

Chemical characteristics of soil after application of tannery sludge as fertilizer in the sugarcane plant crop

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Abstract

The aim of this study was to examine the effects of applying tannery sludge as fertilizer in the sugarcane plant crop and its impact on soil chemical characteristics. The soil in the experimental area was classified as dystrophic red latosol type (Oxisol). The experiment was set up as a randomized-block design with four replicates, with treatments represented by five doses of tannery sludge (0, 4500, 9000, 13500 and 18000 kg ha⁻¹) plus one treatment with inorganic fertilization (90 kg ha⁻¹ N, 180 kg ha⁻¹ P₂O₅ and 120 kg ha⁻¹ K₂O). Soil chemical characteristics and sugarcane nutrition and production traits were evaluated. Tannery sludge application increased the organic matter, Ca, S and Na contents in the soil layers of 0-0.20 and 0.20-0.40 m. Heavy metal contents in the soil were not influenced by the treatments. Tannery sludge showed the potential to supply important macronutrients, especially at the highest doses tested. Tannery sludge doses between 10000 and 16250 kg ha⁻¹ provided the greatest plant height and diameter and the highest number of stalks. The highest sugarcane yield, 149.55 t ha⁻¹, was obtained with the sludge dose of 18000 kg ha⁻¹.

Keywords: Industrial waste, Nitrogen, Plant nutrition, Recycling, *Saccharum officinarum*.

Introduction

Forage-sugarcane production is an interesting activity for farmers, as this plant constitutes high-quality roughage material to be used during the critical period of pasture production, especially in the Central-West region of Brazil. Moreover, the sugarcane crop could be easily implemented and maintained, producing high-yielding (Landell et al., 2002; Guimarães et al., 2016).

A great part of the Central-West region of Brazil is characterized by typical features of the *Cerrado* biome, with irregular rainfall including long drought periods; low soil organic matter contents; and acid soils of low natural fertility (Crusciol et al., 2016). Thus, to increase the yield of crops grown in those soils, amendments and assertive fertilization are necessary (Sousa et al., 2015). More specifically in the sugarcane crop, N and K are elements of great importance in fertilization (Coleti et al., 2006).

Nitrogen fertilizers are highly demanded by the plant organism and, consequently, in agriculture. Cabrera and Zuaznábar (2010) conducted an experiment in the province of Havana, Cuba, for 27 years, involving three sugarcane

varieties. The varieties were grown for four to five cycles in ratoon fertilized with N doses of 0 to 180 kg ha⁻¹. They concluded that the N requirements differ in each stage, but the yield of the sugarcane plant crop does not respond to N fertilization.

In contrast, in Brazilian conditions, nitrogen fertilization is extremely important for the nutrition, growth and yield of the sugarcane plant crop (Otto et al., 2009; Trivelin et al., 2002).

Because N has a dynamic behavior in the soil and undergoes diverse transformations, its utilization is influenced by the source and mode of application (Vitti et al., 2007). Due to the demanded quantity and cost of nitrogen fertilizers, efficient alternative sources are highly sought after.

Positive results have been observed in the sugarcane plant and in the soil following application of poultry litter waste (Guimarães et al., 2016); composted sewage sludge (McCray, Ji and Ulloa et al., 2017); and steel slag (Prado et al., 2002), which can all be used as fertilizers or even soil amendment agents.

Tannery sludge (TS), a waste from the cattle hide processing industry that contains considerable amounts of organic material and nutrients, has also been tested as an alternative fertilizer source. However, the solid waste and effluent from this industry are characterized by having high levels of heavy metals (Godecke et al., 2012), one of the most important of which is chromium (Cr), posing a threat to environmental and human health. These metals must be properly managed so that their pollution potential can be lessened (Hu et al., 2010).

After successive application of TS at doses up to 20 t ha⁻¹ for four and six years in sandy soils planted with cowpea, Oliveira et al. (2015) and Araújo et al. (2016) observed Cr concentrations of 37 and 246 mg kg⁻¹ in the soil in the respective periods, at the maximum dose. According to Pacheco (2005), the sludge composition varies according to the stage, at which it is extracted.

Several studies have shown gains in plant development and in the yield of species grown in soil treated with tannery sludge (Araújo et al., 2011; Gonçalves et al., 2014; Possato et al., 2014). However, no information exists on the application of this sludge in sugarcane production.

The aim of this study was to examine the effects of using tannery sludge as fertilizer in the sugarcane plant crop and its impact on soil chemical characteristics.

