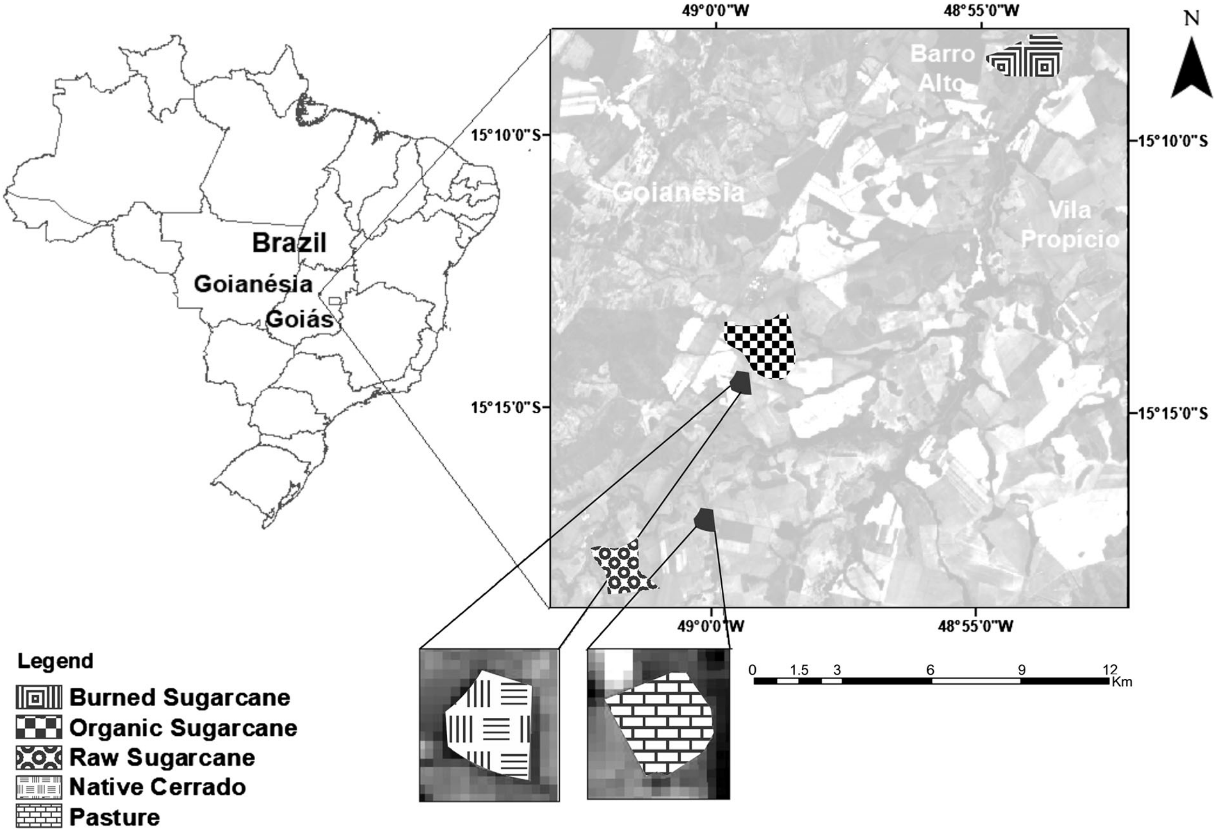


**Fig. 1** Localization of studied areas

In the cultivated areas subjected to the conventional system, weed control was done with the use of herbicides, and pest control was carried out with the recommended chemical insecticides for the crop. In the organic area, weed control was done manually. Pest control, when necessary, was done with biological control methods, such as the use of wasps for the management of sugarcane borer and *Metarizium* fungi for the control of spittlebugs.

