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Vinasse improves soil quality and increases the yields of soybean, maize, and pasture[1]

Vinhaça melhora a qualidade do solo e aumenta a produtividade da soja, milho e pastagem

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HIGHLIGHTS:

Application of vinasse in the soil can replace potassium mineral fertilization for yield gains in crops.
The dehydration of vinasse proved to be viable to reduce the volume applied with improved agronomic performance.
After two years of vinasse application there was gain in organic carbon in the soil, and reduction in microbial biomass carbon.

ABSTRACT: Vinasse can be a suitable alternative to improve soil attributes and increase crop yield. This study evaluated the effect of fresh and concentrated vinasse on soil chemical and biological attributes and on the yields of soybean, maize, and pasture. The design was in randomized blocks with four replications and five treatments: T1 (250 kg ha^{-1} 08:28:16 at sowing + 40 kg ha^{-1} K_2O at topdressing); T2 (250 kg ha^{-1} 08:28:16 at sowing + 2450 L ha^{-1} of fresh vinasse at topdressing); T3 (250 kg ha^{-1} 08:28:16 at sowing + 190 L ha^{-1} of concentrated vinasse at topdressing); T4 (4100 and 2450 L ha^{-1} of fresh vinasse at sowing and topdressing, respectively); T5 (315 and 190 L ha^{-1} of concentrated vinasse at sowing and topdressing, respectively). These treatments were applied during the soybean growth in 2017 and 2018. After soybean harvesting and before maize and pasture in 2018, soil chemical and biological attributes were assessed. Vinasse increased the concentrations of carbon and phosphorus, while decreasing those of potassium and sulfur. Vinasse reduced the carbon concentration of the microbial biomass by 50%, but increased the nitrogen concentration of the microbial biomass by 67%. The activity of dehydrogenase was higher with the application of fresh vinasse. Application of vinasse for two years improves soil chemical and biological attributes and increases the yields of soybean, maize, and pasture.

Key words: *Urochloa brizantha*, sugarcane residue, soil microbiology, soil fertility

RESUMO: A vinhaça pode ser uma alternativa adequada para melhorar os atributos do solo e aumentar a produtividade das culturas. Este estudo avaliou o efeito da vinhaça fresca e concentrada nos atributos químicos e biológicos do solo e na produtividade da soja, milho e pastagem. O delineamento foi em blocos ao acaso com quatro repetições e cinco tratamentos: T1 (250 kg ha^{-1} 08:28:16 na semeadura + 40 kg ha^{-1} K_2O na cobertura); T2 (250 kg ha^{-1} 08:28:16 na semeadura + 2450 L ha^{-1} de vinhaça fresca em cobertura); T3 (250 kg ha^{-1} 08:28:16 na semeadura + 190 L ha^{-1} de vinhaça concentrada em cobertura); T4 (4100 e 2450 L ha^{-1} de vinhaça fresca na semeadura e cobertura, respectivamente); T5 (315 e 190 L ha^{-1} de vinhaça concentrada na semeadura e cobertura, respectivamente). Esses tratamentos foram aplicados na cultura da soja em 2017 e 2018. Após a colheita da soja e antes do milho e pastagem em 2018, foram avaliados os atributos químicos e biológicos do solo. A vinhaça aumentou a concentração de carbono e fósforo, enquanto diminuiu o potássio e o enxofre. A vinhaça reduziu a concentração de carbono da biomassa microbiana em 50%, mas aumentou a concentração de nitrogênio na biomassa microbiana em 67%. A atividade da desidrogenase foi maior com a aplicação de vinhaça fresca. A aplicação de vinhaça por dois anos melhora os atributos químicos e biológicos do solo e aumenta a produtividade da soja, do milho e das pastagem.

