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Papers

Influence of Vinasse and Mechanized Harvesting on the Physical and Chemical Aspects of Soil in Paudalho Municipality - PE

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Abstract
Sugarcane cultivation methods and processes usually have negative impacts on the environment. However, this industry has been seeking more sustainable technologies, ranging from the adequate disposal of the organic residues produced to the elimination of pre-harvest burning and introduction of mechanized harvest. The objective of this work was to verify the influence of vinasse application and mechanized harvesting on the physical and chemical aspects of a dystrophic Red Yellow Argisol of medium texture, cultivated with sugarcane. For this, a field experiment in a Completely Randomized Design, with a factorial scheme was conducted. Four management treatments, with three replications, were evaluated: T1 - Without application of vinasse, burned cane followed by manual harvest, without irrigation; T2 - With application of vinasse, mechanized harvest, without irrigation; T3 - With application of vinasse, mechanized harvest, with irrigation; T4 - With application of vinasse, burned cane followed by manual harvest, without irrigation. Soil samples were collected in three depths (0 – 20 cm, 20 – 40 cm and 40 – 60 cm) and soil physical and chemical characteristics were determined. The data obtained were submitted to ANOVA and compared by the Tukey test ($p \leq 0.05$) of probability, using the statistical program ASSISTAT 7.7 beta. The results showed that fertigation with vinasse did not influence soil density, particle density, and total porosity. However, mechanized harvesting increased soil density and total porosity. The soil in the experimental unit without vinasse application presented a more acidic pH and high levels of aluminum saturation, causing a decrease in the availability of nutrients, and the soils treated with vinasse had an increase in nutrient availability. Therefore, the addition of vinasse can be an important strategy in maintaining and increasing long-term soil fertility in sugarcane cropping systems.

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INTRODUCTION

Brazil stands out in the sugar and alcohol global market, being the only country that dominates all stages of sugarcane production technology, presenting an organized and robust production chain (Silva, 2010). However, the cultivation of large areas with sugarcane for long periods may lead to soil degradation. Therefore, there is a need to identify more sustainable cultivation practices to guarantee the long-term maintenance of production. In this regard, two practices have been widely proposed. First, the irrigation with vinasse, which replaces organic matter and nutrients to the soils and reuses this residue from the ethanol production process. Besides, there has been an increasing elimination of pre-harvest burning and the adoption of mechanized harvest. Thus, the understanding of the impacts of these practices needs to be better investigated.

The assessment of the physical, chemical, and biological conditions of soils subjected to fertigation with vinasse is essential to improve soil attributes and increase sugarcane production. Marques (2006) states that vinasse is composed, on average, of 93% water and 7% solids, 75% of which correspond to organic matter. The solid fraction consists mainly of organic compounds and mineral elements. There are several nutrients necessary for the development of sugar cane, which requires large amounts of Nitrogen (N), Phosphorus (P) and Potassium (K). However, sugarcane also needs other macronutrients: Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sulfur (S) and micronutrients: Boron (B), Copper (Cu^{2+}), Iron (Fe^{2+}), Manganese (Mn^{2+}) and Zinc (Zn^{2+}). To assess the status of soil fertility, it is necessary to quantify the availability of each nutrient, as well as the variables derived from them (CTC – Cation Exchange Capacity; SB – Sum of Bases; V (%) – Saturation Volume per Bases; in % - Percentage of saturation by aluminum).