## Soil sampling and laboratory analysis

In the said areas, two soil samples were collected, the first in August 2008, 1 week after the third sugarcane cut, and the second in August 2009, 1 week after the fourth sugarcane cut. In each area, five random points were sampled in a 1-ha area (100 × 100 m), totaling five replicates. In a 30-m radius around each point, 15 subsamples were collected to form a composite sample for each of the six depths studied: 0–10, 10–20, 20–30, 30–40, 40–50, and 50–60 cm, using a Dutch auger. The samples were air-dried and passed through a 2-mm sieve. The total organic carbon and total soil nitrogen contents were analyzed (Nelson and Sommers 1996).

In order to determine the soil density, undisturbed soil samples were collected at the six depths described above, using a metal cylinder (5 × 5 cm), according to the methodology described by Blake & Hartge (1986a). In each area, two trenches measuring 0.8 × 0.8 × 0.80 m were opened, and three simple undeformed samples were collected, totaling six subsamples per depth per area, in the two evaluation periods. The soil particle density was determined by means of a volumetric flask method (Blake and Hartge 1986b), so that together with the soil bulk density data (BD), total porosity (TP) was calculated using the equation proposed by Vomocil (1965), where $\text{TP}\ (\%) = (1 - (\text{BD} / \text{TP})) \times 100$.

## Calculation of carbon and nitrogen stocks

The carbon and nitrogen stocks ($\text{Mg ha}^{-1}$) were calculated for each of the six depths by multiplying the element concentration (%) by the soil BD ($\text{g cm}^{-3}$) and layer

**Table 1** Fertilizers and the respective amount used in organic and conventional systems in a cycle of 5 years. N nitrogen, $P_2O_5$ phosphorus, $K_2O$ potassium, Ca calcium, Mg magnesium, S sulfur, and OM organic matter. CS conventional system, Org. organic system

| Year | Fertilizations | Systems | | N | $P_2O_5$ | $K_2O$ | Ca | Mg | S | OM |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Org. | CS | kg $ha^{-1}$ | | | | | | |
| 1 | 2 months before sugarcane planting | | | | | | | | | |
| | 1500 kg $ha^{-1}$ Dolomitic lime | x | x | – | – | – | 675.0 | 90.0 | – | – |
| | 1000 kg $ha^{-1}$ Natural phosphate | x | – | – | 80.0 | – | 200.0 | 10.0 | 30.0 | – |
| | 1000 kg $ha^{-1}$ Thermal phosphate | – | x | – | 170.0 | – | 200.0 | 70.0 | 40.0 | – |
| | *Crotalaria juncea* | x | x | – | – | – | – | – | – | – |
| | At the planting | | | | | | | | | |
| | 400 kg $ha^{-1}$ formula NPK (4-28-20) | – | x | 16.0 | 112.0 | 80.0 | – | – | – | – |
| | 30,000 kg $ha^{-1}$ Filter cake | x | – | 179.0 | 193.0 | 26.0 | 208.0 | 22.0 | 33.0 | 1725 |
| | Covering fertilization | | | | | | | | | |
| | 50 kg $ha^{-1}$ (liquid urea) | – | x | 50.0 | – | – | – | – | – | – |
| | 120 kg $ha^{-1}$ (liquid KCl) | – | x | – | 120.0 | – | – | – | – | – |
| | 600 $m^3$ $ha^{-1}$ Vinasse | x | – | 70.2 | 31.9 | 866.0 | 14.9 | 4.9 | – | – |
| 2 | Ratoon fertilization | | | | | | | | | |
| 3 | 8000 kg $ha^{-1}$ Organic compost | x | – | 71.6 | 124.4 | 8.8 | 66.0 | 22.8 | – | 7360 |
| 4 | 50 kg $ha^{-1}$ N | – | x | 50.0 | – | – | – | – | – | – |
| 5 | 35 kg ha $P_2O_5$ | – | x | – | 35.0 | – | – | – | – | – |
| | 125 kg $ha^{-1}$ $K_2O$ | – | x | – | – | 125.0 | – | – | – | – |
| | Covering fertilization | | | | | | | | | |
| | 50 kg $ha^{-1}$ (liquid urea) | – | x | 50.0 | – | – | – | – | – | – |
| | 120 kg $ha^{-1}$ $K_2O$ (liquid KCl) | – | x | – | 120.0 | – | – | – | – | – |
| | 600 $m^3$ $ha^{-1}$ Vinasse | x | – | 70.2 | 31.9 | 866.0 | 14.9 | 4.9 | – | – |
| Total inputs in organic system | | | | 816.4 | 930.1 | 4391.2 | 1421.5 | 237.7 | 66.0 | 31,165 |
| Total inputs in conventional system | | | | 466.0 | 1022.0 | 580.0 | 875.0 | 160.0 | 40.0 | – |

