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TRATAMENTO SORTIVO DA VINHAÇA COM CINZA VEGETAL PARA APLICAÇÃO NA FERTIRRIGAÇÃO

JULIANA GILBERT PESSOA[1], LINO CARLOS SITOE[2], JOSIANE DE LIMA SOUZA[3], ROSELENA FAEZ[4], CLAUDINEI FONSECA SOUZA[5]

[1] Departamento de Recursos Naturais e Proteção Ambiental, Universidade Federal de São Carlos, Rodovia Anhanguera Km 174 - Zona Rural - Cep 13604-900 – Araras – SP - Brasil, ORCID 0009-0000-1809-2116 juliana@ufscar.br.
[2]Departamento de Recursos Naturais e Proteção Ambiental, Universidade Federal de São Carlos, Rodovia Anhanguera Km 174 - Zona Rural - Cep 13604-900 – Araras – SP - Brasil, ORCID 0009-0003-2171-0044 linocs@estudante.ufscar.br.
[3] Departamento de Ciências Naturais, Matemática e Educação, Universidade Federal de São Carlos, Rodovia Anhanguera Km 174 - Zona Rural - Cep 13604-900 – Araras – SP - Brasil, ORCID 0000-0002-0013-8603 josianels2@gmail.com.
[4] Departamento de Ciências Naturais, Matemática e Educação, Universidade Federal de São Carlos, Rodovia Anhanguera Km 174 - Zona Rural - Cep 13604-900 – Araras – SP - Brasil, ORCID 0000-0003-1263-7837 faez@ufscar.br.
[5] Departamento de Recursos Naturais e Proteção Ambiental, Universidade Federal de São Carlos, Rodovia Anhanguera Km 174 - Zona Rural - Cep 13604-900 – Araras – SP - Brasil, ORCID 0000-0001-9501-0794 cfsouza@ufscar.br.

RESUMO: A produção sucroenergética, essencial ao agronegócio brasileiro, gera grandes volumes de resíduos, entre eles a vinhaça, efluente líquido rico em nutrientes e frequentemente aplicado como fertilizante. Outro resíduo relevante é a cinza do bagaço de cana-de-açúcar (CBCA), que apresenta propriedades alcalinizantes e adsorventes. Este estudo avaliou o uso da CBCA como adsorvente no tratamento da vinhaça, buscando melhorar sua estabilidade química e seu aproveitamento na fertirrigação. O experimento foi realizado no Laboratório de Física de Solo, no Centro de Ciências Agrárias, da UFSCar, seguiu um delineamento inteiramente casualizado, em esquema fatorial 2 × 2, avaliando dois tipos de CBCA (lavada e não lavada) e duas doses (2,5 g e 5,0 g), com três repetições. A CBCA foi adicionada a 100 mL de vinhaça in natura e agitada por 72 horas. Medições de pH e condutividade elétrica (CE) foram feitas aos 24, 48 e 72 horas. Os resultados mostraram que a CBCA aumentou o pH e a CE, promovendo maior estabilidade química. Conclui-se que a CBCA é uma alternativa potencial, de baixo custo, para tratar a vinhaça e promover práticas agrícolas mais sustentáveis.

Palavras-chave: adsorção, cana-de-açúcar, sustentabilidade agrícola.

SORPTION TREATMENT OF VINASSE WITH PLANT ASH FOR APPLICATION IN FERTIGATION

ABSTRACT: Sugar-energy production, which is essential to agribusiness in Brazil, generates large volumes of waste, including vinasse, a nutrient-rich liquid effluent often applied as fertilizer. Another significant byproduct is sugarcane bagasse ash (CBCA), which has alkaline and adsorptive properties. In this study, the use of CBCA as an adsorbent in vinasse treatment was evaluated, with the goal of improving its chemical stability and potential for fertigation. The experiment was conducted at the Soil Physics Laboratory of the Center for Agricultural Sciences, UFSCar, following a completely randomized design with a 2 × 2 factorial scheme. Two types of CBCA (washed and unwashed) and two doses (2.5 g and 5.0 g) were tested, with three replications. CBCA was added to 100 mL of raw vinasse and stirred for 72 hours. The pH and electrical conductivity (EC) were measured at 24, 48, and 72 hours. The results showed that CBCA increased both the pH and the EC, promoting greater chemical stability. CBCA is a potential low-cost alternative for treating vinasse and promoting more sustainable agricultural practices.

