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FERTIRRIGAÇÃO COM VINHAÇA NA CANA-DE-AÇÚCAR: AVALIAÇÃO DO DESENVOLVIMENTO INICIAL, CONDUTIVIDADE ELÉTRICA E TEOR DE POTÁSSIO NO SOLO*

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1 RESUMO

A cana-de-açúcar é essencial no Brasil, ocupando 8,3 milhões de hectares e produzindo 30 bilhões de litros de etanol na safra 2021/2022. A vinhaça, subproduto dessa indústria, contém nutrientes como potássio, nitrogênio e fósforo, podendo beneficiar a fertilidade do solo e a saúde das plantas, promovendo uma agricultura mais sustentável. Este estudo avaliou os efeitos da aplicação localizada de vinhaça no crescimento inicial da cana-de-açúcar em solo arenoso na Fazenda Santa Rita (SR), Pirassununga – SP. O experimento foi realizado em um canavial de 9 ha com 200 linhas de 300 metros, espaçadas a 1,5 m, com 4 tratamentos: vinhaça localizada (Vlocal), vinhaça em área total (Vtotal), água localizada (W) e testemunha (T), cada um com 5 repetições. A aplicação de vinhaça foi de 3 mm (30 m³/ha). Analisaram-se a condutividade elétrica do solo, o teor de potássio e o desenvolvimento inicial da cana, com medições antes e após 30 dias. A vinhaça localizada aumentou a salinidade e o teor de potássio na camada superficial do solo, reduzindo o crescimento inicial das plantas, enquanto a vinhaça total também teve efeitos negativos, mas menos severos. Recomenda-se cautela no uso da vinhaça e estudos adicionais em solos arenosos e regiões com alta pluviosidade.

Palavras-chave: Irrigação, Fertilização, Lixiviação, Sustentabilidade.

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2 ABSTRACT

Sugarcane is essential in Brazil, covering 8.3 million hectares and producing 30 billion liters of ethanol in the 2021/2022 harvest. Vinasse, a byproduct of this industry, contains nutrients such as potassium, nitrogen, and phosphorus, which can benefit soil fertility and plant health, promoting more sustainable agriculture. This study evaluated the effects of localized vinasse application on the initial growth of sugarcane in sandy soil at Fazenda Santa Rita (SR),

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Pirassununga, SP. The experiment was conducted in a 9-hectare sugarcane field with 200 rows of 300 meters spaced 1.5 meters apart, with 4 treatments: localized vinasse (Vlocal), total area vinasse (Vtotal), localized water (W), and control (T), each with 5 replications. The vinasse application was 3 mm (30 m³/ha). The soil electrical conductivity, potassium content, and initial sugarcane development were analyzed, with measurements taken before and 30 days after application. Localized vinasse increased salinity and potassium in the surface layer, reducing initial plant growth, whereas total vinasse also had negative effects, although they were less severe. Caution is recommended in the use of vinasse, with further studies needed in sandy soils and high-rainfall areas.

Keywords: Irrigation, Fertilization, Leaching, Sustainability.

3 INTRODUCTION

Sugarcane (*Saccharum officinarum*) is one of the main Brazilian crops, occupying a significant area of 8.3 million hectares in the 2021/2022 harvest. Brazil's sugarcane sector plays a crucial role, contributing to the production of sugar, electricity, and ethanol. At the same harvest, total ethanol production, which is composed of anhydrous ethanol (40%) and hydrated ethanol (60%), reached an impressive level of 30 billion liters (Cana-de-Açúcar, 2022).

The trajectory of alcohol production from sugarcane in Brazil, which began in 1925 and was consolidated in 1938 with the regulation of the mixture of ethanol in gasoline (Law No. 737), highlights the historical importance of this sector (Brazil, 1938).

However, this production scenario presents challenges related to waste management, especially the most abundant waste in the ethanol production process: vinasse. With an average of 12 liters generated for each liter of ethanol, the 2021/2022 harvest resulted in the accumulation of an impressive 360 billion liters of vinasse (Elia Neto, 2019).

Environmental awareness gained momentum in 1978, with Ordinance No. 323 of the Ministry of the Interior, which prohibited the dumping of vinasse into water bodies (Brazil, 1978). Currently, the application of vinasse follows national regulations, such as CNRH Resolution No. 15 of 2001 and Ministry of Health Ordinance No. 518/04 of 2004 (Brazil, 2001, 2004).