thickness (10 cm). Because the samples were collected at fixed depths, to correct the effect of differences between soil densities due to changes in land use, the carbon stock was corrected to a soil mass equivalent (SME), using the soil mass with native *Cerradão* vegetation within a depth of 60 cm as a reference and making the corresponding corrections for cultivated soils, according to Ellert and Bettany (1995) and Franco et al. (2015).

The equivalent soil layers for the same soil mass of the 60 cm reference profile (EL) were calculated as follows: (i) the average weighted apparent density in the corresponding soil layer of the EL ($M_{EL}$) was determined; (ii) the average weighted apparent density in the corresponding soil layer in each area (pasture, burned sugarcane, raw sugarcane, and organic sugarcane) ($M_{AREA}$) was calculated and (iii) the equivalent layer was then calculated according to the following equation:

$$\text{Equivalent soil layer (cm)} = (M_{EL}/M_{AREA}) \times 60.$$

## Statistical analysis

The mixed model was used for data analysis:

$$y_{ijkl} = \mu + S_i + R_j(S_i) + E_k + (SE)_{ik} + R_jE_K(S_i) + P_l + (SP)_{il} + (EP)_{kl} + (SEP)_{ikl} + \varepsilon_{ijkl}$$

where $S_i$, system i; $R_j(S_i)$, sample j within system i; $E_k$, period k; $(SE)_{ik}$, system × period interaction; $R_jE_k(S_i)$, repetition × period interaction within the system; $P_l$, depth l; $(SP)_{il}$, system × depth interaction; $(EP)_{kl}$, period × depth interaction; $(SEP)_{ikl}$, system × period × depth interaction and $\varepsilon_{ijkl}$ is the error.

The analysis method was the maximum restricted likelihood, described by Searle et al. (2003). Because it is not an experiment but an observational study, the structure of variances and covariates of the data is not known; therefore, a statistical study was conducted to indicate the best structure. Two other studies were also conducted: one to verify normal distribution of the data

**Table 2** Soil density (g cm$^{-3}$), total porosity (cm$^{-3}$ cm$^{-3}$), organic carbon content (g kg$^{-1}$), and total nitrogen content (g kg$^{-1}$) in areas of *Cerradão*, pasture, organic sugarcane, conventional burned, and conventional raw sugarcane, in Goianésia, GO, Brazil