Keywords: Adsorption, Sugarcane, Agricultural sustainability

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1 INTRODUCTION

Brazil is the world's largest producer of sugarcane (*Saccharum spp*.), with the state of São Paulo accounting for the majority of national production. The expansion of this crop accelerated in the 1970s with the implementation of the National Alcohol Program (Proálcool), which strengthened the sugar-energy sector and significantly increased the generation of byproducts, such as vinasse, a liquid residue resulting from ethanol distillation (Araújo and Araújo Sobrinho, 2024). It is estimated that for every liter of ethanol produced, between 12 and 18 liters of vinasse are generated, which is rich in organic matter and nutrients.

Fertigation with vinasse is a sustainable and economically viable practice since it promotes nutrient recycling and reduces the dependence on mineral fertilizers (Soares *et al.*, 2024). The application of 150 m^3 ha^{-1} of vinasse can supply soil with approximately 61 kg ha^{-1} of nitrogen, 343 kg ha^{-1} of potassium, and 108 kg ha^{-1} of calcium, which contributes to plant growth and improves the physical and chemical properties of the soil (Parsaee; Kiani; Karimi, 2019). However, inadequate management of vinasse can cause serious environmental impacts, such as soil acidification, groundwater contamination, and eutrophication of water bodies (Carrilho; Labuto; Kamogawa, 2016).

It is therefore essential to develop effective strategies for the treatment of this residue, aiming to mitigate its harmful effects. Sugarcane bagasse ash (CBCA) has emerged as a promising alternative, not only because of its high availability but also because of its favorable chemical properties. CBCAs rich in metallic oxides, such as calcium oxide (CaO), magnesium oxide (MgO), potassium oxide (K_2O) and silica oxide (SiO_2), present alkalizing and adsorbent characteristics (Santos, 2020).

With respect to its production, approximately 5 million tons of CBCA are estimated to be generated annually in Brazil, resulting from the burning of approximately 200 million tons of bagasse, a fibrous byproduct obtained from the milling of approximately 663 million tons of sugarcane per harvest (Unica, 2025; Sugarcane, 2025). For each ton of dry bagasse burned, approximately 25 kg of ash is generated, a value that can vary according to the combustion efficiency and the moisture content of the material (Bayapureddy; Muniraj; Mutukura, 2024). This high availability of CBCA, combined with its residual nature, highlights its potential for large-scale reuse, mainly in environmental applications, such as in the pretreatment of vinasse, correction of soil acidity, and nutrient recovery (Santos, 2020).

Studies have shown that applying CBCA to vinasse corrects acidity, increasing the pH from values generally below 4 to levels close to neutrality, thus reducing toxicity to the soil and the environment (Chingono *et al*., 2018). Therefore, the use of vinasse treated with CBCA presents itself as a technically and environmentally viable alternative for the reuse of these agro-industrial residues, both of which originate from the sugarcane production chain and favor its integration into sustainable waste utilization strategies (Antonio; Faez, 2024).

On the basis of this scenario, this study evaluated the effectiveness of CBCA in the treatment of vinasse, aiming at its sustainable use in fertigation.