Results and Discussion

Soil properties

The TS doses affected the OM, Ca, S and Na levels ($p < 0.05$) in the 0.00-0.20 and 0.20-0.40-m depth layers (Table 1).

The inorganic fertilization recommended for the crop resulted in lower mean values ($p < 0.05$) than those obtained with the use of TS for the attributes it influenced. This shows the residual effect of this waste on surface and at depths, unlike what happens with the inorganic fertilizer (IF). Prado and Pancelli (2008) used N fertilization in sugarcane at levels up to 200 kg ha⁻¹ and observed changes in the Ca, Mg, H+Al, SB and BS% values only in the 0.00-0.20-m layer at 12 and 18 months of experimentation.

In the 0.00-0.20-m layer, OM responded quadratically to the TS doses, with 30.5 g dm³, at the estimated dose of 12500 kg ha⁻¹. In the 0.20-0.40-m layer, in turn, OM responded linearly; i.e., the highest mean (31.0 g dm³) was obtained with the highest dose, which may be explained by its incorporation on surface in the planting furrow and its leaching through the soil, since the waste was in the liquid state. In the uppermost soil layer, the OM content in the treatment involving IF was equivalent to that obtained in the treatments with zero and 4500 kg ha⁻¹ of TS; i.e., the use of TS doses greater than 9000 kg ha⁻¹ provided an increase in the soil organic matter when compared to IF. Cunha et al. (2016) also observed an increase in soil OM in a tomato crop fertilized with a TS vermicompost and irrigated with domestic wastewater, in addition to increases in CEC and BS%. The sulfate S content in the 0.00-0.20-m layer varied similarly to the OM content, with the TS dose of 12500 kg ha⁻¹ providing the highest values. In the deeper layer; however, there was a trend for a linear increase with the TS doses. The S content of 1.0 g L⁻¹ in TS explains this trend, especially in the subsurface layer, since sulfate is easily leached in tropical soils. Because the sources used in IF

(urea, triple superphosphate and potassium chloride) do not include sulfur, TS provided a higher sulfate S content than IF, in both layers.

The soil Ca content in both layers responded quadratically to the TS doses. In the 0.00-0.20 m layer, the TS dose of 15000 kg ha⁻¹ provided a Ca content of 33.6 mmol_c dm³. In the 0.20-0.40 m layer; however, the maximum Ca concentration was achieved with the dose of 18000 kg ha⁻¹. At those TS doses, the soil Ca content was higher than in the treatment with IF, which shows that Ca did not originate only from triple superphosphate. The application of sludge in the soil at the dose of 18000 kg ha⁻¹ provided 65 kg ha⁻¹ of Ca. Despite this increase in the soil Ca content, neither pH nor base saturation was influenced in either layer, suggesting that this Ca was not bound to any base such as carbonate, for instance.

In both layers, the Ca:Mg ratio varied from 4:1 to 7:1 from the lowest to the highest TS dose. Therefore, irrespective of the dose, the Ca:Mg ratio remained within the adequate range of 1:1 to 10:1 for this crop in *Cerrado* soils (Sousa and Lobato, 2004).

The amount of Mg supplied by the wastes was low—approximately 0.36 kg ha⁻¹ for the highest applied dose (18000 kg ha⁻¹). For this reason, no significant increases were detected in Mg content with the application of TS, when compared to control treatment and IF.

In the surface layer, the soil Na content responded quadratically, whereas in the subsurface layer it responded linearly to the TS doses. The TS dose of 12500 kg ha⁻¹ provided the maximum Na concentrations of 27 mg dm⁻³ in the 0.00-0.20-m layer and 37 g dm⁻³ in the 0.20-0.40-m layer. After 210 days of treatment, TS application left 54 and 74 kg ha⁻¹ of Na at the depths of 0-0.20 and 0.20-0.40 m respectively, which are 1.51 and 1.6 times higher than the Na values obtained with IF (Table 1). Increasing soil Na contents following application of tannery sludge was also observed by Araújo et al. (2016), while they reported a higher value (395 mg dm⁻³), compared to those found in the present experiment, which could be due to fertilization with the waste for six consecutive years.

In the present study, the treatment involving application of 18000 kg ha⁻¹ of sludge provided sodium adsorption ratios (SAR) of 1.4 and 2.2 in the 0-0.20 and 0.20-0.40-m layers, respectively. Konrad and Castilhos (2002) found increasing sludge doses during liming resulted in SAR of 5.8 and 9.4, which they considered high for adequate plant development.

