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Evaluation of the effects of biocompost based on sugarcane cachaza on soil physical properties

Evaluación de los efectos del biocompost a base de cachaza de caña de azúcar en las propiedades físicas del suelo

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Abstract

The study assessed the effects of sugarcane cachaza biocompost on soil physical properties in the Huasteca Norte. Significant improvements were observed in bulk density, real density, and porosity, indicating a more favorable soil structure with increased biocompost. Additionally, there was an increase in water retention percentage with the addition of biocompost. Organic matter analysis revealed notable differences among treatments, with Treatment T4 exhibiting the highest content. These results suggest the positive potential of biocompost in enhancing soil quality in the region. The discussion will focus on the relevance of these findings for sustainable agricultural practices and effective soil management in the Huasteca Norte, as well as potential implications for productivity and environmental sustainability in the region.

Biocompost, Soil, Sugarcane cachaza

Resumen

El estudio evaluó los efectos del biocompost de cachaza de caña de azúcar en propiedades físicas del suelo en la Huasteca Norte. Se observaron mejoras significativas en densidad aparente, densidad real y porosidad, indicando una estructura del suelo más favorable con el aumento del biocompost. Además, se destacó un incremento en el porcentaje de retención de agua con la adición de biocompost. El análisis de materia orgánica reveló diferencias notables entre tratamientos, con el tratamiento T4 mostrando el contenido más alto. Estos resultados indican el potencial positivo del biocompost en la mejora de la calidad del suelo en la región. La discusión se centrará en la relevancia de estos hallazgos para prácticas agrícolas sostenibles y la gestión efectiva de suelos en la Huasteca Norte, así como posibles implicaciones para la productividad y sostenibilidad ambiental en la región.

Biocompost, Suelo, Cachaza

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Introduction

With climate change emerging as one of the most pressing challenges of the 21st century, its significant impacts on food security and the sustainability of agricultural systems worldwide cannot be overlooked. Mexico, with its rich geographic diversity and historical dependence on agriculture, is immersed in the effects of climate change. Alterations in weather patterns, rising temperatures and the frequency of extreme weather events have exacerbated the vulnerability of Mexican agricultural systems, compromising the country's food security and economic stability.

This scenario manifests itself critically in the agricultural sector, where changes in climatic conditions can have devastating consequences for crop productivity and quality. Mexico's agricultural regions, including the Huasteca Norte in San Luis Potosí, face direct threats such as prolonged droughts, flash floods and changes in the availability of water resources. This reality underscores the urgent need to develop adaptive and mitigation strategies that strengthen the resilience of agricultural systems to climate change.

In particular, the Huasteca Norte region has experienced these problems, which demonstrate the exacerbated vulnerability of its agricultural fields, especially those dedicated to the cultivation of sugar cane (Saccharum officinarum L.). This crop, emblematic of the region, is not only crucial for the local economy but also for the national sugar industry.

In this context, the present article focuses on the evaluation of the effects of sugarcane pulp biocompost on the physical properties of the soil. Cachaza, a by-product of the sugar industry, is presented as a valuable resource that, when converted into biocompost, could offer significant benefits for improving soil resilience and counteracting the adverse effects of climate change on sugarcane fields in the Huasteca Norte region. To support this research, a comprehensive, evidence-based analysis was carried out to contribute to a holistic understanding of the challenges and potential solutions at the interface between climate change, agriculture and soil sustainability.

The present study proposes to address this need by assessing the effects of sugarcane cachaza-based biocompost on the physical properties of soil typical of the region. Cachaça, an abundant by-product of the sugar industry, has been identified as a promising source of nutrients and organic matter to improve soil quality (Senatore et al., 2023). The transformation of cachaza into biocompost not only presents a solution to sustainable industrial waste management, but also raises the possibility of strengthening the resilience of agricultural soil to climate stresses (Mahapatra et al., 2022).