In São Paulo, the CETESB plays a crucial role in regulation and monitoring, establishing guiding values for soil and groundwater through Board Decisions No. 195--2005–No. 103/2007/C/E (CETESB, 2005, 2007). Technical Standard P4.231, prepared in 2015, defines criteria and procedures for the application of vinasse to agricultural soil (CETESB, 2015).

Vinasse, a byproduct of the sugar and ethanol industry, is rich in valuable nutrients for agriculture, such as potassium, which helps in water regulation and photosynthesis; nitrogen, which is essential for growth and protein formation; and phosphorus, which is important for cellular energy and root development. In addition, vinasse provides micronutrients such as calcium, magnesium and sulfur, which are crucial for plant health. Its application to soil can improve soil fertility and structure, promoting more sustainable agriculture by reusing useful industrial waste (Silva; Griebeler; Borges, 2007).

Despite advances in rules and procedures to assess the environmental impacts of vinasse application, current standards have been developed for traditional methods, such as total area spraying. These guidelines do not consider localized application of vinasse, nor do they establish appropriate sampling procedures for these areas.

Another aspect not considered is the period of the cultivation cycle, in which sugarcane demands nutrients more sharply. Studies, such as that of Santana *et al.* (2007), highlight that significant potassium extraction occurs in the final phase of the physiological cycle, while the initial application can result in potassium leaching, increasing soil salinity.

Given the development limitations imposed by increased electrical conductivity, irrigation with water has emerged as a crucial tool to increase sugarcane productivity and preserve crop quality. In a scenario where the irrigated area in Brazil has significant growth potential, reaching 55 million hectares, sugarcane irrigation can not only reduce production costs but also maintain vital economic activity, reduce the cultivated area, reduce the distance between planting and harvesting, and serve as a vehicle for the fractional application of nutrients, especially at the time of greatest demand during the final cycle (ANA, 2022). This study explores these critical aspects, providing a comprehensive understanding of vinasse management and its implications for contemporary agricultural scenarios.

In this context, the general hypothesis is that localized application of vinasse may lead to an increase in soil salinity, compromising the initial development of sugarcane and leading to potassium leaching below the effective root depth. This investigation aims to contribute significantly to the understanding and optimization of this practice, considering its impacts on agricultural and environmental aspects. This study aimed to evaluate the effects of the localized application of vinasse on the initial development of sugarcane in comparison with those of the conventional method.

4 MATERIALS AND METHODS

4.1 Characterization of the study area

The present experiment was conducted in a sugarcane cultivation area belonging to Fazenda Santa Rita (SR), located in Pirassununga, SP, with a predominant soil class of Neossolo. Quartzarenic. The area was chosen after the completion of the first sugarcane harvest, which occurred on 03/12/2021, and the variety cultivated was RB966928. The Köppen climate classification for Pirassununga is Cwa, characterized by a dry season in winter (May--October) and a rainy season in summer (November--April), with an average temperature of approximately 21 °C and annual rainfall of approximately 1,400 mm.

The physical and chemical attributes of the soil in the experimental area are detailed in Table 1. The analyses followed the guidelines proposed by Raij *et al.* (2001).

Table 1. Physical and chemical attributes of the soil in the experimental area.