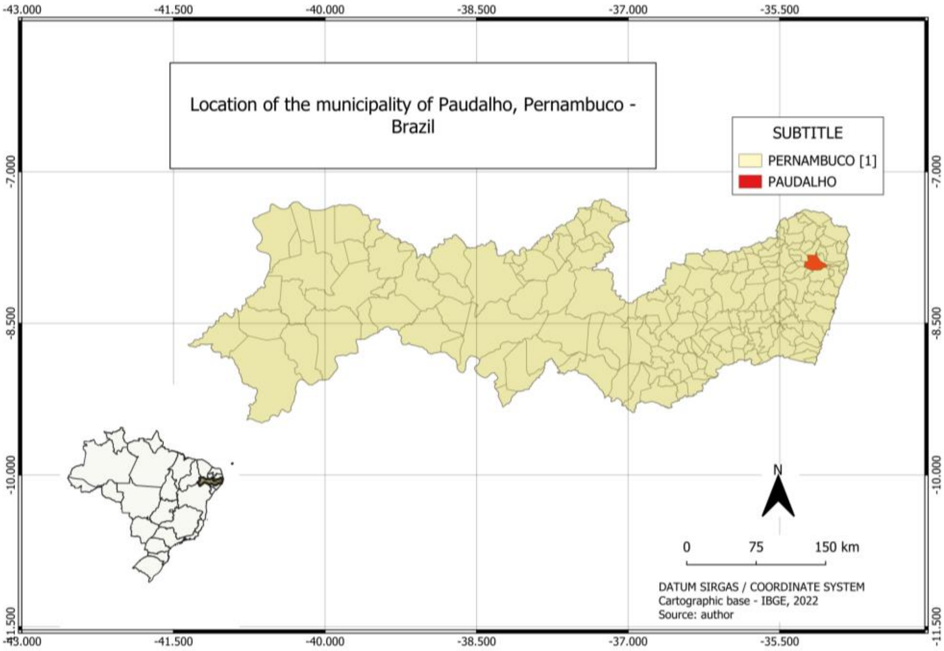
Research that encompasses the physical quality of the soil is of great importance in determining the type of management to be used. According to Sales *et al.* (2010), studies on the physical quality of soil have evolved significantly in recent years, almost always justified by the need to evaluate the behavior of different soil physical attributes in cultivated areas. Souza *et al.* (2012) mention that the constant need to increase productivity promotes the disorderly and intense use of machinery and equipment traffic in crops and soil, which results in degrading effects on the physical quality of the soil. Bertol *et al.* (2010) also consider that agricultural mechanization is a factor that can cause greater or lesser soil degradation, where this type of practice for a certain period negatively alters some of its physical characteristics. Soil density and porosity determinations are the most common and widespread assessments to identify compacted layers in the soil (Lanzanova *et al.*, 2007).

However, the objective of this work was to verify the effects of vinasse application and mechanized harvest on nutrient availability and physical attributes of an Argisol cultivated with sugarcane.

MATERIALS AND METHODS

The study region was located in the State of Pernambuco, NE Brazil, in the municipality of Paudalho - PE, within cultivated plots of Petribú Mill, a traditional sugarcane production company, as shown in figure 1.

Figure 1 - Location of the municipality of Paudalho, Pernambuco - Brazil



Source: The authors (2023).

According to the Köppen -Geiger climate classification, the study region presents an As' climate (hot and humid climate with autumn and winter rains), with a balanced temperature throughout the year, with minimum averages around 15 °C and maximum averages around 36 °C. Total annual rainfall averages 2,500 mm, with relative humidity varying between 30% and 100%.

The soil in the region was classified as dystrophic Red Yellow Argisol of medium texture, according to the existing soil survey carried out by the technical team of Petribú Mill. In all plots evaluated, the same variety of sugar cane was cultivated, RB867515, which is a variety commonly cultivated in this region.

The study area consisted of four experimental field units subjected to different management treatments, with three replications within each unit. Chart 1 shows the locations of the soil collection points.