2 MATERIALS AND METHODS

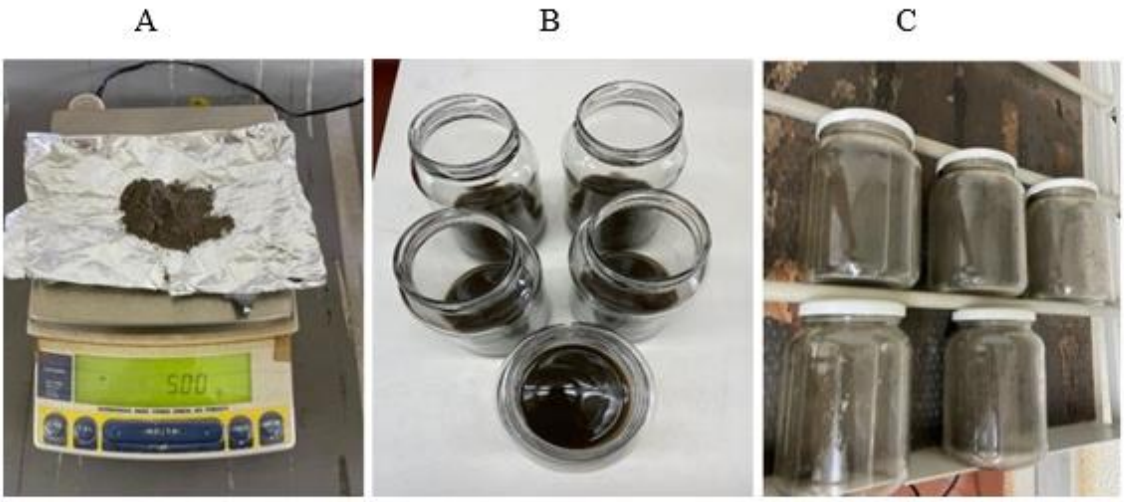
The experiment was conducted at the Soil Physics Laboratory of the Center for Agricultural Sciences of the Federal University of São Carlos - Araras Campus (CCA/UFSCar) from August 2024 to January 2025. The experimental design adopted was a 2×2 factorial design, with three replications per treatment. Two main factors were evaluated: type of CBCA (washed/dried and untreated) and CBCA mass (2.5 g and 5.0 g), with samples of raw vinasse as the adsorbate and all materials being supplied by local production units.

The CBCAs were initially vacuum-washed with distilled water (Milli -Q, Millipore) to obtain approximately 7.5 g of CBCA in a volume of 1 L. They were then dried in a circulating and air-renewing oven (model TE394/1 - Tecnal) at 100 °C for 3 h until they reached constant mass, according to the methodology described by Antônio; Faez (2024). From this prepared batch, aliquots of 2.5 g and 5.0 g of washed/dried CBCA were weighed, and in parallel, the same masses of untreated CBCA were used in comparative tests.

Each sample (in triplicate) consisted of a mixture of 100 mL of raw vinasse with the designated quantity of CBCA, placed in flasks and kept under reciprocating agitation (Nova Técnica shaker table) at 150 rpm for 72 h. The process comprised three 24-h cycles, with sample collection after 24 h, 48 h, and 72 h. At the end of each cycle, the CBCA was separated from the vinasse by centrifugation and filtration, and the same vinasse was reused for the next batch, but with a new mass of CBCA.

pH and electrical conductivity (EC) readings were taken before the start of the test, at the end of each sorption cycle, and at the end of 72 h. These measurements allowed monitoring of the evolution of acidity neutralization and the change in solution ionization over time. The effectiveness of the process was evaluated by comparing the effects of CBCA mass and contact time on the increase in vinasse pH on the basis of its initial acidity in each cycle. The main steps of the sorption test are shown in Figure 1.

Figure 1. Steps of the sorption test with CBCA: (A) weighing the mass of CBCA; (B) vinasse + CBCA; (C) reciprocating agitation.



Source: Author's own work (2025)

3 RESULTS AND DISCUSSION

Analysis of the interaction between ash and vinasse is fundamental to understanding the sorption process, identifying challenges, and proposing improvements to optimize performance. Tests conducted with raw CBCA and previously washed and dried CBCA allowed the establishment of ideal conditions, on the basis of an initial comparison of kinetics using 2.5 g of ash and, subsequently, 5.0 g, to analyze the pH and EC parameters of the solutions.