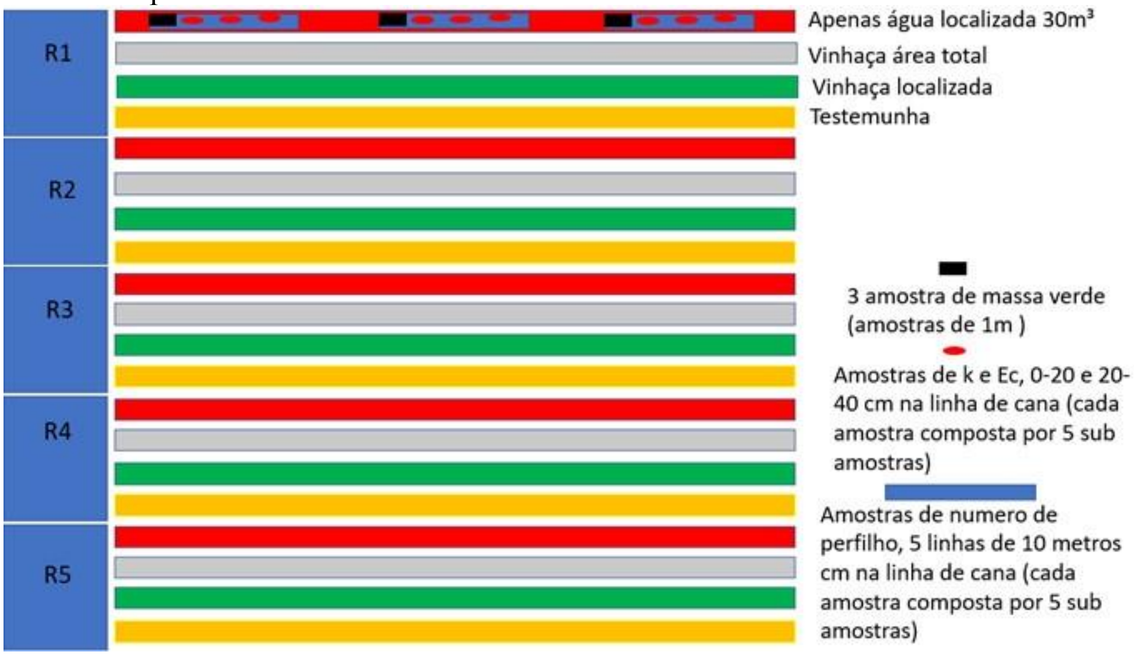
Attributes	**Saint Rita**
Field capacity (%)	36
Permanent wilting point (%)	22
Fine sand (g/kg)	550
Coarse sand (g/kg)	260
Total sand (g/kg)	810
Clay (g/kg)	142
Silt (g/kg)	48
Textural class	Sandy
pH_{CaCl2}	4.8
P Resin (mg/dm^3)	5
K^+ ($mmol_c/dm^3$)	1.9
Ca^{2+} ($mmol_c/dm^3$)	18
Mg^{2+} ($mmol_c/dm^3$)	6
Al^{3+} ($mmol_c/dm^3$)	<1
H + Al ($mmol_c/dm^3$)	35
S-SO4 $^{-2}$ (mg/dm^3)	14
Sum of Bases ($mmol_c/dm^3$)	30.4
Cation Exchange Capacity ($mmol_c/dm^3$)	44.2
Base Saturation (%)	42.1
Aluminum saturation (%)	1
%K in CTC	2.9
%Ca in CTC	46
%Mg in CTC	12.9
B ($mg/^{dm3}$)	0.15
Cu ($mg/^{dm3}$)	1.9
Mn ($mg/^{dm3}$)	2.1
Fe ($mg/^{dm3}$)	21
Zn ($mg/^{dm3}$)	0.9
Electrical conductivity (dS/m)	0.065

Source: the authors.

4.2 Experimental design

The experiment was implemented in a newly sprouted sugarcane field in 9 ha plots distributed in 200 rows of 300 meters, with a spacing of 1.5 m. Four treatments were applied, each with 5 replicates, in the 160 central rows. Each plot consisted of 8 rows, as shown in Figure 1. The treatments included the application of localized vinasse (Vlocal), total area vinasse (Vtotal), localized water (W), and a control (T), without any application. The vinasse layer applied was 3 mm (30 $m3^{/}ha$), and to ensure uniformity with the "Nonino" truck, long rows were used to minimize the variation in the distribution of the product.

Figure 1. Sketch of the experiment carried out in Santa Rita and the locations of the collected samples.



Source: the authors.

The application of localized vinasse was carried out by truck, simultaneously reaching 8 rows, while the total area vinasse was dispersed with a diffuser that spread the product throughout the area; the vinasse used contained 6 kg of potassium per m³, resulting in 180 kg of potassium/ha, according to the limits established by CETESB for areas with potassium-saturated CTC. The experiment was conducted during the low rainfall season (March to July 2021), with a rain gauge installed in the area to record rainfall.