The conceptual basis of this approach lies in the ability of compost to improve soil physical properties such as structure, water holding capacity and microbial activity (Smith et al., 2010; Lehmann et al., 2011). Previous studies have shown that the addition of compost to soil can improve soil structure, promote moisture retention and increase the availability of essential plant nutrients. In addition, compost can act as a buffer against extreme weather events, protecting soil health and promoting crop resilience (Pratap and Prabha, 2017).

Cachaza, in its composition, is rich in organic matter, an essential component for soil health. Organic matter acts as a source of carbon and energy for soil microorganisms, thereby promoting microbial activity and improving soil structure (Mahapatra et al., 2022; Smith et al., 2010). In addition, cachaza contains essential nutrients, such as nitrogen, phosphorus and potassium, which are essential for plant growth (Senatore et al., 2023; Lehmann et al., 2011). The presence of these nutrients makes cachaza a valuable resource for enriching the soil and improving the availability of nutrients for crops.

Four treatments were designed for this research, consisting of a mixture of typical soil and biocompost in varying proportions (10%, 20%, 30% and 40%), together with a negative control representing conditions without compost addition (Lehmann et al., 2011). These proportions were selected in order to systematically evaluate the effects of biocompost on the soil and to determine the optimal dosage to improve physical properties without causing adverse impacts.

Methodology to be developed

Experimental design

The experimental design was carried out in the experimental field of the Environmental Research and Monitoring Laboratory of the Tecnológico Nacional de México, Campus Ciudad Valles. It was structured around the evaluation of four treatments with different proportions of biocompost based on sugar cane waste (10%, 20%, 30%, 40%) and a fifth treatment that represented the typical soil of the Northern Huasteca region in San Luis Potosí, used as a negative control. Each of the treatments, including the negative control, was replicated five times, distributing the replicates randomly in the experimental field. In this context, it is important to highlight that, according to Shrivas et al. (2023), organic amendments such as biocompost can have a significant impact on the diversity of the rhizospheric bacterial community, a crucial aspect for soil health and crop growth. These findings underline the relevance of our study in the broader context of research on soil sustainability and agriculture.

The scion technique was implemented to simulate realistic agricultural conditions. It consisted of taking healthy segments of sugarcane and planting them at a uniform depth of 30 cm in the soil of the cultivation boxes. This technique facilitated the germination and uniform growth of the sugar cane, allowing an accurate assessment of the effects of the biocompost on the crop.

Continuous monitoring was extended over 30 days, during which time the progress of the crop was closely monitored and observable changes in the physical properties of the soil were recorded. This experimental design, implemented in the experimental field of the Environmental Research and Monitoring Laboratory, provides a robust framework for evaluating the effects of biocompost in a controlled environment representative of local conditions in the Northern Huasteca region.

Study material: biocompost composition

In this study, biocompost made from sugarcane cachaza, a by-product obtained through collaboration between the Environmental Research and Monitoring Laboratory of the Tecnológico Nacional de México, Campus Ciudad Valles, and the Asociación de Cañeros CNPR del Ingenio Plan de San Luis, was used. This by-product was subjected to an open-pit composting process, a technique also employed by Saengsanga and Noinumsai (2023), who experimented with water hyacinth and spent coffee grounds as biocompost feedstocks. Their study demonstrated the feasibility and diversity of organic by-products in biocompost production, ensuring controlled biological decomposition. During the process, optimal conditions of temperature (50-60 °C) and relative humidity (50-60%) were maintained, facilitating microbial activity and effective decomposition of organic matter. This semi-industrial collaboration ensured a biocompost of representative quality, reflecting the usual practices of the local sugar industry.

Detailed monitoring of the composting process ensured the consistency and quality of the biocompost applied in the treatments. This material, rich in pulp and bagasse, became a valuable soil amendment. Its open-pit production not only highlights its viability and efficiency, but also its alignment with sustainable agricultural practices. This approach not only makes efficient use of bagasse as a valuable resource, but also addresses the responsible management of industrial waste.