The B, Cu, Fe, Mn, Zn, Ba, Pb and Cr levels were not altered by the treatments (Table 1). The Cr content is described as a hindrance to the use of TS, since this waste contributes to raising the Cr values in the soil and in the plant to toxic levels (Araújo et al., 2015; Araújo et al., 2016; Sousa et al., 2017). However, TS did not contain Cr because the waste was collected before the tanning step, and thus no Cr was added via the basic chromium sulfate product, which explains the results.

Sugarcane leaves properties

The indirect chlorophyll measurement (ICM) in the sugarcane leaves was influenced by the TS doses, but no differences were detected in relation to IF. This variable responded quadratically to the TS doses, with the highest

Table 1. Chemical characteristics of soil planted with sugarcane according to the doses of tannery sludge (TS) and inorganic fertilization (IF) in the 0.00-0.20 and 0.20-0.40-m layers.

Characteristic	TS dose (kg ha ⁻¹)					IF	CV	Equation for doses	R ²
	0	4500	9000	13500	18000				
0.00-0.20-m layer									
pH (CaCl ₂)	5.4	5.5	5.3	5.4	5.5	5.3	2.67	-	-
OM (g dm ⁻³)	24c	28ab	30a	30a	29a	25bc	6.01	$y=-4^{-08}x^2+0.001x+24.286$	0.99**
P (mg dm ⁻³)	3.2b	21.2 ^a	21.2a	19.2ab	23.2a	21.0a	42.41	-	-
K (mmol _c dm ⁻³)	0.9	1.2	0.9	0.9	0.8	0.8	23.39	-	-
Ca (mmol _c dm ⁻³)	29ab	32ab	32ab	34a	33ab	27b	9.36	$y=-2^{-08}x^2+0.0006x+29.14$	0.90**
Mg (mmol _c dm ⁻³)	6.5	5.0	6.2	6.0	5.2	6.0	15.23	-	-
CEC (mmol _c dm ⁻³)	58	60	64	64	64	58	5.27	-	-
BS%	62	64	61	64	64	58	5.11	-	-
S (mg dm ⁻³)	4.0c	5.0bc	6.2ab	8.2a	6.2ab	3.7c	7.41	$y=-2^{-08}x^2+0.0005x+3.657$	0.78**
B (mg dm ⁻³)	0.30	0.22	0.32	0.25	0.25	0.28	21.46	-	-
Cu (mg dm ⁻³)	1.2	1.2	1.1	1.1	1.3	1.3	11.75	-	-
Fe (mg dm ⁻³)	14	14	15	14	14	15	11.52	-	-
Mn (mg dm ⁻³)	3.7	4.0	4.2	4.2	4.2	3.9	13.76	-	-
Zn (mg dm ⁻³)	2.0	2.0	2.1	2.1	2.0	1.5	51.92	-	-
Na (mg dm ⁻³)	21bc	25a	26a	28a	26a	18c	9.59	$y=-4^{-8}x^2+0.001x+21.03$	0.95**
Cr (μg kg ⁻¹)	12	18	17	11	20	18	-	-	-
Ba (μg kg ⁻¹)	171	178	164	187	181	158	-	-	-
Pb (μg kg ⁻¹)	152	243	243	232	236	252	-	-	-
0.20-0.40-m layer									
pH (CaCl ₂)	5.3	5.3	5.1	5.3	5.2	5.3	2.08	-	-
OM (g dm ⁻³)	23c	26bc	27abc	29ab	31a	24c	8.89	$y=0.0004x+23.4$	0.98**
P (mg dm ⁻³)	2.5b	8.2 ^a	8.0a	8.2a	7.0ab	6.2ab	35.65	-	-
K (mmol _c dm ⁻³)	0.8	1.3	0.8	0.8	0.9	1.3	39.67	-	-
Ca (mmol _c dm ⁻³)	24ab	25ab	25ab	27a	26a	22b	5.93	$y=-7^{-9}x^2+0.0003x+23.914$	0.75**
Mg (mmol _c dm ⁻³)	5.7	4.7	4.2	4.7	3.7	5.2	18.57	-	-
CEC (mmol _c dm ⁻³)	53	55	57	58	56	53	8.36	-	-
BS%	57	57	54	56	56	55	6.12	-	-
S (mg dm ⁻³)	6.5b	13.5 ^a	13.2a	13.7a	15.7a	7.2b	21.98	$y=0.0004x+8.8$	0.70**
B (mg dm ⁻³)	0.25	0.23	0.28	0.28	0.26	0.23	19.77	-	-
Cu (mg dm ⁻³)	1.3	1.5	1.4	1.4	1.6	1.4	16.22	-	-
Fe (mg dm ⁻³)	14	15	15	14	15	14	14.32	-	-
Mn (mg dm ⁻³)	3.1	3.3	3.4	3.4	3.4	3.0	9.35	-	-
Zn (mg dm ⁻³)	4.1	4.0	2.5	4.1	4.7	3.1	55.28	-	-
Na (g dm ⁻³)	22b	28ab	28ab	33ab	37a	23b	19.68	$y=0.0008x+22.6$	0.95**
Cr (μg kg ⁻¹)	7	11	9	9	11	10	18.77	-	-
Ba (μg kg ⁻¹)	151	200	178	204	194	180	17.84	-	-
Pb (μg kg ⁻¹)	299	316	286	294	303	307	20.03	-	-