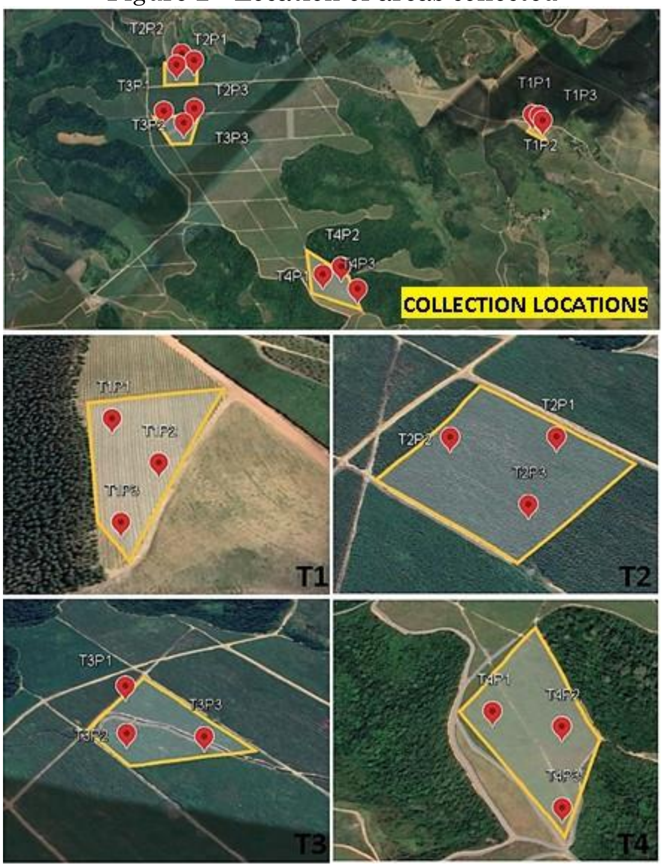
In each experimental unit, 3 (three) trenches were opened with dimensions of 0.60m wide, 0.80m long, and 0.60m deep. Samples were collected in layers 0-20, 20-40 and 40-60 cm deep. All soil sample collections followed the criteria of the EMBRAPA soil sample description and collection manual (EMBRAPA, 2011). Figure 2 shows an enlargement of the collection points in each area.

Chart 1 - Description of the experimental treatments and location of sampling points of the study.

Treatment	Management	Sampling Points (Replications)	LOCATION
T1	Without application of vinasse; burned cane followed by manual harvest; without irrigation.	P1	07°56'38.1" South latitude and 35°12'18.0" West longitude
		P2	07°56'37.9" South latitude and 35°12'18.5" West longitude
		P3	07°56'37.5" South latitude and 35°12'19.0" West longitude
T2	With application of vinasse; mechanized harvest; without irrigation.	P1	07°55'38.4" South latitude and 35°13'11.5" West longitude
		P2	07°55'38.4" South latitude and 35°13'10.8" West longitude
		P3	07°55'38.2" South latitude and 35°13'10.2" West longitude
T3	With application of vinasse; mechanized harvest; with irrigation.	P1	07°55'41.8" South latitude and 35°13'19.0" West longitude
		P2	07°55'42.2" South latitude and 35°13'19.1" West longitude
		P3	07°55'42.8" South latitude and 35°13'19.0" West longitude
T4	With application of vinasse; burned cane followed by manual harvest; without irrigation.	P1	07°56'28.2" South latitude and 35°13'16.2" West longitude
		P2	07°56'27.9" South latitude and 35°13'15.7" West longitude
		P3	07°56'27.7" South latitude and 35°13'15.4" West longitude

Source: The authors (2023).

Figure 2 - Location of areas collected



Source: The authors (2023).

To carry out chemical analyses, three deformed soil samples were collected from the 0-20 cm, 20-40 cm, and 40-60 cm layers in each trench. Therefore, for each experimental unit, 3 samples were obtained per layer, totaling 36 samples overall.

After collecting the soil samples for chemical analyses, the samples were air-dried, homogenized, and sieved to pass a 2 mm mesh opening to obtain Air-Dried Fine Earth (TFSA). Subsequently, they were placed in identified plastic deposits and stored until analysis.

Chemical and physical analyses were carried out at the Estação Experimental de Cana-de-açúcar de Carpina (EECAC), laboratory responsible for carrying out soil analysis, linked to the to the higher education institution Universidade Federal Rural de Pernambuco – UFRPE, except for the N analysis, which was carried out at the Departamento de Agrônomia (DEPA) linked to the to the higher education institution Universidade Federal Rural de Pernambuco – UFRPE.

The following chemical attributes were determined in the TFSA: pH in H_2O, Total Organic Carbon (TOC), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^+), Sodium (Na^+), potential acidity ($H^+ + Al^{3+}$), Hydrogen (H^+), Total Nitrogen (N), organic matter (MO), Cation Exchange Capacity (CEC) and Sum of bases (SB). The references used in the analysis of these attributes are presented in Chart 2.