Palavras-chave: *Urochloa brizantha*, resíduo de cana-de-açúcar, microbiologia do solo, fertilidade do solo

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Introduction

The industrial processing of sugarcane generates a specific organic waste known as vinasse, which has low pH and high concentrations of volatile solids, organic and inorganic elements, mainly potassium (K) (Có Júnior et al., 2008). Particularly, K is an essential nutrient to plants and, thus, the use of vinasse as biofertilizer has been stimulated as an alternative to increase the availability of K (Prado et al., 2014). In addition, the application of vinasse increases the concentrations of organic matter and N in the soil (Moran-Salazar et al., 2016). Consequently, vinasse has been recognized as important to improve soil attributes (Aquino et al., 2015) and could increase crop yield (Oliveira et al., 2014). Indeed, previous studies have reported the potential of vinasse in improving the yields of sugarcane (Cardin et al., 2016), spinach and barley (Mahmoud et al., 2019).

Although these previous studies reported improved crop yield after the application of vinasse, there is no information about the potential of this waste on plant species under crop rotation. In Brazil, an important crop rotation strategy includes soybean, maize, and pastures under the no-tillage system, and this strategy has contributed to improving the soil and crop yield (Silva et al., 2020). Therefore, the use of vinasse could partly or totally support the growth and yield of soybean, maize, and pastures with consequent decrease in the dependence on mineral fertilizer.

Here, we hypothesized that the application of vinasse could positively influence soybean, maize, and pastures under crop rotation. In addition, the use of fresh and concentrated vinasse could differently affect soil chemical and biological attributes. Thus, this study aimed to evaluate soil chemical and biological attributes and the yields of soybean, maize, and pasture after the application of both fresh and concentrated vinasse for two years.

Material and Methods

This experiment was conducted at the Experimental Field located at Presidente Bernardes, São Paulo state, Brazil (22° 28’ -25’ S and 51° 67’ -88’ W, 430 m), between 2016/2017 and 2017/2018 (for two crop seasons). The region has annual average temperatures of 24.3 °C and rainfall of 1550 mm. Figure 1 shows maximum/minimum temperatures and rainfall recorded during the experiment.

The soil of the area is classified as Oxisol, of sandy texture. Before this experiment, the area had been occupied by pasture (*Urochloa brizantha*) for five years and the soil had the following chemical characteristics: organic matter - 7.4 g kg^{-1}; pH ($CaCl_2$) - 5.7; P - 10.1 mg kg^{-1}; K - 51.6 mg kg^{-1}; Ca - 14 $mmol_c$ kg^{-1}; Mg - 7.9 $mmol_c$ kg^{-1}; and base saturation (V) - 63%. In this experiment, two types of vinasse (fresh and concentrated) were obtained from a sugar-ethanol industry located at Presidente Prudente, SP, Brazil. The concentrated vinasse (reduction of volume about 70%) was obtained by evaporative dehydration process after heating in stainless steel tanks. Both fresh and concentrated vinasses were subjected to chemical analysis according to LANARV (1988) (Table 1).

The experimental design was randomized blocks with four replicates. The experiment was designed with five treatments: T1 (250 kg ha^{-1} 08:28:16 at sowing + 40 kg ha^{-1} K_2O at topdressing); T2 (250 kg ha^{-1} 08:28:16 at sowing + 2450 L ha^{-1} of fresh vinasse at topdressing); T3 (250 kg ha^{-1} 08:28:16 at sowing + 190 L ha^{-1} of concentrated vinasse at topdressing); T4 (4100 and 2450 L ha^{-1} of fresh vinasse at sowing and topdressing, respectively); T5 (315 and 190 L ha^{-1} of concentrated vinasse at sowing and topdressing, respectively). The doses of both fresh and concentrated vinasse were estimated according to their concentration of K and the requirements by the crops (van Raij et al., 1997). The treatments were applied during the sowing of soybean in 2017 and 2018, in the second half of