| | Soil density (g cm$^{-3}$) | | | | | |
|---|---|---|---|---|---|---|
| Depth | 0–10 | 10–20 | 20–30 | 30–40 | 40–50 | 50–60 |
| *Cerradão* | 1.03 cA(1) | 1.08 cAB | 1.11 cB | 1.09 cB | 1.06 dAB | 1.10 dB |
| Pasture | 1.43 aB | 1.39 aAB | 1.39 aAB | 1.40 aAB | 1.37 aAB | 1.34 aA |
| Raw sugarcane | 1.39 aB | 1.44 aBC | 1.41 aB | 1.35 aAB | 1.29 bA | 1.27 bA |
| Burned sugarcane | 1.21 bAB | 1.19 bA | 1.26 bB | 1.26 bB | 1.21 cAB | 1.17 cA |
| Organic sugarcane | 1.09 cA | 1.06 cA | 1.08 cA | 1.09 cA | 1.10 dA | 1.12 cdA |
| CV (%) | 5.1 | 3.5 | 6.0 | 4.20 | 4.1 | 4.4 |
| | Total porosity (cm$^{-3}$ cm$^{-3}$) | | | | | |
| *Cerradão* | 59.40 aA(1) | 59.62 aA | 58.38 aA | 59.26 aA | 60.69 aA | 59.15 aA |
| Pasture | 44.11 cA | 45.25 cA | 45.85 cA | 45.89 cA | 47.23 dB | 48.39 cB |
| Raw sugarcane | 45.51 cA | 43.81 cA | 46.42 cAB | 48.10 cB | 50.26 cBC | 51.62 bC |
| Burned sugarcane | 53.11 bAB | 53.55 bAB | 51.43 bA | 52.55 bAB | 54.71 bB | 57.13 aB |
| Organic sugarcane | 57.83 aA | 60.15 aA | 59.68 aA | 60.03 aA | 59.52 aA | 58.50 aA |
| CV (%) | 4.8 | 4.5 | 7.6 | 3.9 | 3.6 | 3.4 |
| | Total organic carbon (g kg$^{-1}$) | | | | | |
| *Cerradão* | 26.77 aA(1) | 18.62 bB | 14.75 abC | 12.73 abD | 10.53 aE | 8.42 aF |
| Pasture | 17.83 cA | 17.87 bA | 14.21 bB | 11.86 bC | 10.10 aD | 7.30 bE |
| Raw sugarcane | 10.21 eA | 9.72 dA | 8.29 dB | 7.30 dBC | 6.84 bC | 5.38 cD |
| Burned sugarcane | 13.48 dA | 13.68 cA | 11.92 cB | 10.13 cC | 8.02 bD | 6.83 bE |
| Organic sugarcane | 23.00 bA | 20.51 aB | 15.68 aC | 13.65 aD | 11.17 aE | 9.36 aF |
| CV (%) | 13.7 | 8.7 | 8.9 | 8.5 | 13.5 | 11.4 |
| | Total nitrogen (g kg$^{-1}$) | | | | | |
| *Cerradão* | 2.42 aA(1) | 1.46 aB | 1.09 aC | 0.95 aD | 0.79 aE | 0.64 aF |
| Pasture | 1.31 cA | 1.31 bA | 1.10 aB | 0.83 bC | 0.67 bD | 0.55 bE |
| Raw sugarcane | 0.83 dA | 0.77 dB | 0.67 cC | 0.61 cCD | 0.55 cD | 0.46 cE |
| Burned sugarcane | 0.88 dA | 0.88 cA | 0.79 bB | 0.67 cC | 0.55 cD | 0.49 bcD |
| Organic sugarcane | 1.55 bA | 1.33 bB | 1.08 aC | 0.89 abD | 0.75 abE | 0.67 aE |
| CV (%) | 5.0 | 8.4 | 8.9 | 8.3 | 8.4 | 6.6 |

(1) Means followed by different lower case in the column and upper case letter in the line indicate the significant differences ($P < 0.05$) based on the *t* test. *CV* coefficient of variation

and a second one to detect discrepant measures. The techniques for the three studies are described in Littel et al. (2006). Statistical analysis was performed using SAS (2003) (Searle et al. 2003).

## Results and discussion

### Soil bulk density and total porosity

The replacement of native *Cerradão* vegetation caused changes in TP and soil BD (Table 2) for all evaluated systems, except for the area under organic cultivation. In all soil layers, the area under organic cultivation presented soil density and total porosity similar to the native *Cerradão* area. In the other production systems, the BD increased, and the TP decreased in all the studied layers. The major alterations occurred in the more superficial soil layers, and when the native *Cerradão* vegetation was replaced with *Brachiaria* pasture.