The results presented in Table 1 indicate the variation in the pH before, during, and after the sorption contact between vinasse and ash, both raw and washed, when masses of 2.5 g and 5.0 g of the material were used. A gradual increase in pH is observed, indicating that the ashes exert an alkalizing effect on the vinasse. This increase in pH reflects the release of alkaline compounds present in the ashes, which interact with the ions of the vinasse, modifying its chemical properties (Antonio; Faez, 2024).

Table 1. pH variation before, during, and after sorption contact with different masses of raw ash and washed ash.

	pH			
Treatment/Time	0	24 h	48 h	72 h
Raw ash (2.5 g)	4.70 Ac	5.20 Cb	5.30 Cb	5.83 Ba
Raw ash (5.0 g)	4.70 Ad	5.50 Bc	6.10 Bb	6.33 Aa
Washed ash (2.5 g)	4.70 Ac	5.47 Bb	5.50 Cb	6.23 Aa
Washed ash (5.0 g)	4.70 Ac	5.80 Ab	6.33 Aa	6.13 Aa

Tukey's test was applied to the columns (uppercase letters) and rows (lowercase letters). Means followed by the same letter do not differ from each other at a significance level of 5%.

In the treatment with raw ash (2.5 g), the pH increased from 4.70 to 5.83 after 72 h. This gradual increase suggests that the interaction between vinasse and raw ash occurred steadily over time, resulting in a progressive change in the pH. Compared with that of raw ash (5.0 g), the initial pH of vinasse was also 4.70, but the increase was more significant, reaching 6.33 after 72 h. This result indicates that the larger amount of ash (5.0 g) generated a more significant change in the pH of the vinasse, promoting more pronounced alkalization than the smaller dose (2.5 g). Bega (2014), evaluating the application of CBCA in Oxisol with sugarcane cultivation, reported that base saturation increased as a result of increasing doses of ash, a direct reflection of the reduction in the potential acidity of the soil. Thus, this behavior suggests that the amount of ash applied is directly related to the intensity of the change in pH, with higher doses of ash potentially promoting a more significant alteration in the acidity of the vinasse.

In the treatments with washed/dried ash, increases in pH were also evident, with a gradual behavior. Compared with the raw ash, the washed ash (2.5 g) showed a pH variation from 4.70 to 6.23 after 72 h, with a more significant increase, suggesting that washing the ash may reduce the amount of soluble compounds, a fact that contributes to the increase in pH. In the case of the washed ash (5.0 g), the pH increased from 4.70 to 6.33 after 48 h, a more pronounced increase than that observed for the other treatments, according to statistical comparisons. However, after the 72 h sorption cycle, the pH decreased to 6.13, indicating a slight decline in the neutralization process. The reduction in the pH after 72 h, from 6.33 to 6.13, suggests the depletion of the soluble alkaline cations initially released by the washed ash, followed by the formation of less soluble compounds, which promotes the stabilization of the system. This behavior is consistent with the dynamics observed in biomass ash, whose initial alkalinity tends to decrease over time because of the transformation of cations into less available forms in the reaction medium (Maj *et al.*, 2025).

Initially, all the treatments resulted in homogeneous conditions, as indicated by the similar pH values among the samples. Over time, the increase in pH was more pronounced in the first 48 hours, except for the treatment with 2.5 g of raw CBCA. Chingono *et al.* (2018), when a kinetic study of the interaction between CBCA and vinasse for COD removal was conducted, reported that the initial pH of 3.50 increased to 8.01 between 4 and 6 h of contact, indicating that, in addition to the mass of the adsorbent, the contact time also directly influenced the increase in the pH of the vinasse (Table 1).

Thus, the results indicate that the use of ash, especially in relatively large quantities, has a significant effect on neutralizing the pH of vinasse, since compared with the use of washed ash, the use of raw ash promoted a greater increase in the pH at the end of the cycle. These results are important for the application of vinasse treated with ash in soils, as pH modification can directly influence nutrient availability and soil health; thus, rigorous control is needed to ensure that the soil does not become excessively alkaline, which can ultimately negatively affect plant growth (Neina, 2019).