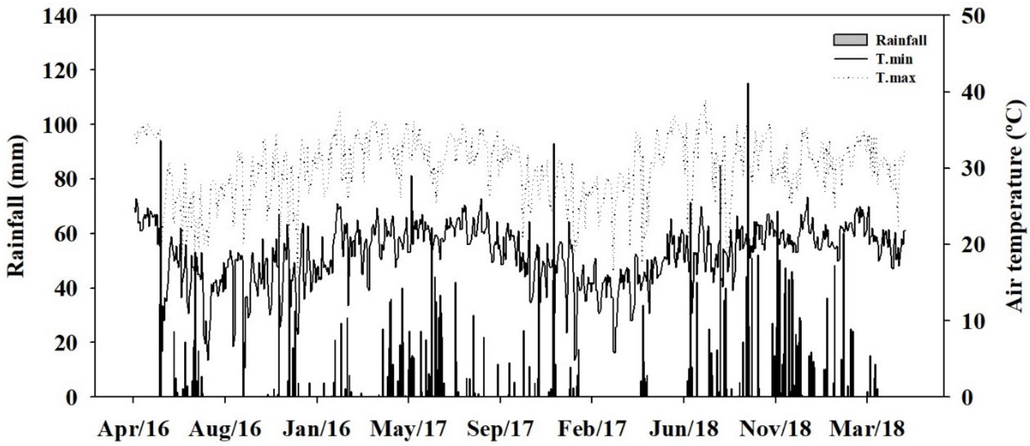

Figure 1. Rainfall and maximum/minimum air temperatures during the study. Presidente Bernardes, São Paulo, 2016-2018

Table 1. Chemical composition of fresh and concentrated vinasses

	pH	Macronutrients						Micronutrients			
		N	P	K	Ca	Mg	S	Cu	Fe	Mn	Zn
		($g L^{-1}$)						($mg L^{-1}$)			
FV – 2017	3.8	0.2	0.03	0.6	0.3	0.1	0.1	1.2	18	1.3	0.8
CV – 2017	3.8	0.8	0.14	4.3	1.6	1.2	0.3	2.3	119	18	3.4
FV – 2018	3.9	0.3	0.05	8.8	2.1	2.4	0.1	94.3	1373	444	164.3
CV – 2018	3.9	1.8	0.29	113.8	8.1	13.8	0.8	234.7	6830	1649	16.7

FV - Fresh vinasse; CV - Concentrated vinasse

November each year. Each experimental plot was 35 m^2 and the treatments were applied uniformly between rows of the soybean crop. In the application of vinasses, the amounts were diluted in 20 L of water and distributed uniformly, manually, and homogenously to the soil. The topdressing application for all treatments was done at 35 days after soybean emergence.

In 2016 and 2017, seeds of soybean were sown at spacing of 0.45 m between rows (15 seeds m^{-1}). After soybean harvesting, seeds of maize were sown at spacing of 0.70 m between rows (4 seeds m^{-1}). Maize plants were intercropped with *Urochloa brizantha* (variety Marandu), whose seeds were distributed on the soil surface in the amount of 5 kg of seeds ha^{-1}. The grain yields were determined at the R8 stage. Soybean yield, at 120 days after sowing (R8 stage), was evaluated in 6 m (three rows of plants). Maize and pasture yields, at 130 days after sowing, were evaluated in 9 m (three plants per row). Soybean and maize yields (grain yield at 13% moisture) were estimated per area, in four replicates. Pasture yield was evaluated by dry biomass per area (65% moisture).

Soil samples were taken, in the third year (2018), during the soybean harvesting and before maize and pasture sowing. Soil samples (500 g) were collected at 0-20 cm depth and six subsample points were taken together as a composite sample per plot. Portions of soil samples (300 g) were stored in bags and kept at 4 °C for microbial analysis. For chemical analysis, portions of soil samples (200 g) were air-dried, sieved (2 mm) and homogenized.