Chart 2 - Chemical attributes analyzed in the soil samples of the study

Attributes	Methods	References
pH in H_2O	pH meter	EMBRAPA (2011)
Phosphorus	Mehlich-1 extracting solution (0.05 M hydrochloric acid + 0.0125 M sulfuric acid) and determination by spectrophotometry	
Calcium (Ca^{2+}), Magnesium (Mg^{2+}) and Aluminum (Al^{3+})	Extraction with 1 mol.L $^{-1}$ potassium chloride (KCl) solution, and determination by atomic absorption spectrophotometry.	
Potassium (K^+) and Sodium (Na^+)	Flame photometry, soil extractor using Mehlich-1 solution	
potential acidity ($H^+ + Al^{3+}$)	Extraction with calcium acetate solution Ca $(C_2H_3O_2)_2$ with phenolphthalein indicator, followed by titration with 0.025 mol.L^{-1} Sodium Hydroxide solution	
CEC (T) at pH 7.0	$T = SB + H^+ + Al^{3+}$	
Percentage of base saturation (V%)	V(%) = SB x 100/T	
Aluminum saturation	m(%) = Al^{3+} x 100/t	
Hydrogen (H^+)	Subtraction of Aluminum (Al^{3+}) from the amount of potential acidity ($H^+ + Al^{3+}$)	
SB base sums	$SB = Ca^{2+} + Mg^{2+} + K^+ + Na^+$	
Effective CEC (t)	$t = SB + Al^{3+}$	Lopes and Guilherme (2004).
Nitrogen (N)	The sample was crushed in a mortar and passed through a 60 mesh (0.250 mm) sieve, dosed by ammonia distillation in a Kjeldahl distiller, after sulfuric digestion.	Mendonça and Matos (2005).

Source: The authors (2023).

The following soil physical analyzes were carried out: bulk density, granulometry, particle density, and total porosity. To determine soil density, the volumetric ring method was used with the Uhland type sampler. Three samples were collected from each layer, 0-20, 20-40 and 40-60 cm soil depth, at 12 points, making a total of 108 soil samples. The dimensions of the volumetric ring were 5 cm in diameter and 5 cm in height, and the soil structures were kept undeformed. After removing the sampler ring, the toilet was performed, according to EMBRAPA (2011). The calculations were carried out through the ratio of the mass of oven-dried soil to the total volume of soil.

The soil granulometry analysis was carried out using the densimeter method (EMBRAPA, 1997 modified by Almeida, 2008). To do so, 20g of TFSA soil was weighed and placed in 500 ml PET bottles, adding 100 ml of water and 25 ml of the dispersant, sodium hydroxide. They were placed in a Wagner-type shaker for 16 hours. After stirring, the content was washed with water and passed through a 0.053 mm mesh sieve placed on a funnel attached to a support. The suspension was collected in a 1,000 ml beaker, the contents of which were filled to approximately 840 ml by stirring the liquid contained in the beaker with a stick for 20 seconds, and then kept at rest for 24 hours. Subsequently, the reading was carried out with the densimeter. The sand retained in the sieve was washed and placed in an oven at 65°C until constant weight and the silt was determined by difference. Soil textural classes were obtained from the Textural Triangle of the United States Department of Agriculture (USDA).

To determine particle density, 20g of soil dried in an oven at 105º C were weighed, using the volumetric flask method. In this analysis, 50 ml of ethyl alcohol was used, and then the volume of alcohol used to fill the pore space of the soil was subtracted. Particle density was determined by the ratio between the mass of oven-dried soil and the volume of solids. Total porosity was determined from the percentage ratio of the values found in soil density and particle density.

The experiment was carried out using a Completely Randomized Design, with a factorial scheme, in three replications. In order to analyze the interaction between the factors treatments x depths. To this end, four treatments were used (T1, T2, T3, and T4), as shown in Chart 3, at three depths (0–20 cm, 20–40 cm, and 40–60 cm).

Chart 3 - Identification of treatments and management practices evaluated in the study.