With respect to the results of the EC analysis, as shown in Table 2, an initial increase occurred after 24 h of contact, suggesting a significant interaction between the compounds present in the ash and the ions in the vinasse. This increase is expected since the ashes, both untreated and washed/dried, contain minerals and soluble compounds that are released into the aqueous medium, contributing to the increase in electrical conductivity, an indication of ion exchange between the materials (Rehl; Reimer; Rutherford, 2021).

Table 2. Variation in electrical conductivity, in terms of dS m⁻¹, before, during and after sorption contact with different masses of raw ash and washed ash.

Electrical conductivity (dS m ⁻¹)				
Treatment/Time	0	24 h	48 h	72 h
Raw ash (2.5 g)	8.59 Ad	9.90 Aa	9.45 Ac	9.67 Ab
Raw ash (5.0 g)	8.59 Ac	9.74 Aa	9.19 Bb	9.14 Cb
Washed ash (2.5 g)	8.59 Ac	9.79 Aa	9.45 Ab	9.36 BCb
Washed ash (5.0 g)	8.59 Ac	9.87 Aa	9.51 Ab	9.49 ABb

Tukey's test was applied to the columns (uppercase letters) and rows (lowercase letters). Means followed by the same letter do not differ from each other at a significance level of 5%.

The results indicate that after 48 hours of sorptive contact, there was a statistically significant difference between the treatments with raw ash as a function of the applied mass. The treatment with the lowest mass (2.5 g) resulted in higher EC values throughout the experimental period, with the highest values reaching 72 hours. However, the treatment with 5.0 g tended to stabilize the EC from the same point. This behavior may be related to ionic adsorption processes on the particle surfaces, solution saturation, or the precipitation of less soluble compounds over time (Mota; Villas Bôas; Sousa, 2006).

After 48 hours, the differences between treatments became more evident, especially for the washed ash (5.0 g), whose EC was 9.51 ^{dS} m^{-1}, which was significantly greater than that of the raw ash of the same mass (9.19 dS m^{-1}). This suggests that, despite being washed to remove soluble salts, the washed ash still retains releasable ions, especially in larger quantities, contradicting the expectation of less solute release (Quirantes *et al*., 2016). Furthermore, the treatments with washed ash showed more uniform behavior over time, with less fluctuation between the evaluated intervals. This pattern may indicate that the washing pretreatment stabilizes ionic release, although it does not necessarily reduce the final concentration of ions in solution, especially when larger quantities of material are applied (Jiang *et al*., 2022; Chen *et al*., 2016).

The data obtained demonstrate that the application of ash as a sorption material significantly alters the ionic composition of the medium, which reinforces the importance of considering both the dosage and the pretreatment of the material in applications aimed at controlling salinity or removing ions in aqueous solutions (Buema *et al*., 2021). According to Antonio and Faez (2024), the direction of nutrient flow depends on the concentration gradient between the medium and the sorption material: when the concentration of nutrients in the solution is higher than that present in the ash, sorption of these elements occurs; on the other hand, at lower concentrations, ions are released from the material into the system. In this context, the interaction between vinasse and larger quantities of ash can result in a more significant increase in electrical conductivity, indicating an increase in the concentration of available ions, which potentially alters the chemical characteristics of vinasse, including the pH (Francisco *et al*., 2016).

Notably, the results highlight the importance of controlling both the type and quantity of ash used, as well as the contact time. The use of raw ash may be more effective at rapidly modifying the chemical properties of vinasse, but it also presents greater variation in behavior over time, which may require more careful monitoring.

4 CONCLUSIONS

The application of raw CBCA, especially at a dosage of 5.0 g for 72 h, demonstrated high potential for the treatment of vinasse, promoting a significant increase in the pH and stabilization of electrical conductivity after 24 h of contact. It is concluded that CBCA is an efficient alternative for neutralizing the acidity and controlling the salinity of vinasse, suggesting that its agronomic reuse is environmentally safe.

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