4.3 Sample collection and procedures

Soil samples were collected at four different times in relation to treatment application (1 day before (D-1), 1 day after (D+1), 30 days after (D+30) and 75 days after (D+75)), with collection carried out at three points along the 5 central lines (beginning, middle and end), totaling 15 samples per plot (Figure 1), with each sample composed of 5 subsamples. In addition, the number of tillers was assessed at three points along the lines, which were marked with strings, totaling 5 streets, each with 3 points of 20 m.

With the beginning and end defined by the string template, the soil samples were sent to the associated laboratories of Fazenda Santa Rita for analysis of the potassium content in the layers of 0–20 cm, 20–40 cm and 75–85 cm, in addition to the electrical conductivity in the layers of 0–20 cm and 20–40 cm; the collection of the 75–85 cm layer was carried out in the period D+75 to evaluate potassium leaching, which coincided with the end of the initial development of the sugarcane, according to the objective of the work.

The green mass samples were weighed in the field via a precision scale, from which samples were taken to determine the average moisture percentage, and the tiller count was also determined in the field. The dates of each operation, as well as the periods in days between them, are presented in Table 2.

Table 2. Dates and time intervals for sampling and events in the cultivation cycle in the Santa Rita Farm area.

Event	**Santa Rita Farm**
plot	A18
Planting Date	10/02/2020
Last Harvest Date	03/12/2021
Initial Sampling Date (D-1)	03/23/2021
Days between Sampling (D-1) and Harvest	11
Date of Application of Treatments	04/13/2021
Days between Application of Treatments and Harvest	32
Sampling Date (D+1)	04/14/2021
Days between Sampling (D+1) and Harvest	33
Days between Sampling (D+1) and Application	1
Sampling Date (D+30)	05/18/2021
Days between Sampling (D+30) and Harvest	67
Days between Sampling (D+30) and Application	35
Tiller Sampling Date	06/25/2021
Days between Productivity and Tillers and Harvest	105
Days between Productivity and Profiles and Application	73
Sampling Date (D+75)	02/07/2021

(D-1): one day before the application of the treatments; (D+1): one day after the application of the treatments; (D+30): 30 days after the application of the treatments; (D+75): 75 days after the application of the treatments.
Source: the authors.

4.4 Data analysis

The statistical analysis stage included comparisons between treatments and evaluation periods for each variable studied, including potassium content, electrical conductivity, number of tillers and green mass. In the presence of interaction between the application period and the treatment, the data were segregated, allowing different analyses for each period.

In all the analytical procedures, crucial checks were performed to ensure the robustness and reliability of the results. The normality of the residuals was assessed via the Shapiro–Wilk test, whereas the homogeneity of the variances was verified via the Levene test. In cases where the residuals did not meet the normality criteria and/or the variances were not homogeneous, the data were transformed via the Box–Cox method (Box; Cox, 1964).

When data transformation was effective in resolving the identified discrepancies, ANOVA and Tukey's test (95%) were applied for paired comparisons. In situations where the transformation was not sufficient, the nonparametric robust ANOVA test was chosen (Mair; Wilcox, 2020), with the comparison being made via the Wilcoxon test (Wilcox, 2017).

Illustrative graphs were constructed with the help of the *ggplot2 package* (Wickham, 2016), providing a clear and informative visualization of the results. All analyses were conducted in the R environment (R Core Team, 2020), ensuring consistency and accuracy in the statistical procedures applied to the collected dataset. This meticulous approach aims to ensure the reliability and accurate interpretation of the results obtained during the experiment.

5 RESULTS AND DISCUSSION

5.1 Monthly rainfall

Table 3 presents significant variations in precipitation at Fazenda Santa Rita during the experiment. In March, 35 mm of precipitation was recorded, which may have provided important initial soil moisture. However, the absence of precipitation in April and July likely resulted in dry conditions, impacting water availability and requiring management adjustments, such as additional irrigation. Low precipitation in May and June (3.5 mm and 2.5 mm, respectively) may have affected the soil moisture and the effectiveness of the treatments applied. The interaction between precipitation and management practices is crucial to understanding the impact of weather conditions on the effectiveness of treatments and on the variables studied, such as plant growth and nutrient uptake.

Table 3. Monthly and periodic rainfall at Fazendas Santa Rita during the experiment.

Period 2021	**Precipitation mm**
March 10-31	35
April	0
May	3.5
June	2.5
July	0

Source: the authors.