Means followed by common letters in the row do not differ, according to Tukey's test at the 5% probability level.

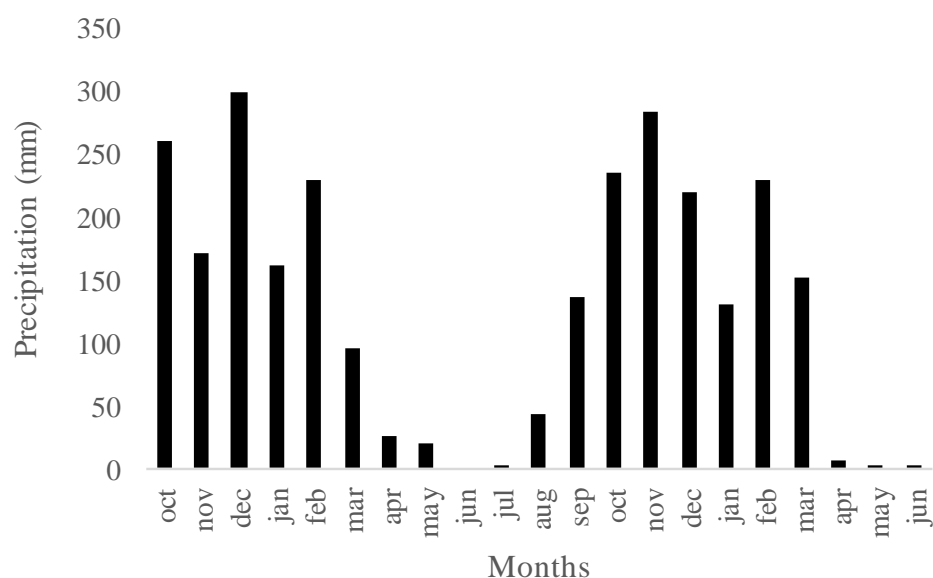


Fig 1. Precipitation data during the experimental period. São Luís de Montes Belos - GO, Brazil.

Table 2. Indirect chlorophyll measurement (ICM) and macro- and micronutrient concentration in the leaves of sugarcane fertilized with levels of tannery sludge (TS) and inorganic fertilization (IF), at 120 days after planting.

Variable	TS dose (kg ha ⁻¹)					IF	CV%	Equation for doses	R ²
	0	4500	9000	13500	18000				
ICM	48.0b	50.5ab	51.0a	51.7a	51.5a	51.2a	2.38	$y=-2^{-08}x^2+0.0005x+48.157$	0.97**
N (g kg ⁻¹)	14c	15b	15b	16a	16a	16a	2.03	$y=-4^{-09}x^2+0.0002x+14.057$	0.92**
P (g kg ⁻¹)	1.1b	1.2ab	1.3a	1.3a	1.3a	1.3a	4.44	$y=-1^{-09}x^2+3^{-05}x+1.0971$	0.98**
K (g kg ⁻¹)	11	10	10	9	10	10	11.87	-	-
Ca (g kg ⁻¹)	5c	6b	6b	7a	6b	6b	6.09	$y=-1^{-08}x^2+0.0003x+4.9714$	0.77**
Mg (g kg ⁻¹)	1.9b	2.1ab	2.4ab	2.5ab	2.6a	2.1ab	11.44	$y=4^{-05}x+1.94$	0.95**
S (g kg ⁻¹)	1.4	1.3	1.3	1.3	1.4	1.4	4.69	-	-
B (mg kg ⁻¹)	15	15	14	14	12	12	14.93	-	-
Cu (mg kg ⁻¹)	7	6	7	7	7	7	9.48	-	-
Fe (mg kg ⁻¹)	68	66	66	66	74	68	7.90	-	-
Mn (mg kg ⁻¹)	33c	38ab	41a	42a	41a	32bc	4.12	$y=-5^{-08}x^2+0.0013x+33$	0.99**
Zn (mg kg ⁻¹)	14	13	12	13	13	14	4.00	-	-
Na (mg kg ⁻¹)	105bc	107abc	110abc	117ab	120a	97c	5.74	$y=0.0009x+103.8$	0.96**