The use of this biocompost in the study treatments ensures that the results obtained are directly applicable to real agricultural scenarios, providing relevant and practical information for the implementation of sustainable strategies in the Huasteca Norte region.

ISSN: 2410-3454

December 2023, Vol.10 No.30 22-29

Measurement of parameters

In the evaluation of soil physical properties, accuracy and validity of measurements are essential. To determine the True Soil Density, the cylinder method of known volume was used, according to ASTM D7928-17. Bulk Density was evaluated using the known volume cylinder method, following the guidelines established by ASTM D5550-18. Soil Porosity was determined by the saturation and weighing method, based on ISO 11274:2014. Water Retention was analysed using the Richards pressure table method, according to ASTM D6836-16. Soil Organic Matter was quantified using the Walkley-Black method supported by ISO 14235:1998. This method, based on the oxidation of organic carbon, provides an accurate estimate of soil organic matter, crucial for understanding soil fertility and long-term health. The implementation of these methods guarantees the analytical quality, consistency and validity of the measurements, ensuring the robustness of the results obtained in this study.

Statistical analysis

For the evaluation of significant differences between treatments, a robust statistical approach was implemented. Initially, normality (Shapiro-Wilk) and homogeneity of variance (Bartlett) tests were performed to confirm the normal distribution of the data and the equality of variances between groups, respectively.

Subsequently, one-way analysis of variance (ANOVA) was applied for each soil property evaluated: Apparent Density (AD), True Density (RD), Porosity (PR), Water Retention Percentage (WR) and Soil Organic Matter Percentage (SOM). We used Tukey's test to perform multiple comparisons of means, identifying significant differences between treatments.

All statistical analyses were carried out at a significance level of 0.05 ($\alpha = 0.05$) to determine the presence of significant statistical differences. In addition, we employed specialised statistical software, specifically Google Colab and Python, to ensure the accuracy and reliability of the results. This statistical approach provided a rigorous and informed assessment of variations in soil properties between treatments, allowing conclusions to be supported by statistical evidence.

Results

Statistical analyses of soil physical properties reveal distinctive patterns among the treatments in the experiment, where the impact of sugarcane cane biocompost on soil in the Huasteca Norte was assessed. This aligns with the findings of Meena and Pradhan (2023), who reported that industrial biocompost derived from rubbish improves soil organic carbon fractions and CO2 biosequestration. Also, parallel research by EL Moussaoui, Ainlhout and Bouqbis (2023) highlighted positive effects of biocompost on alfalfa growth and productivity, demonstrating the efficacy of biocompost in different agricultural contexts. For the Control treatment (T0), which represents the typical soil of the region, an average bulk density (DA) of 1.128 g/cm³, true density (RD) of 1.211 g/cm³ and porosity (PR) of 6.8% were observed. As the proportion of biocompost increased in treatments T1 (10%), T2 (20%), T3 (30%), and T4 (40%), significant changes in these physical properties were observed, with values of DA, DR and PR varying coherently with the increase in biocompost, as shown in Figures 1, 2 and 3.

The analysis of variance (ANOVA) and Tukey's tests highlight statistically significant differences between treatments for these properties ($p < 0.05$), showing the positive impact of biocompost on the physical structure of the soil. In particular, it is observed that the T4 treatment presents a lower bulk density (0.905 g/cm³), lower real density (1.038 g/cm³) and higher porosity (12.8%), indicating substantial improvements in soil structure, according to the data presented in Figures 1, 2 and 3.

Regarding the percentage of water retention (ret_water), significant variations were observed between treatments, with the T1 treatment standing out with 64.4% and the T0 with 52.3%. These data are presented in Figure 4.