The results related to the treatments are presented for the four variables evaluated: potassium content in the soil, electrical conductivity in the soil, number of tillers and green mass.

5.2 Potassium content

5.2.1 Potassium content in the 0--20 cm depth layer

Table 4 presents the soil potassium levels in the 0--20 cm layer measured 1 and 30 days after application of the treatments: control (T), localized vinasse (Vlocal), total vinasse (Vtotal) and localized water (W). Analysis of the results provides insights into the effectiveness of each treatment in altering soil potassium levels over time.

Table 4. Potassium content in the soil (mg/kg - 0 to 20 cm) at 1 and 30 days after application of localized vinasse (Vlocal), total vinasse (Vtotal), localized water (W) and the control (T).

Treatment	Average	DevPad	Min.	Max.	Wilcox
1 day after application					
T	2.37	0.24	2.10	2.7	B
Vlocal	4.87	0.73	4.13	5.67	THE
Vtotal	4.04	0.65	3.07	4.80	B
W	2.34	0.53	1.62	2.92	B
30 days after application					
T	2.25	0.11	2.13	2.40	B
Vlocal	3.75	0.20	3.53	4.03	THE
Vtotal	3.44	0.42	2.73	3.83	THE
W	2.09	0.16	1.87	2.30	B

Source: the authors.

The Vlocal treatment presented the highest potassium concentration immediately after application, with a mean value of 4.87 mg/kg, a standard deviation of 0.73 and a range of values between 4.13 and 5.67 mg/kg. The "A" classification in the Wilcoxon test indicates that this treatment is statistically superior to the other treatments in terms of the immediate increase in potassium levels. This is due to the direct application of vinasse in specific areas, allowing plants to quickly access the high concentration of potassium in the soil, as suggested by Marschner (2012), who highlighted the effectiveness of localized application of fertilizers to optimize nutrient availability. On the other hand, compared with the localized treatment, the total vinasse treatment resulted in a significant increase in potassium levels (4.04 mg/kg), although with less intensity. The "B" rating suggests that although the effect is positive, it is not as pronounced as that of Vlocal, possibly because of the dilution of potassium concentration by uniform application, which is corroborated by Fageria and Baligar (2005), who explain how uniform application can reduce nutrient concentration.

Both the control (2.37 mg/kg) and localized water (2.34 mg/kg) treatments resulted in similar and relatively low potassium levels, with a "B" classification. These findings confirm that the application of water alone and the absence of nutrients do not significantly affect the increase in potassium levels in the soil.

After 30 days, the Vlocal treatment still resulted in the highest mean potassium concentration (3.75 mg/kg), with a standard deviation of 0.20 and values ranging from 3.53 to 4.03 mg/kg. The persistence of the effectiveness of Vlocal in maintaining high potassium levels is evidenced by the "A" rating, suggesting that localized application remains the most effective approach for maintaining soil potassium levels over time. Studies have shown that localized application of fertilizers can significantly improve nutrient use efficiency and, therefore, crop results (Marschner, 2012). The potassium level for Vtotal (3.44 mg/kg) was significantly lower than that for Vlocal but still higher than those for T and W. The "B" rating indicates that the effect of total vinasse remains positive, although its effectiveness is lower than that of localized application. This difference may be attributed to the wider dispersion of potassium by total application, which may result in a lower soil concentration, as discussed in research on fertilizer distribution and efficiency (Nkebiwe *et al.*, 2016).

The data indicate that localized application of vinasse (Vlocal) is the most effective at increasing and maintaining soil potassium levels, both immediately after application and after 30 days. Direct application of vinasse at specific points provides a relatively high concentration of potassium where plants can quickly access it, resulting in relatively good results in the short and medium terms. The total application of vinasse (Vtotal) also increased the soil potassium level, but its effectiveness was lower than that of localized application. This may be due to the dilution of potassium over a larger area.

Localized water (W) and the control (T) did not have a significant effect on potassium levels, highlighting the importance of using treatments that add nutrients to the soil to obtain significant improvements.