Treatments	Management
T1	Without vinasse application; burned sugarcane followed by manual harvest; without irrigation.
T2	With vinasse application; Mechanized Harvest; without irrigation.
T3	With vinasse application; Mechanized Harvest; with irrigation.
T4	With vinasse application; burned sugarcane followed by manual harvest; without irrigation

Source: The authors (2023).

The results were analyzed with the Tukey test ($p \leq 0.05$ and $p \leq 0.01$) at 5% and 1% probability, respectively, using the ASSISTAT 7.7 beta statistical program.

RESULTS AND DISCUSSIONS

Soil physical analysis

In factorial experiments, it is possible, through the effects of interactions, to verify whether a factor is independent or dependent on the other(s). If an interaction is non-significant, it shows that the factors are independent, that is, the behavior of one factor is independent of the variation (absence or presence) of another factor.

In this case, separate conclusions for the factors are valid. However, if an interaction is significant, it indicates that the response of one factor depends on the presence or absence of the other. In these cases, one of the alternatives is to study the behavior of a factor within each level of another factor (Storck *et al*., 2006).

In the present study, it was observed through analysis of variance that there was no significant interaction between the factors treatments x depths for any of the variables analyzed. Therefore, the factors were analyzed independently of each other, as described in chart 4.

Chart 4 – Results of the analysis of variance

Statistical analysis	Physical attributes
Significant for treatment and depth (with interaction)	-
Significant for treatment and depth (no interaction)	-
Significant only for depth	-
Significant only for treatment	DS, PT
Not significant for any of the factors	DP

Source: The authors (2023).

For all factors analyzed concerning particle density, it was found that the results were non-significant, while for soil density and total porosity, the interaction was significant only for the treatment factor.

Therefore, it can be concluded that particle density was not influenced by the types of treatments carried out or by the depths studied. The values found for soil density and total porosity were significant depending on the type of treatment carried out.

The soil physical characteristics for all sampling depths are described in table 1.

Table 1 – Depth-independent analysis

	Depth		
	0 - 20 cm	**20 – 40 cm**	**40 - 60 cm**
D.S.	1.70583a	1.69139a	1.71472a
DP	2.55263a	2.54906a	2.53343a
PT	33.17583a	33.60528a	32.26181a

Source: The authors (2023).

Soil density, particle density, and total porosity were not significantly influenced by sampling depth. These results contrast with those observed by Reinert and Reichert (2006), who stated that soil density tends to increase with increasing depth in the profile.

Table 2 presents the results of the influence of the management treatments on the soil physical characteristics analyzed.

Table 2 – Independent analysis of management treatments on soil physical characteristics

	Treatments			
	T1	**T2**	**T3**	**T4**
D.S.	1.58815c	1.75482b	1.88222a	1.59074c
DP	2.55060a	2.53070a	2.57706a	2.52181a
PT	37.68871a	30.57092b	26.90074b	36.89685a

Source: The authors (2023).

Regarding soil density, it is possible to observe that soils subjected to mechanized harvesting presented higher values for soil density. Collares *et al.* (2011), also found similar results where they showed that high machine traffic tends to increase the density and reduce the porosity of the soil, favoring its degradation.

We also observed that the application of vinasse did not influence soil density. However, for Barros *et al.* (2010), the addition of organic residues through the application of vinasse can result in an increase in organic matter in the soil. Miranda *et al.* (2012) report that soil humidity, porosity and density are sensitive to the addition of vinasse, promoting reductions in soil density and increases in humidity and porosity. Maybe, in the present study, there was still not enough time since the beginning of the treatment to detect influences of vinasse application on soil density.

For particle density, it was noticed that the treatments studied showed no significant differences. According to Nascimento *et al.* (2017), fertigation for longer period led to greater particle density and hydraulic conductivity in their studies, however, it did not influence soil density and total porosity.

Regarding total porosity, it was observed that fertigation did not influence it, similarly to the observed by Nascimento *et al.* (2017). However, it was possible to observe in the present study that soils managed with mechanized harvesting showed a decrease in total soil porosity. Grego (2010), states that the intensification of mechanization in the various phases of the sugarcane production process has a strong impact on the soil, which reduces its porosity and permeability.