Means followed by common letters in the row do not differ, according to Tukey's test at the 5% probability level. CV: coefficient of variation.

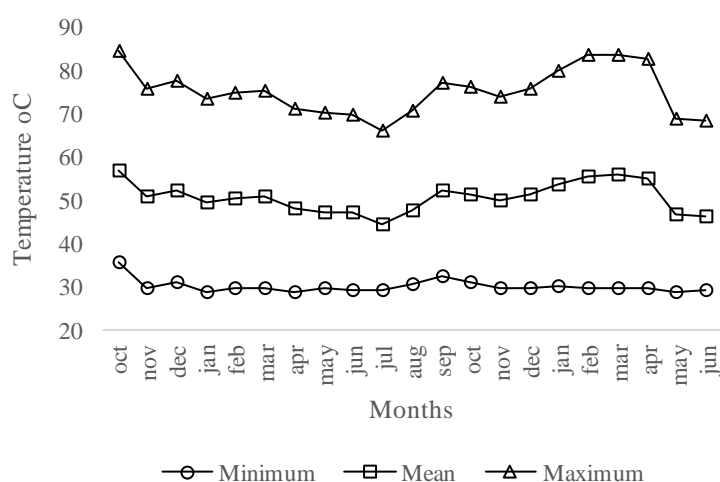


Fig 2. Temperature data during the experimental period. São Luís de Montes Belos - GO, Brazil.

Table 3. Height and diameter of sugarcane stalks, evaluated at 210, 300, 390 and 480 days after planting (DAP), number of stalks, plant dry matter and stalk yield assessed at the end of the cycle according to the doses of tannery sludge (TS) and inorganic fertilization (IF)

Evaluation time	TS dose (kg ha ⁻¹)					IF	CV	Equation for doses	R ²
	0	4500	9000	13500	18000				
Plant height (cm)									
210 DAP	135b	175a	181a	196a	193a	184a	8.58	$y=-3^{-07}x^2+0.0079x+137.6$	0.96**
300 DAP	142c	180b	196ab	198a	201a	190b	4.25	$y=-3^{-07}x^2+0.0084x+144.2$	0.98**
390 DAP	153c	192ab	202ab	205ab	209a	190b	3.84	$y=-3^{-07}x^2+0.0077x+156.2$	0.95**
480 DAP	210b	241a	248a	254a	251a	240a	3.70	$y=-2^{-07}x^2+0.0065x+211.9$	0.97**
Stalk diameter (mm)									
210 DAP	23.7b	26.5a	27.0a	26.5a	25.7ab	25.5ab	3.85	$y=-3^{-08}x^2+0.0006x+23.94$	0.95**
300 DAP	25.2b	28.0ab	27.7ab	28.7a	27.7ab	28.0ab	5.03	$y=-2^{-08}x^2+0.0005x+25.456$	0.87**
390 DAP	25.7	29.0	29.6	29.2	29.2	28.5	6.86	$y=-3^{-08}x^2+0.0006x+26.02$	0.91**
480 DAP	26.2	29.4	29.8	29.5	29.7	29.0	5.37	$y=-2^{-08}x^2+0.0006x+26.54$	0.88**
Number of stalks per meter									
	20b	25a	26a	26a	24ab	25a	7.78	$y=-5^{-08}x^2+0.0012x+20.26$	0.97**
Shoot dry matter (g plant ⁻¹)									
End of cycle	363b	388b	456a	477a	479a	480a	6.64	$y=0.071x+368.4$	0.89**
Stalk yield (t ha ⁻¹)									
	78.5d	101.2cd	114.5bc	135.7ab	147.5a	149.7a	10.85	$y=0.0038x+81.15$	0.98**

Means followed by common letters in the row do not differ, according to Tukey's test at the 5% probability level. CV: coefficient of variation.

value obtained with the application of 12500 kg ha⁻¹ (Table 2). In N-deficient conditions, increases in the TS dose lead to an increase in chlorophyll content, intensifying the green color of the leaves.