5.1.2 Potassium content in the 20--40 cm depth layer

The potassium content in the 20–40 cm layer is shown in Table 5. One day after application, the Vtotal treatment resulted in the highest mean potassium content (2.87 mg/kg), indicating rapid release and an increase in potassium in the soil. The "AB" classification suggests that the effect is significant, although it is not the most prominent among all the treatments. The relatively high standard deviation (0.47) and the range of values (2.33 to 3.50 mg/kg) indicate some variability in efficacy. The Vlocal treatment also resulted in a high potassium concentration (2.58 mg/kg) one day after application, with less variability (standard deviation of 0.32). The "AB" classification suggests an intermediate effect, demonstrating that localized application is effective but not as intense as total application (Nkebiwe *et al.*, 2016).

Table 5. Potassium content in the soil (mg/kg - 20 to 40 cm) at 1 and 30 days after application of localized vinasse (Vlocal), total vinasse (Vtotal), localized water (W) and the control (T).

Treatment	Average	DevPad	Min.	Max.	Wilcox
1 day after application					
T	2.20	0.34	1.70	2.53	THE
Vlocal	2.58	0.32	2.13	2.90	AB
Vtotal	2.87	0.47	2.33	3.50	AB
W	2.05	0.37	1.62	2.55	B
30 days after application					
T	1.95	0.11	1.77	2.07	THE
Vlocal	2.86	0.38	2.23	3.17	B
Vtotal	2.25	0.19	2.03	2.43	B
W	2.02	0.25	1.63	2.30	B

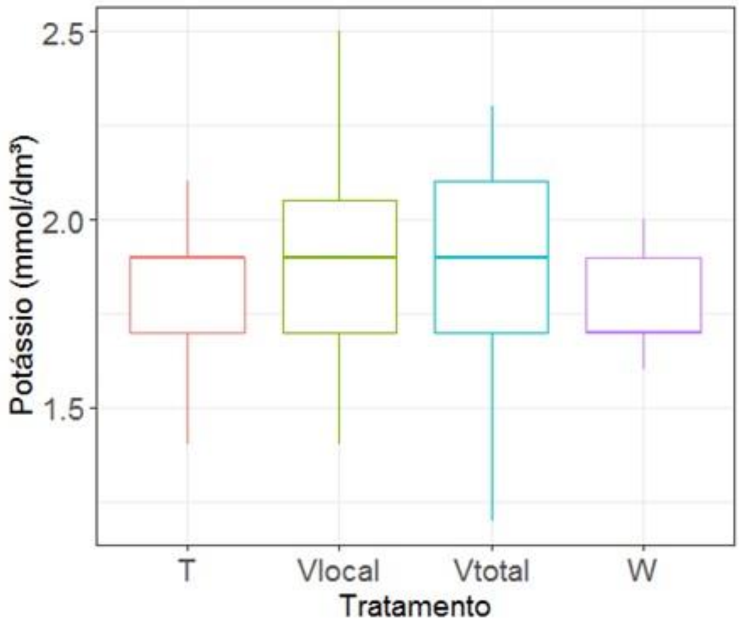
Source: the authors.

The control (2.20 mg/kg) and localized water (2.05 mg/kg) treatments presented the lowest potassium levels, with the “B” classification indicating that these treatments had similar impacts and were not significantly different from each other. This confirms that water does not contribute to the increase in soil potassium levels (Mendes *et al.*, 2016). After 30 days of application, the soil potassium level remained high for the localized vinasse treatment (Vlocal), with an average of 2.86 mg/kg, although the "B" classification indicated that its effect was not significantly different from that of the other nonfertilizer treatments. This suggests that the effectiveness of Vlocal may not be as long-lasting as initially observed. On the other hand, the total vinasse treatment (Vtotal) resulted in a reduction in potassium levels to 2.25 mg/kg, which was higher than the values found in the control (T) and localized water (W) treatments, which were 1.95 mg/kg and 2.02 mg/kg, respectively. The "B" rating for these treatments suggested that after 30 days, there was no significant effect on the long-term increase in potassium levels (Qiu *et al.*, 2014).

5.1.3 Potassium content in the 75--85 cm depth layer

Figure 2 shows the boxplot of the potassium content in the 75--85 cm layer for the 75-day period after the application of the treatments. Statistical analysis revealed no significant difference in potassium values between treatments, indicating that the application of vinasse, whether localized or in the total area, did not increase the potassium content below the root zone, minimizing the risk of soil and groundwater contamination. Similarly, when applied correctly, vinasse does not tend to move significantly to deeper soil layers, which helps to avoid groundwater contamination (Buvaneshwari *et al.*, 2020).