Soil chemical attributes were determined according to Tedesco et al. (1995). Briefly, soil pH was estimated in water (1:2.5 v:v) and measured using a pH meter. Available P and exchangeable K and Ca were extracted using the Mehlich-1 extraction method and determined according to Tedesco et al. (1995). Total organic C (TOC) was determined by wet combustion using a mixture of 5 mL of 0.167 mol L^{-1} potassium dichromate and 7.5 mL of concentrated sulfuric acid under heating (170 °C for 30 min) (Yeomans & Bremmer, 1988).

Microbial biomass C (MBC) and N (MBN) were estimated using the chloroform fumigation-extraction method according to Vance et al. (1987) and Brookes et al. (1985), respectively. The extraction efficiency coefficients of 0.38 and 0.45 were used to convert the difference in C and N between fumigated and non-fumigated soils into MBC and MBN, respectively. The microbial quotient (qMic) was calculated as the ratio of MBC to TOC, expressed as percentage (%). Dehydrogenase (DHA) activity was determined according to Casida et al. (1964) by using 2,3,5-triphenyl-tetrazolium chloride as substrate.

After the normality and homogeneity tests, the data were subjected to ANOVA. Statistical analysis was performed by analysis of variance and a comparison of means by Tukey's test at $p \leq 0.05$. For the yield data, the year was considered as a factor. As there was interaction, the data was presented separately. Sisvar statistical software was used.

Results and Discussion

Crop yield varied between treatments according to the different plant species (Table 2). In 2017 and 2018, soybean had higher yield in T5, while maize had higher yield in T3 and T4 (2017), and in T2, T3, T4, and T5 (2018). The pasture had higher production of biomass in T4 and T5 (2017), and in T5 (2018). In all plant species, the lowest values of yield (soybean and maize) and biomass (pasture) were found in T1.

Table 2. Yields of soybean (grain), maize (grain), and pasture (biomass) in soils after the application of fresh and concentrated vinasses

	Soybean	Maize	Pasture
		(kg ha^{-1})	
		2017	
T1	1562 c	4958 c	2862 c
T2	1875 b	5531 b	3226 b
T3	1794 b	6488 a	3091 b
T4	1863 b	6981 a	3534 a
T5	2118 a	5721 b	3433 a
CV%	11.9	13.5	12.8
		2018	
T1	2200 c	5541 b	2448 d
T2	2361 c	6078 a	3293 c
T3	2595 b	6374 a	3681 b
T4	2482 bc	6298 a	3740 b
T5	2862 a	6773 a	4604 a
CV%	12.9	15.8	10.8
p value			
Treatment	0.0011	0.0458	0.0054
Year	0.0058	0.0180	0.0220
Treatment*Year	0.0270	0.080	0.0250

In each column, means with the same letters do not differ significantly by the Tukey test ($p \leq 0.05$). T1 (250 kg ha^{-1} 08:28:16 at sowing + 40 kg ha^{-1} K_2O at topdressing); T2 (250 kg ha^{-1} 08:28:16 at sowing + 2450 L ha^{-1} of fresh vinasse at topdressing); T3 (250 kg ha^{-1} 08:28:16 at sowing + 190 L ha^{-1} of concentrated vinasse at topdressing); T4 (4100 and 2450 L ha^{-1} of fresh vinasse at sowing and topdressing, respectively); T5 (315 and 190 L ha^{-1} of concentrated vinasse at sowing and topdressing, respectively)

Soil pH and Ca did not vary between treatments (Figure 2). The concentration of P was higher in T5 (Figure 2A), while K concentration increased in T1 and T2, with a significant difference for treatments that received the highest dose of vinasse (Figure 2C). The concentration of Mg was higher in T3, while S concentration was higher in T1, T2, and T3 (Figure 2B). Soil MBC and MBC:MBN ratio were higher in T1, while MBN was higher in T2 and T3 (Figures 3A and C). DHA expressed greater enzymatic activity in T4 as compared to T1 (Figure 3D). TOC concentration was higher in T2, T3, T4, and T5, while MBC:TOC ratio was higher in T1 (Figures 4A and B).