The ICM was positively correlated with the foliar N content measured at the same time ($r=0.93$), indicating that the use of the chlorophyll meter may be a good option to estimate the N content in the leaves.

The foliar concentrations of N, P, Ca, Mg, Mn and Na were influenced by the fertilization source (Table 2). The N, P and Mg contents in the leaves, resulted in similar concentrations after using TS and IF. The foliar concentrations of N, P and Ca responded quadratically to the TS doses, with maximum expression occurring at the doses of 18000 kg ha⁻¹ for N and 15000 kg ha⁻¹ for P and Ca, whereas the Mg content rose linearly up to the TS dose of 18000 kg ha⁻¹, as shown by the equations (Table 2). These results suggest the potential of TS to supply three important macronutrients, especially at the highest tested doses.

The average Mn contents in the leaves were higher in the treatments with TS doses greater than 9000 kg ha⁻¹, compared to the treatment with IF. The foliar concentrations of Mn responded quadratically to the TS doses, with a maximum value of 41.5 mg kg⁻¹ achieved at the TS dose of 13000 kg ha⁻¹. Sodium, in turn, showed a linear response; i.e., the Na contents in the sugarcane leaves increased along with the applied TS dose.

The Na concentration in the soil followed the pattern seen in the leaves (Table 1). This finding evidences the potential of TS as a supplier of Na to the soil and to the plant, which is a consequence of the products used during the cleaning/hydration processes performed at the tannery. However, the Na content in the soil and in the plant is a matter of concern from the plant fertility and nutritional standpoints, as this element competes with the other nutrients mainly K, in addition to compromising the soil physical properties (Oliveira et al., 2002). In terms of animal nutrition, considering that animals are the final consumer, Na is a regulator of mineral-supplement intake. Thus, when using this sugarcane variety, the producer should adjust the diet aiming at nutritional efficiency (Nicoldemo, 2001).

Morphological characteristics

Regarding height development in the sugarcane plants, fertilization both in organic form, via TS, or inorganic, provided equal results at 210 and 480 DAP. However, at 300 and 390 DAP, organic fertilization with the highest dose of TS resulted in longer stalks than inorganic fertilization (Table 3). Plant height showed a quadratic response to the TS doses at all evaluated times, with maximum values estimated at the TS doses of 13167, 14000, 12833 and 16250 kg ha⁻¹ at 210, 300, 390 and 480 DAP, respectively. Castro et al. (2014) tested N doses of up to 160 kg ha⁻¹ in sugarcane ratoon and also observed a quadratic response, with 2.5-m-long plants under the N dose of 87.5 kg ha⁻¹ at harvest. However, in the present study, although the maximum height of 2.7 m was obtained at the TS dose corresponding to 60 kg N ha⁻¹ as shown by the equation, the cultivars used in the experiments were different and TS supplied not only N but also other nutrients, as cited in the methodology section. Mean stalk diameter did not differ between inorganic fertilization and the TS doses at any of the evaluation dates.

Stalk diameter responded quadratically to TS, with maximum values attained at the doses of 10000, 12500, 10000 and 15000 kg ha⁻¹ at 210, 300, 390 and 480 DAP, respectively. Despite the statistical differences, the obtained values are quantitatively similar to those found by Morais et al. (2017), who worked with 10 cultivars of sugarcane in plant crop.

The TS dose that provided the highest number of stalks (27 m⁻¹) was 12000 kg ha⁻¹, which did not differ from the result obtained with IF. Moraes et al. (2016) tested a dose equivalent to 27 kg ha⁻¹ N and obtained an approximate yield of 14.9 stalks m⁻¹, which is lower than the average obtained in our study, but is explained by the amount of N used, despite the TS doses (Table 2).

Sugar cane yield

Shoot dry matter accumulation in the sugarcane plant rose linearly with the TS doses. Inorganic fertilization provided higher results for this variable than control treatment and the lowest TS dose (Table 2).

Stalk yield also increased linearly, with 3.8 t ha⁻¹ gained at every ton of TS applied. The yields obtained with IF were higher than those attained with control treatment and with the TS doses of 4500 and 9000 kg ha⁻¹.