To classify the textural classes, an average of the repetitions of each soil layer was taken and classified according to Ferret's triangle (Table 3).

Table 3 – Textural class of soils analyzed by each sampling depth

		TFSA granulometry			
		Sand	**Silt**	**Clay**	**Textural Class**
		..........................%..........................			
T1	**0-20cm**	53.08	8.22	38.69	Sandy clay
	20-40cm	42.25	5.05	52.69	Clayey
	40-60cm	30.38	4.26	65.35	Very clayey
T2	**0-20cm**	64.48	8.82	26.69	Sandy clay
	20-40cm	57.1	3.56	39.33	Sandy clay
	40-60cm	46.5	1.49	52	Clayey
T3	**0-20cm**	67.75	7.58	24.66	Sandy clay
	20-40cm	60.82	5.87	33.3	Sandy clay
	40-60cm	44.45	0.23	55.3	Clayey
T4	**0-20cm**	46.44	11.56	42	Sandy clay
	20-40cm	35.14	6.21	58.64	Clayey
	40-60cm	25.54	1.79	72.66	Very Clayy

Source: The authors (2023).

A sandy clay textural class was observed in the 0-20 cm layer for all treatments in the present study. For the 20-40 cm layer, it was possible to observe that the treatments with burned sugarcane had a clayey texture, while the soils with mechanized harvesting management had a sandy clayey texture. In relation to the 40-60 cm layer, all treatments presented a texture classified between clayey and very clayey.

According to EMBRAPA (2013), this increase in the percentage of clay is consistent with the Argisol class, characterized by the presence of a textural B horizon, where there is an increase in clay at depth.

Soil chemical analysis

Analysis of variance was performed to verify whether the management treatments presented interactions with sampling depth. The result is presented in chart 5.

Chart 5 – Result of variance analysis

Statistical analysis	**Chemical attributes**
Significant for treatment and depth (with interaction)	Ca^{+2}, Mg^{+2}, V(%), (H^{+} +Al^{3+}), m(%)
Significant for treatment and depth (no interaction)	pH, K^{+}, N, P, SB, CTC
Significant only for depth	-
Significant only for treatment	-
Not significant for any of the factors	-

Source: The authors (2023).

The analysis of variance indicated that the interaction between treatments x depths was significant for Ca^{+2}, Mg^{+2}, V (%), (H^{+} + Al^{3+}) in (%).

The attributes pH, K^{+}, N, P, SB, and CTC did not show a significant interaction between treatments x depths, so the factors treatments and depths were analyzed independently.

The results presented in Table 4 analyze the interactions between management treatments and sampling depth. Relationships between the same treatment for different depths are verified in the table lines using capital letters. To analyze the interaction between different treatments at the same depth, check the table columns using lowercase letters.

Table 4 - Analysis of soil chemical elements that had a significant interaction between treatments x depths.

Soil Depth	Treatment	Ca^{+2}	Mg^{+2}	V (%)	$(H^{+}+Al^{3+})$	m (%)	Al^{3+}	H^{+}
0 - 20 cm	**T1**	1.8333dA	0.3333cA	47.4088bA	2.7667aA	10.8682aB	0.3000bA	2.4667Aa
	T2	3.3667aA	1.0000aA	80.1502aA	1.2000bB	0.0000bB	0.0000aB	1.2000Bb
	T3	2.6667bA	0.8333bA	80.7180aA	1.0000bB	0.0000bB	0.0000aB	1.0000bB
	T4	2.2667cA	0.4000cA	54.6346bA	2.8667aA	8.3176abA	0.3000aA	2.5667aA
20 - 40 cm	**T1**	0.3333cB	0.3000aA	18.8289bB	3.2333aA	66.2234aA	1.4667aA	1.7667aB
	T2	1.9000abB	0.3333aB	53.8280aB	2.2000bA	5.1571bB	0.1333bB	2.0667aA
	T3	1.5667bB	0.3333aB	57.8104aB	1.9333bA	8.5908bA	0.2333baA	1.7000aA
	T4	2.1000aA	0.3333aA	57.1899aA	2.2667bB	12.9174bA	0.4333bA	1.8333aB
40 - 60 cm	**T1**	0.3333cB	0.3000aA	18.1992cB	3.1333aA	68.4890aA	1.5000aA	1.6333abB
	T2	0.9000bC	0.3000aB	36.3197bC	2.5667abA	37.3688bA	0.8000bA	1.7667aA
	T3	1.3000aB	0.3333aB	58.8662aB	1.5667cAB	16.9467cA	0.4333cA	1.1333bB
	T4	1.3667aB	0.3000aA	51.9883aA	2.0333bcB	8.6383cA	0.2000cA	1.8333aB