Figure 2. Boxplot of potassium contents in the 75–85 cm layer in the different treatments: Vtotal: vinasse in the total area; Vlocal: localized vinasse; W: localized water; T: control.



Source: the authors.

5.2 Electrical conductivity of the soil

5.2.1 Electrical conductivity in the 0--20 cm deep layer

Compared with the other treatments, the localized vinasse treatment (Vlocal) resulted in an average electrical conductivity of 1.43 dS/m (Table 6), with a standard deviation of 0.05, indicating a substantial and significant increase, corroborating similar results described by Carmo, Lima and Silva (2016) with the application of organic residues in the soil. Although the "B" classification suggests that this effect is not significantly different from that of the total vinasse treatment (Vtotal), which had an average of 0.37 dS/m, Vlocal still demonstrated a more pronounced increase. On the other hand, the control (T) and localized water (W) treatments presented very low levels of electrical conductivity, both with an average of 0.1 dS/m, and received the "A" classification, indicating that there was no significant increase in electrical conductivity due to these treatments.

Table 6. Electrical conductivity values (dS/m - 0 to 20 cm) at 1 and 30 days after the application of localized vinasse (Vlocal), total vinasse (Vtotal), localized water (W) and the control (T).

Treatment	Average	DevPad	Min.	Max.	Wilcox
1 day after application					
T	0.10	0.01	0.09	0.11	THE
Vlocal	1.43	0.05	1.37	1.51	B
Vtotal	0.37	0.18	0.18	0.65	THE
W	0.10	0.01	0.10	0.11	THE
30 days after application					
T	0.10	0.01	0.09	0.11	THE
Vlocal	1.20	0.16	1.01	1.40	B
Vtotal	0.36	0.14	0.24	0.58	THE
W	0.07	0.01	0.07	0.09	THE

Source: the authors.

After 30 days, the average electrical conductivity for the localized vinasse treatment (Vlocal) was 1.2 dS/m, which was still significantly greater than that of the other treatments but slightly lower than the initial value of 1.43 dS/m. The "B" classification suggests that, despite the reduction, the soil electrical conductivity remains high, although the effect is more moderate than the initial increase (Carmo; Lima; Silva, 2016). The total vinasse treatment (Vtotal) resulted in a small reduction to 0.36 dS/m, which was greater than that of the control and localized water treatments. The "A" classification indicates that, after one month, the electrical conductivity of Vtotal does not differ significantly from the levels observed for the control and localized water treatments. Both the control (T) and localized water (W) samples presented low electrical conductivity values, 0.1 dS/m and 0.07 dS/m, respectively, and were classified as "A", indicating that there was no significant difference in the long term (Qiu *et al.*, 2014).

5.2.2 Electrical conductivity in the 20--40 cm deep layer

Compared with the other treatments, the localized vinasse treatment (Vlocal) resulted in the highest mean electrical conductivity of 0.99 dS/m, with a standard deviation of 0.18 (Table 7), indicating a significant increase and a more pronounced immediate impact. In contrast, total vinasse (Vtotal) had a mean electrical conductivity of 0.42 dS/m, which was higher than that of the control and localized water treatments but lower than that of Vlocal, resulting in the classification "B", which reflects a notable effect but is less intense than that of Vlocal. On the other hand, the Control (T) and Localized Water (W) treatments presented very low electrical conductivities, with means of 0.11 and 0.08 dS/m, respectively, with the classification "D" for W and "C" for T, indicating that these treatments do not have a significant effect on electrical conductivity (Mendes *et al.*, 2016).

Table 7. Electrical conductivity values (dS/m - 20 to 40 cm) at 1 and 30 days after the application of localized vinasse (Vlocal), total vinasse (Vtotal), localized water (W) and the control (T).

Treatment	Average	DevPad	Min.	Max.	Wilcox
1 day after application					
T	0.11	0.01	0.10	0.12	W
Vlocal	0.99	0.18	0.74	1.23	THE
Vtotal	0.42	0.15	0.21	0.57	B
W	0.08	0.01	0.08	0.09	D
30 days after application					
T	0.08	0.02	0.07	0.11	THE
Vlocal	0.67	0.10	0.52	0.75	W
Vtotal	0.24	0.04	0.20	0.27	B
W	0.10	0.01	0.09	0.11	THE

Source: the authors.