In the pasture area, the soil BD increased from 1.03 to 1.43 g cm$^{-3}$, and TP decreased from 59 to 44% in relation to the area of native *Cerradão* vegetation (Table 2). Sugarcane cultivation in a conventional system, with and without burning, increased the soil BD to 1.39 g cm$^{-3}$ and 1.21 g cm$^{-3}$ and reduced the TP to 45%

and 53%, respectively. According to Brady and Weil (2013), it is ideal that 50% of the soil is occupied by pores. All studied layers of the pasture soil present TP lower than ideal (Table 2). The area with raw sugarcane presents porosity greater than 50% only in deeper soil layers (40–50 and 50–60 cm); although the soil with burned sugarcane presented a decrease in TP in relation to the area with native *Cerradão* vegetation, it showed values exceeding 50% in all studied layers. The organic production system restored this soil attribute similarly to those of the native *Cerradão* vegetation in all the studied layers.

The changes in TP and soil BD observed in areas with pasture and conventional sugarcane are due to the external compaction pressures, which alter soil pore space and aeration and increase the risk of soil erosion (Cherubin et al. 2016). The soil with burned sugarcane presented lower density than the soil with the raw cane because in that area, the sugarcane harvest was performed manually, reducing the traffic of agricultural machines compared to the area of raw sugarcane, in which harvest is mechanized. According to Carvalho et al. (2010), the increase in soil BD in areas under conventional cultivation in relation to soils under native *Cerradão* vegetation is due to changes in the soil structure associated with the use of agricultural machinery.

The restoration of TP and soil BD in the area with organic sugarcane can be attributed to soil enrichment with the organic matter, once the greater the amount of organic material in the soil the lower its susceptibility to compaction (Slesak et al. 2017)). Cherubin et al. (2017) observed greater soil resistance to the action of external loads in management systems, which provide greater input of organic matter to the soil since it is the main cementing agent for the formation of soil aggregates. It should be noted that machine traffic in the organic area does not differ from the area with raw sugarcane. Even in this case, the organic area presented soil attributes similar to those of the area with native *Cerradão* vegetation.