Soybean yield increased significantly when concentrated vinasse was applied. However, maize yield increased in treatments with both vinasses, alone and associated with chemical fertilization, as compared to chemical fertilization. Gonzalez et al. (2018) also verified increase in soybean yield after vinasse application, but it depends on the applied residue dose. Regarding the pasture biomass, it was increased initially in treatments with both vinasses, and later with concentrated vinasse.

Interestingly, the concentration of P was significantly higher in the treatment with exclusive application of concentrated vinasse (T5) and it could partly explain the better performance shown by soybean, maize and pastures. This higher concentration of P in the soil can be due to the high concentration of this element in the concentrated vinasse. According to Naspolini et al. (2017), during the concentration of vinasse, the temperature favors the mineralization of P, thereby increasing its concentration in the waste. This result agrees with that reported by Silva et al. (2015), who observed

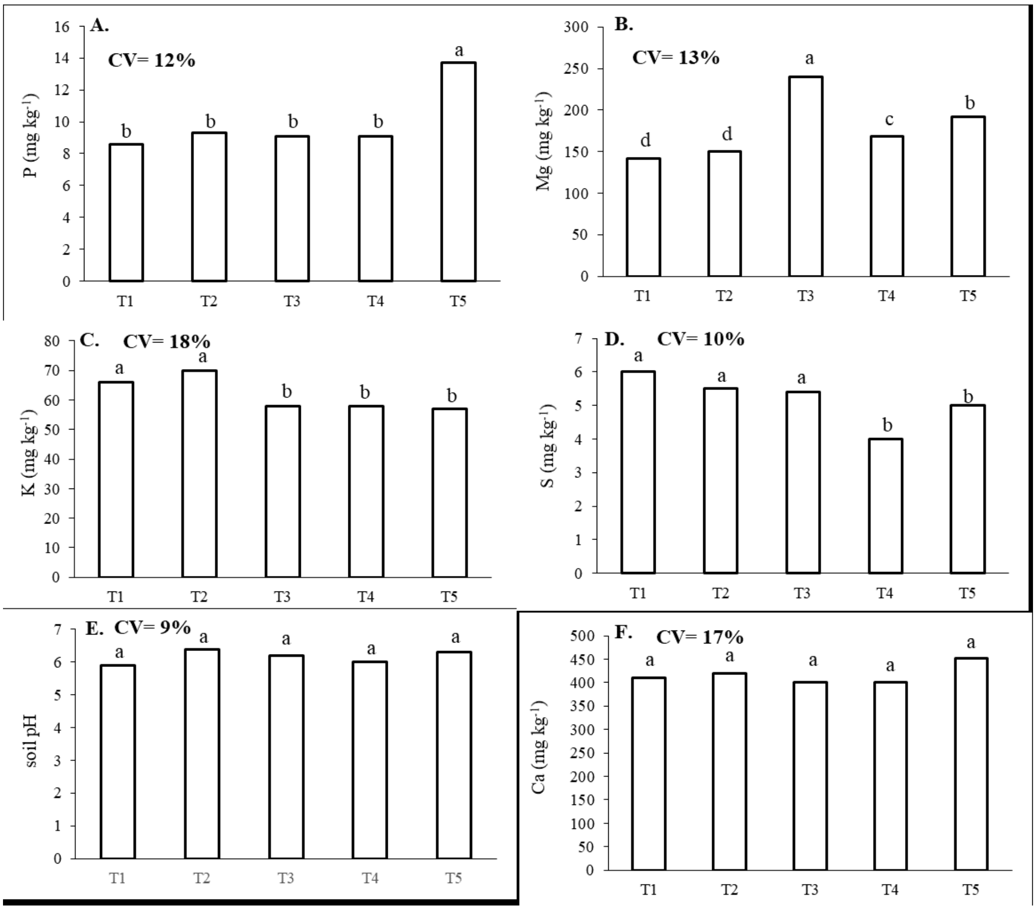

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Figure 2. Values of P (A), Mg (B), K (C), S (D), pH (E), and Ca (F) in soils after the application of fresh and concentrated vinasses