After 30 days, Vlocal showed a reduced average electrical conductivity of 0.67 dS/m, which was still significantly greater than that of the control and localized water treatments. The "C" classification reflects that although the conductivity decreased, it remained high in relation to the other treatments but had a moderate effect compared with the initial increase (Carmo; Lima; Silva, 2016). The Vtotal decreased to 0.24 dS/m, which was greater than that of the control and localized water treatments. The "B" classification indicates that after 30 days, the effect of total vinasse was still significant but less pronounced than that of localized vinasse. The control (T) and localized water (W) treatments resulted in low electrical conductivities, with averages of 0.08 and 0.10 dS/m, respectively, and received the "A" classification, indicating that there was no significant difference in long-term electrical conductivity between these treatments.

5.3 Number of tillers and green mass

The T, W and Vtotal treatments resulted in more tillers than did the Vlocal treatment (Table 8). For the number of tillers, the treatments with localized vinasse (Vlocal) and total vinasse (Vtotal) presented averages of 115.50 and 134.94, respectively, both of which were lower than those of the control (T) and localized water (W) treatments, which presented averages of 139.84 and 137.30, respectively. The classification "A" for T and W suggests that these treatments resulted in a significantly greater number of tillers than Vlocal, which resulted in the classification "B". These findings indicate that the use of vinasse, both in the total and localized areas, may not have been as effective in promoting tiller development as the control treatments. The reduced number of tillers in the vinasse treatment can be attributed to adverse effects of vinasse on the plant, such as high salinity or excess nutrients that can inhibit growth (Holanda *et al.*, 2011).

Table 8. Comparison of the number of tillers and green mass in the four treatments (Vtotal: vinasse in the total area; Vlocal: localized vinasse; W: localized water; T: control).

Treatment	**Average**	**Standard Deviation**	**Min.**	**Max.**	**Wilcox**
		Number of Tillers			
T	139.84	21.35	104	210	THE
Vlocal	115.50	12,14	88	142	B
W	137.30	15.29	102	175	THE
Vtotal	134.94	12.01	99	161	THE
		Green mass (g)			
Treatment	Average	DevPad	Min.	Max	Wilcox
T	4.25	0.56	3.15	5.15	THE
Vlocal	3.20	1.01	1.90	5.60	W
W	4.35	1.17	2.20	7.10	AB
Vtotal	3.84	0.81	2.80	5.90	B

Source: the authors.

In terms of green mass, the control treatment (T) presented the highest average value of 4.25 g, followed by the localized water (W) treatment (4.35 g), both with classification "A" and "AB", respectively, indicating significantly high values. In contrast, the Localized Vinasse treatment (Vlocal) had the lowest average green mass (3.20 g) and obtained the classification "C", suggesting that the application of localized vinasse may have had a negative effect on the mass of the plants. The total Vinasse (Vtotal), with an average of 3.84 g, also presented lower values than did the controls, but with a classification of "B", indicating a less severe but still adverse effect on the growth of the green mass.

These results indicate that although vinasse may have beneficial effects under some conditions, it may also have negative impacts on plant growth, especially in terms of tiller number and green mass. The reduction in plant performance in response to vinasse treatment may be related to factors such as high salt concentrations or nutrient imbalances, which may require adjustments in management practices to mitigate these adverse effects (Santana *et al.*, 2007). The difference observed between the treatments highlights the need for a careful balance when vinasse is used as a fertilizer, with the aim of optimizing the benefits while minimizing the negative impacts on plant growth.

6 CONCLUSIONS

Localized application of vinasse increased soil potassium availability, but its beneficial effect diminished after 30 days. Furthermore, there was no leaching to deeper layers during periods of extremely low precipitation. Compared with the control and localized water treatments, localized vinasse resulted in lower tiller numbers and green masses during early sugarcane development. Total vinasse also had negative effects but was less severe than localized vinasse. In summary, although the localized application of vinasse effectively provides potassium, its adverse impact on sugarcane growth suggests that its use should be managed carefully to avoid negative effects.

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