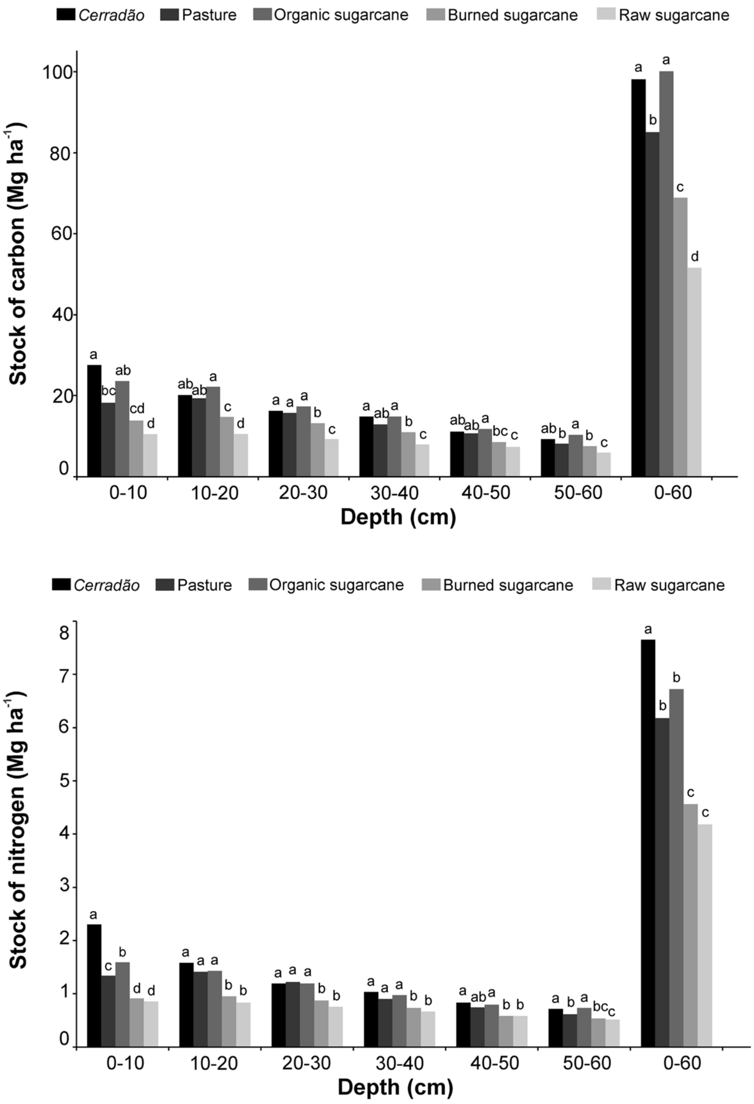
## Total organic carbon

In the area with native *Cerradão* vegetation, the organic carbon contents decreased with depth. The same behavior was observed in areas cultivated with pasture and with sugarcane. The data from this study showed that the substitution of native *Cerradão* vegetation for pasture or sugarcane cultivation significantly reduced soil organic carbon in depths up to 60 cm (Table 2), corroborating the results obtained by Mello et al. (2014). In general, for all analyzed layers, the greatest losses of organic carbon occurred in the area planted with raw sugarcane, followed by the area with burned sugarcane and pasture. The area with organic sugarcane presented total organic carbon (TOC) content lower than the area with native *Cerradão* vegetation only in the 0–10-cm layer. In the 10–20-cm layer, TOC in the organic area was higher and the other layers were statistically similar to those of the *Cerradão* area. However, in relation to soil carbon stock, no difference was observed between the area with organic sugarcane and the area with native vegetation—*Cerradão* (Fig. 2), showing that organic cultivation restored the soil organic carbon, as opposed to the conventional system and pasture.

The capacity of organic sugarcane cultivation to reestablish the organic carbon content in the soil is due to the great contribution of organic matter that enters this production system. As shown in Table 1, in a 5-year cycle, an input of 31,165 kg ha$^{-1}$ of organic matter in the form of organic compost and filter cake was obtained. With the increase in organic matter content, soil physical properties improved, reflecting the soil BD and TP of the area under organic cultivation, which was similar to the area with native *Cerradão* vegetation. The increase in TP favors root growth in deeper layers of the soil, causing them to explore a larger volume of soil, increasing the absorption of water and nutrients, resulting in higher productivity, as verified by Borges et al. (2015) in areas with sugarcane under organic cultivation. Furthermore, the carbon input increases its stock in the soil (Bayer et al. 2006).

Plants that produce a large amount of shoot biomass also produce a high volume of roots, which contributes to increasing the organic matter content at greater depth (Dignac et al. 2017). In this study, it was observed that up to 60 cm deep, the soil organic carbon content increases in the area with organic sugarcane, probably due to the higher volume of roots in this production system. It is worth noting that sugarcane cultivation, both in organic and conventional systems, was inserted in areas previously occupied with pasture. This shows that organic cultivation restored the soil organic carbon that was lost during the replacement of native *Cerradão* vegetation with pasture, which did not occur when the crop was cultivated in a conventional system, which further reduced the soil organic carbon (Table 2 and Fig. 2). Similar results were obtained by Mello et al.

**Fig. 2** Stock of carbon and nitrogen in the soil in *Cerradão*, pasture, organic sugarcane, conventional burned sugarcane, and raw sugarcane



(2014), who verified that the conversion of pastures to sugarcane resulted in carbon losses in the soil.