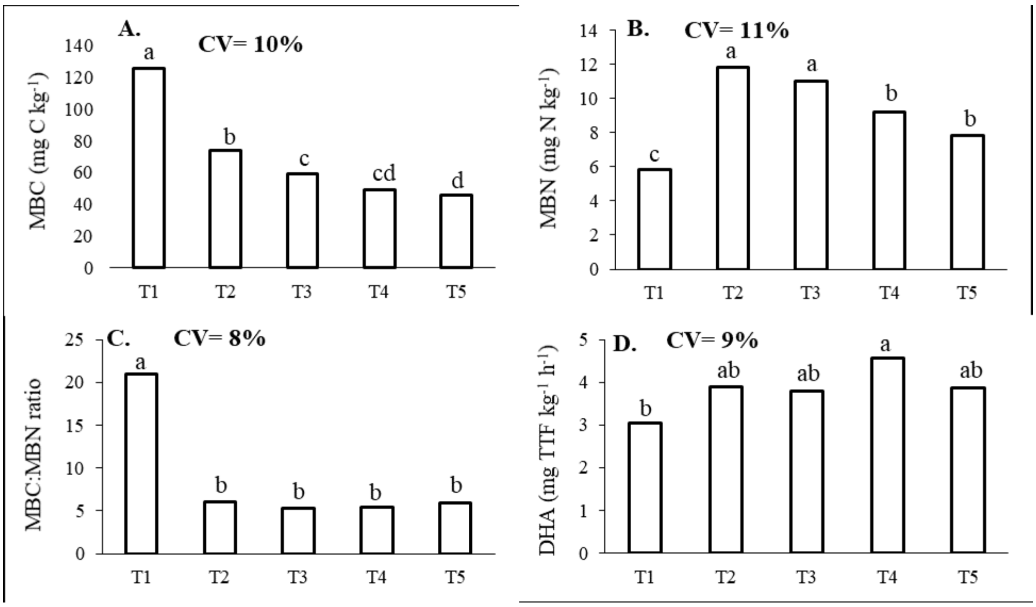

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Figure 3. Values of microbial biomass C (A), microbial biomass N (B), MBC:MBN ratio (C), and dehydrogenase activity (D) in soils after the application of fresh and concentrated vinasses

increased concentration of P after application of concentrate vinasse in an experiment with sugarcane. According to Aquino et al. (2015), soil attributes are benefited by the addition of vinasse to the soil. It was also possible to verify in this study improvements in the evaluated enzymatic activity, which attests to a greater capacity for degradation of organic matter (Cardoso et al., 2013) and, as a consequence, greater availability of soluble nutrients to the soil as in the case of phosphorus.

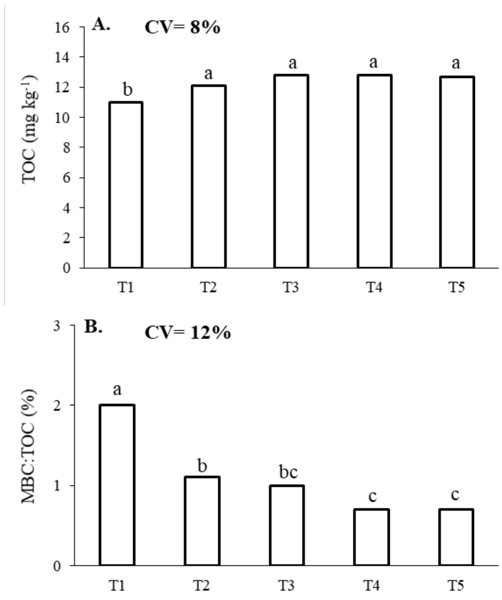

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Figure 4. Values of total organic C (A) and MBC:TOC ratio (B) in soils after the application of fresh and concentrated vinasses