Tannery sludge doses between 13500 and 18000 kg ha⁻¹ and IF, which supplied at 33, 66 and 90 kg ha⁻¹ N, respectively, resulted in the highest, though equivalent, stalk yield. In this way, the use of TS proved efficient, considering its lower N supply compared to that of IF.

The highest yield of 149.55 t ha⁻¹ was attained at the TS dose of 18000 kg ha⁻¹, suggests additional responses (Table 2). Nonetheless, Castro et al. (2014) and Oliveira et al. (2017) evaluated N doses of up to 160 kg ha⁻¹ and obtained maximum yield with the application of 145 and 130 kg ha⁻¹, which provided 119 and 100 t ha⁻¹, respectively.

Although the threshold of response to N is a point to be noted. Restrepo et al. (2016) found that organic sources of nitrogen are appropriate for supplying N to the sugarcane crop, since the supply of approximately 80 kg ha⁻¹, from organic and inorganic sources, resulted in the yields of 214.5 and 177.25 t ha⁻¹, showing the marked impact of organic over inorganic fertilization.

Although stalk yield raised linearly with the TS doses, the other evaluated traits (e.g., height, stalk diameter and number of stalks per meter) and soil chemical characteristics (e.g., OM, Ca, S and N) responded quadratically to the treatments, demonstrating the importance of care in the use of this waste as a nutrient source. Therefore, despite its potential to increase stalk yield in sugarcane, the use of high TS doses may compromise plant development and the availability of these nutrients in the soil. On this basis, the quantity to be used should be carefully established so that benefits to the soil and to the plant can be enhanced.

Materials and Methods

Area description

The experiment took place at *Fazenda Escola*, State University of Goiás, located in São Luís de Montes Belos - GO, Brazil (16° 31' 30" S and 50° 22' 20" W; 579 m altitude).

The soil in the experimental area was classified as a dystrophic red latosol (Oxisol) with clayey texture (EMBRAPA, 2013). At the start of the experiment, the following results were obtained in the soil chemical analysis: pH (CaCl₂) 5.8; 48 g dm⁻³ of organic matter (OM); 5 mg dm⁻³ of P (resin); 22, 1.1, 45 and 7 mmol_c dm⁻³ of H⁺+Al⁺³, K, Ca and Mg, respectively; and 71% base saturation (BS) in the 0.00-0.20 m layer and pH (CaCl₂) 5.2; 29 g dm⁻³ of OM; 5 mg dm⁻³ of P (resin); 18, 0.5, 33 and 3 mmol_c dm⁻³ of H⁺+Al⁺³, K, Ca and Mg, respectively; and 67% BS in the 0.20-0.40-m depth layer.

According to the Köppen classification, the climate in the region is an Aw type, with an average temperature of 23.5 °C, ranging from 20.7 °C (June) to 25.0 °C (December). The average annual precipitation is 1,785 mm, 87%, of which is concentrated between the months of October and March. The region has an average precipitation deficit period of four months (Alvares et al., 2014).

Precipitation and temperature data collected during the experimental period are presented in Figures 1 and 2.

Experimental design and statistical analysis

The experiment was set up as a randomized-block design with four replicates. The treatments were represented by five doses of tannery sludge (0, 4500, 9000, 13500 and 18000 kg ha⁻¹) plus a treatment with inorganic fertilization (90 kg ha⁻¹ N, 180 kg ha⁻¹ P₂O₅ and 120 kg ha⁻¹ K₂O).

In the treatment with inorganic fertilization, 30 kg of N (as urea) were applied at planting and the remaining quantity (60 kg ha⁻¹) was applied as topdressing at 40 days after planting. Phosphorus and potassium were applied in the forms of triple superphosphate and potassium chloride, respectively,

The treatments including tannery sludge were complemented with the same amounts of phosphorus and potassium used in the treatment with inorganic fertilization. Plots were composed of five 6-m-long plant rows spaced 1.5-m apart, in a total area of 45 m². The usable area in the plot was 18 m², comprising the three 4-m-long central rows. One line of sugarcane on each side and 1.0 m at each extremity of the plot were considered the bordering area.

Collected data were subjected to analysis of variance and regression test for the TS doses and means test (Tukey's) to compare the sludge doses and inorganic fertilization. Both tests were performed using Sisvar statistical software (Ferreira, 2014).