Areas with native *Cerradão* vegetation and organic sugarcane presented the highest levels of organic carbon and reduced soil BD. In opposition, the area with raw sugarcane presented the lowest levels of organic carbon and greater soil BD. This reinforces the idea of the possible participation of roots in increasing the soil carbon content, because in soils with lower BD, there is greater development of the root system (Dignac et al. 2017). Although the area with burned sugarcane presented lower soil density than the pasture area, in general, it presented the lowest soil carbon content, but when raw sugarcane is compared with burned sugarcane, the organic carbon content was higher in the area with lower soil BD, i.e., burned sugarcane (Table 2). According to Mello et al. (2014), the greater amount of carbon in pasture areas compared to areas with sugarcane can be explained by differences in land management for sugarcane and pasture. Areas with sugarcane are submitted to a 5-year growing cycle with plowing, fertilization, and replanting of sugarcane, while pasture areas remain for long periods without disturbances to the soil.

The best balance between the various soil components and organic matter is usually found in native systems. Thus, systems that reproduce soil conditions as close as possible to native systems are the most sustainable and therefore more appropriate for plant production (Tivet et al. 2013). It is important to note that the effect of organic management on soil BD and TP was noticeable up to 60 cm deep, indicating that good aeration of the soil allows for development of the roots in deeper soil layers, enriching it with organic matter, once the increased organic matter in the deeper soil layers is mainly due to the contribution of roots (Dignac et al. 2017, Tivet et al. 2013).

### Total soil nitrogen

This study showed that there were losses of nitrogen in the soil due to the substitution of native *Cerradão* vegetation for the implantation of grazing and sugarcane cultivation (Table 2 and Fig. 2). The substitution of native *Cerradão* vegetation for pasture resulted in a significant reduction in soil nitrogen contents and stocks. This suggests that the conversion of pasture areas to sugarcane reduces total soil nitrogen, but the conversion of pasture areas to sugarcane cultivation in the organic system promotes the recovery of total nitrogen contents, so that the soil nitrogen stocks of the organic crop were similar to those of the area under native *Cerradão* vegetation, except in the 0–10-cm layer. These data corroborate those obtained by Anaya and Huber-Sannwald (2015) in a long-term study in areas cultivated with sugarcane, without the use of burnings, fertilizers, and soil cultivation and with no removal of the crop residues (similar to the area of organic cultivation). These authors observed that the substitution of rainforest by sugarcane cultivation decreased the soil nitrogen stock in the 0–10-cm layer but no significant differences in the 10–20-cm layer were observed.

The greater losses of nitrogen than carbon in the soil presented in this study corroborate the work of Anaya and Huber-Sannwald (2015) and Franco et al. (2015). According to these said authors, this can be attributed to a relatively lower N input into soils cultivated with sugarcane when compared to soils in areas under native Cerrado vegetation, due to a lower concentration of N in the sugarcane litter (6.6 mg $g^{-1}$) than the levels observed in forest litter (17.7 mg $g^{-1}$).

The higher content of soil nitrogen in the area under organic cultivation compared to the areas cultivated in the conventional system can be attributed to the non-application of nitrogen fertilizers, which can favor biological nitrogen fixation, increasing the nitrogen stocks in the soil. Urquiaga et al. (2012) studied soils cultivated with sugarcane up to 60 cm deep and observed increases in nitrogen stocks in the soil in areas not fertilized with nitrogen, suggesting the entry of this nutrient into the system through biological nitrogen fixation.

## Conclusions

This study is one of the first to show that sugarcane cultivation in an organic system restores carbon stocks, soil BD, and soil TP to levels similar to those of an area with native *Cerradão* vegetation in the studied depths of up to 60 cm. The conventional systems with and without burning of straw caused negative changes in the soil attributes, reducing nitrogen and total organic carbon contents of the soil, as well as increasing the soil BD and reducing the soil TP. This suggests that the cultivation of sugarcane in organic system is sustainable and may be an alternative to the conventional system with and without burning. The organic system proved to be a viable option for the cultivation of sugarcane in a Cerrado Oxisol, as it improves soil attributes by increasing organic carbon content in the soil and enhances the physical properties of the soil that favor water infiltration and retention. In conclusion, our results suggest that the organic sugarcane cultivation system is recommended for Oxisol in the Cerrado biome.

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