Source: The authors (2023).

The results presented showed that the depth of 0 – 20 cm presented the highest average values of Ca^{2+} and Mg^{2+} for all treatments Silva *et al.* (2006) found decreasing contents of Ca^{2+} and Mg^{2+} with depth in the Yellow Oxisol in the state of Pará. Table 4 shows that the highest calcium values are found in the surface layers of the soil, agreeing with the results of Araújo *et al.* (2004) who observed, in agroforestry systems, higher pH and Ca^{2+} values on the soil surface.

The results found for V (%) in table 4 are in accordance with those found by Ronquim (2010) who found a low percentage of saturation by bases V (%) and a high saturation by aluminum m (%) in acidic soils.

Given the results presented, it was verified that the experimental units treated with vinasse presented higher base content in relation to the experimental unit without vinasse application, for Ca^{2+}, Mg^{2+} and V (%) at all depths.

Ca^{2+} and Mg^{2+} contents decreased with increasing depth, however, treatments with vinasse application provided an increase in Ca^{2+} and Mg^{2+} values, when compared to the treatment without vinasse application. This result agrees with Santos *et al.* (2012) who, studying the addition of vinasse to the soil for 30 years, found an increase in the content of calcium, magnesium, and zinc at increasing soil depths, when compared with areas without the application of vinasse.

For the values found for $(H^{+}+Al^{3+})$ in (%), it was observed that treatments with burned sugarcane presented higher values when compared to treatments with raw sugarcane harvest. These results were also obtained by Souza *et al.* (2012), who observed in a Red Oxisol in the state of São Paulo, lower values of potential acidity $(H^{+}+Al^{3+})$, Al^{3+} and aluminum saturation m (%) in areas under cultivation without burning sugarcane in compared to burnt sugarcane.

The attributes pH, K^{+}, N, P, SB, and CTC did not show significant interactions between treatments and depths, so the factors treatments and depths were analyzed independently. Table 5 presents the behavior of these attributes for all sampling depths analyzed.

Table 5 - Analysis of soil chemical elements that did not present significant interactions between treatments and sampling depths.

	Depth		
	0-20cm	20-40cm	40-60cm
pH	5.6000a	4.78333b	4.27500b
K	0.48803a	0.37543b	0.28587c
N	0.08177a	0.06290b	0.04313c
SB	3.75217a	2.23956b	1.75722b
CTC	3.90217a	2.80623b	2.49055b
P	5.33333a	3.41667a	1.16667b

Source: The authors (2023).

In relation to sampling depths (table 5), it was found that pH decreased with increasing soil depth. This result agrees with Malavolta (1980) who stated that acidity generally increases with soil depth. The results for SB contents corroborate those of Silva *et al*. (2006), who observed that SB decreased with increasing depth when they studied the effects of different land uses on the chemical characteristics of a Yellow Oxisol of the State of Pará, Northern Brazil. The studies by Silva *et al*. (2006) and Araújo *et al*. (2004) also found a decrease in CEC with increasing depth.

Regarding potassium, the results agree with Brito *et al*. (2009), who studied the behavior of vinasse in different soils, and found that the increase in K^+ content in the soil varied with depth.

For P, a decrease in average values was observed with increasing depth. This fact was also observed by Giacomini *et al.* (2003), who state that it is due to the release of phosphorus in greater quantities in the first layers of the soil, due to the accumulation of plant residues from previous crops. Within no-till systems, the release of nutrients from surface residues will depend on the amount of nutrients accumulated by previous cover crops. According to Berwanger (2006), the vertical movement of P in the soil profile is conditioned by the type of soil, and depending on the texture and mineralogy, there may be greater interaction between the soil and the nutrient, resulting in high P adsorption.