Plant and sludge description

Sugarcane variety IAC86-2480 was used in the experiment, as an option for forage purposes. The nutritional management for the sugarcane was determined based on recommendations by Sousa and Lobato (2004) for the *Cerrado* region.

The tannery sludge was acquired from the Progresso tannery, located in Nazário - GO, Brazil, which performs the liming procedure, after the cleaning/hydration processes. Liming is a process for the removal of hairs or residues attached to the skin, using products based on sodium, sulfur and phosphorus such as sodium chloride, caustic soda, sulfates and organophosphates to aid in this cleaning step. After sludge application no other treatment was added. The

tannery sludge presented the following chemical characteristics: 3.6, 0, 0.2, 3.7, 0.02, 1.0, 10 and 6 g L⁻¹ of N, P, K, Ca, Mg, S, OM and organic carbon, respectively; 14300, 0, 9, 0 and 3 mg L⁻¹ of Na, Cu, Fe, Mn and Zn, respectively; C/N ratio of 2, density of 1.02 g mL⁻¹ and pH 13. The following results were obtained in the analysis of heavy metals present in the sludge: <30, 639, <6, 28, 63, <5, <9, 30, <8, 908 and <4 µg L⁻¹ of As, Ba, Cd, Cr, Cu, Mo, Ni, Pb, Se, Zn and Hg. The methodology of USEPA (1998) was adopted to quantify the heavy metals present in the sludge.

Experiment implantation

The soil was prepared by plowing and disking. Subsequently, 0.30-m-deep holes were dug, spaced 1.5 m apart. Both the tannery sludge and the inorganic fertilizer were applied in the furrows in November 2012. The sugarcane plant crop was planted on the same day using whole stalks arranged inside the holes at the density of 20 buds per meter.

The cultivation treatments applied to the sugarcane were weed control and topdressing, followed by harvesting at 18 months after planting.

Soil evaluation

Soil was collected from the depths of 0.00-0.20 m and 0.20-0.40 m at 210 days after the treatments were applied, for chemical characterization and determination of heavy metal contents. Five simple soil samples were collected per layer and per plot, using a probe-type auger. These samples were homogenized in a bucket and packed in labeled plastic bags. After being dried and passed through a 2-mm sieve, the soil samples were sent to the laboratory for determination of fertility. The following variables were analyzed: pH, OM, P, K, Ca, Mg, S, H+Al, sum of bases, CEC, BS%, B, Cu, Fe, Mn and Zn. The sodium concentration in the soil was as determined by the method proposed by Raji et al. (2001). Heavy metals were determined by the ICP-AES method.

Plants evaluation

A ClorofiLOG CFL 1030 chlorophyll meter was used for an indirect chlorophyll measurement (ICM) in the +3 leaves (third leaf with a visible sheath insertion region), at 120 days after planting (DAP). Thirty plants were selected per plot and one leaf from each plant was read in the middle portion, without the main nerves, as recommended by Oliveira (2004).

The same leaves collected for the ICM were used in the analysis of nutritional content. The tips and bases of those leaves were cut off and the central portion of 0.40 m (disregarding the nerves) was dried in a forced-air oven (65 °C) for 72 h. Afterwards, the material was ground and the concentrations of N, P, K, Ca, Mg and S were determined by the methods described by Malavolta et al. (1997).

Plant height was measured at 120, 210, 300, 390 and 480 DAP, whereas stalk diameter was measured at 210, 300, 390 and 480 DAP. Height was measured from the base of the stalk to the insertion of the +1 leaf (first leaf with a visible sheath insertion region) using a tape measure. Stalk diameter was measured using a caliper on the central internode of the stalk, at approximately 8 cm above the soil, in 10 plants per usable area.

The number of stalks was quantified at 540 DAP, by counting them along four linear meters within the usable plot area. After the stalks were counted, the plants were harvested and weighed and stalk yield was determined in kg ha⁻¹. Whole plants were also harvested and sectioned and the material was then weighed and dried in a forced-air oven at 65 °C for 72 h to later determine shoot dry matter.

Conclusions

Application of tannery sludge provided an increase in the soil OM, Ca, S and Na contents in the 0-0.20 and 0.20-0.40 m layers. At the applied doses, tannery sludge provided greater development of the sugarcane plant compared to mineral fertilization, without resulting in chromium accumulation in the soil. The tannery sludge dose of 18000 kg ha⁻¹ provided the maximum yield (149.55 t ha⁻¹) of sugarcane.

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