On the other hand, the decreased concentrations of K and S in all treatments with vinasse could be related to the percolation of these elements in sandy soil when this waste is applied (Moran-Salazar et al., 2016). However, the higher crop yield found in treatments with vinasse indicates that both K and S were significantly extracted from the soil, mainly by soybean and maize. Interestingly, the concentration of Mg increased, while Ca did not vary, after application of vinasse. It can be explained by the higher extraction of Ca compared to Mg. According to Caires & Fonseca (2000), soybean and maize can extract four times more Ca than Mg. The soil pH also did not vary between treatments, agreeing with previous studies that did not find changes in soil pH after application of vinasse (Gallego-Blanco et al., 2012).

Soil microbial biomass C decreased significantly in the treatments with application of both vinasses, being more pronounced in treatments with only application of vinasse. In contrast, soil microbial biomass N increased with the application of vinasse. However, MBN increased significantly when both vinasses were associated with chemical fertilization.

Vinasse has high concentration of organic matter and N, and it contributes to increasing soil microbial biomass (Simanjuntak & Lengkong, 2017). However, the organic fraction of vinasse contains easily biodegraded C source and it may have contributed to faster C decomposition, hence decreasing MBC (Parnaudeau et al., 2008). The decreased MBC:MBN ratio in treatments with vinasse is a consequence of lower MBC and higher MBN. The MBC:MBN ratio can reflect the composition of soil microbial community (Yang et al., 2010), and lower MBC:MBN ratio indicates that bacteria outnumber fungi (Rocha et al., 2019). This higher presence of bacteria than fungi in soil also had an influence of soybean, which usually hosts more bacteria (Souza et al., 2016). In addition, the lower MBC:MBN ratio found in soil with vinasse may confirm the high potential of C mineralization (Rocha et al., 2019) and consequent decreased MBC. According to Braga et al. (2017), the application of vinasse to the soil interferes with competition between microbial communities in the soil, as the antimicrobial compounds present in the vinasse, such as sulfuric acid and biocides (Amorim et al., 2011), may select some more resistant groups in the soil over others, influencing microbial succession over time. This effect may have been responsible for changes found in the relationship of C and N in microbial biomass and metabolic quotient at the end of the experiment. This may indicate that there were changes in the composition of the microbial community with a predominance of more N-immobilizing microorganisms in the system.

The activity of dehydrogenase was higher with fresh vinasse as compared to the chemical fertilization. The application of vinasses increased dehydrogenase activity, and it suggests higher microbial activity decomposing C from vinasse (Cardoso et al., 2013). Therefore, the increased dehydrogenase can confirm the higher C decomposition as reported above.

The application of vinasses, alone or associated with chemical fertilizers, increased TOC concentration. It contributed to the decrease in MBC:TOC ratio. The higher TOC concentration could be a direct response to the application of a residue rich in organic compounds. Vinasse has amino acids, proteins, sugar and lignin, and these characteristics contribute to higher TOC concentration (Gallego-Blanco et al., 2012). The lower MBC:TOC ratios found in treatments with vinasses confirms higher C availability to microbial biomass and lower stability of soil organic matter (Jenkinson & Ladd, 1981). Indeed, the values of MBC:TOC ratio found in treatments with both fresh and concentrated vinasse are below 1% and can be considered lower than the normal range proposed by Jenkinson & Ladd (1981), which is 1 to 4% of TOC.

Thus, it is important to carry out studies using vinasse as a source of biofertilizer, not only evaluating its results in terms of crop yields, but also studying the impact of its application on soil properties.

Conclusions

1. Application of 505 L ha^{-1} of concentrated vinasse increased grain and pasture yields in the two years evaluated.

2. There was reduction in the concentration of potassium in the soil after two years of application and cultivation in the treatments with vinasse.

3. Vinasse application impacted soil microbiology by reducing the proportion of carbon biomass to N biomass in the soil.

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