Table 6 presents the results of the influence of treatments on the soil chemical aspects analyzed.

Table 6 - Analysis of soil chemical elements that did not have a significant interaction between treatments x depths.

	Treatments			
	T1	T2	T3	T4
pH	4.08889b	5.07778a	5.51111a	4.86667a
K	0.14498c	0.26410b	0.60057a	0.52279a
N	0.05324b	0.06160b	0.05751b	0.07804a
SB	1.41692b	2.97811a	3.03632a	2.90057a
CTC	2.50581b	3.28922a	3.25854a	3.21168ab
P	1.44444b	5.66667a	3.55556ab	2.55556b

Source: The authors (2023).

It was observed that soils with vinasse application had a higher pH compared to soils without vinasse. The chemical analysis of vinasse according to Marques (2006) resulted in an acidic character. Initially, it was expected that the addition of vinasse to the soil would result in a decrease in the soil's pH value. According to Magalhães (2010), the increase in pH occurs due to the action of microorganisms, caused by the proliferation of fungi in the area where the vinasse was applied, and, as a result, the soil neutralizes it. When the vinasse is applied, the acidity increases, after which the reduction occurs, increasing the bacteria. However, the values of vinasse applied to the soil, for this experiment, presented a slightly acidic character, which probably helped to increase the pH of soils managed with vinasse.

In relation to sum of bases, it was found that soils with vinasse management presented a higher fertility index, which, according to Lobo and Silva (2008), the sum of bases is an indicator of soil fertility, thus, the higher the value obtained for this parameter, the greater the fertility of the soil.

It was observed that treatments with vinasse application provided better effective CEC compared to soils without vinasse management. According to Glória and Orlando Filho (1983), the increase in CTC can be justified by the large contribution of organic matter represented by the additions of vinasse and filter cake. Due to the colloidal characteristic of the organic matter contained in vinasse, its addition gives the soil a greater number of negative charges, reducing the potential for cation leaching. The results showed a higher K^+ content in soils where vinasse was applied. This result agrees with Glória and Orlando Filho (1983).

As for P, a significant increase was observed in treatments without burning (table 6). The studies by Canellas et al. (2003) also observed an increase in the available P content in a Cambisol cultivated with sugarcane without burning.

CONCLUSIONS

Fertigation with vinasse did not influence soil density, particle density, and total porosity. However, mechanized harvesting increased soil density and total porosity.

Concerning the chemical attributes of the soil, it is concluded that treatments managed with vinasse increased soil pH, K^+, Ca^{2+}, Mg^{2+}, SB, and effective CTC, while the soil without vinasse application presented a more acidic pH and high levels of aluminum saturation.

Soil K^+ levels increased with depth, while soil pH and P decreased with depth, regardless of management and treatment.

The experimental units treated with vinasse had an increase in nutrient availability. Therefore, the addition of vinasse can be an important strategy in maintaining and increasing long-term soil fertility in sugarcane crops.

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AUTHORS CONTRIBUTIONS

Valquíria do Nascimento Tavares conceived the study. She wrote the text, participated in the collection and preparation of samples, performed physical and chemical analyzes in the laboratory and analyzed the data. Inaldo Jerfson Sobreira da Silva was responsible for using the statistical analysis software, interpreting statistical data and participated in sample collection. Fernando Cartaxo Rolim Neto was responsible for the chemical and physical analysis methodology of the soil and participated in collecting the samples. Roberto da Boa Viagem Parahyba was responsible for the soil collection methodology and participated in collecting the samples. Rômulo Simões Cezar Menezes was responsible for reviewing the interpretation of results and structural organization of the article. Marcus Metri Correa was the project co-supervisor. He guided and revised the writing of the article and carried out the literature review. Maria do Socorro Bezerra de Araújo was the project advisor. She was responsible for choosing the study area, research issues and treatments carried out.