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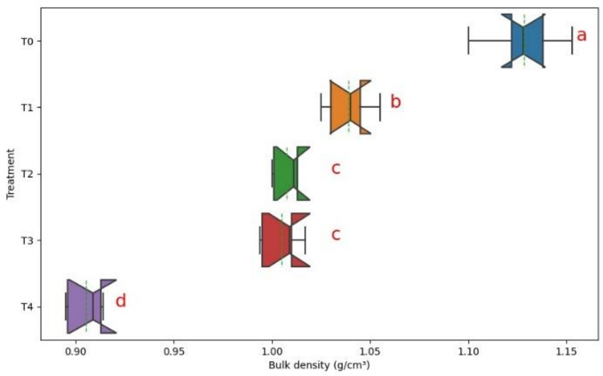

Figure 1 Bulk density (g/cm^3)
Source: Own, Google Colab-Python

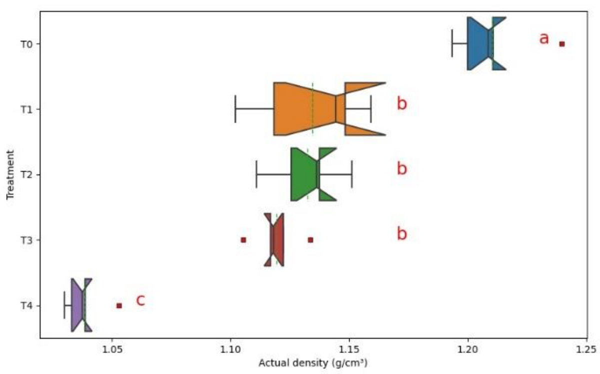

Figure 2 Actual density (g/cm^3)
Source: Own, Google Colab-Python

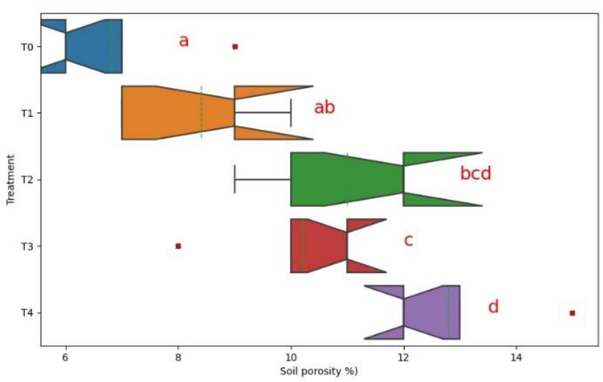

Figure 3 Soil porosity (%)
Source: Own, Google Colab-Python

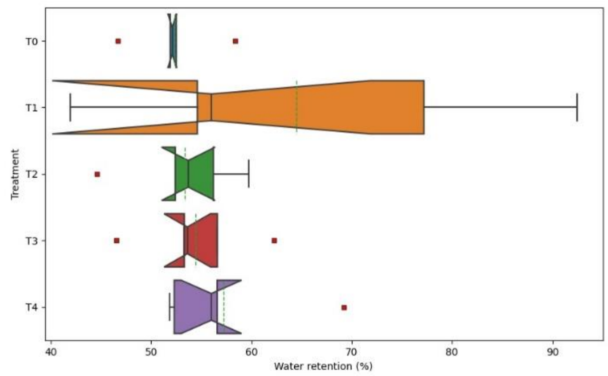

Figure 4 Water retention (%)
Source: Own, Google Colab-Python

Figures 1 to 4 present boxplots illustrating variations in soil physical properties under different biocompost treatments. In each graph, the letters (a, b, c, d, e) indicate significant differences between treatments, providing a visual representation of variations in bulk density, true density, soil porosity and water retention.

When analysing the organic matter content in our treatments, we observed significant variations, which highlights the potential of biocompost to enrich the soil. This phenomenon aligns with the findings of Pradhan and Meena (2023), who highlighted a considerable impact of biocompost on soil nutrient dynamics. This observation is particularly relevant to our study, suggesting that the noted improvements in soil quality could be directly related to changes in nutrient availability and balance, key factors for soil health and productivity. In our results, the T4 treatment showed the highest percentage of soil organic matter (SOM) with 8.3%, in contrast to T0 which showed the lowest with 4.4%. These differences are illustrated in Figure 5, highlighting the variations in organic matter content between the different treatments.

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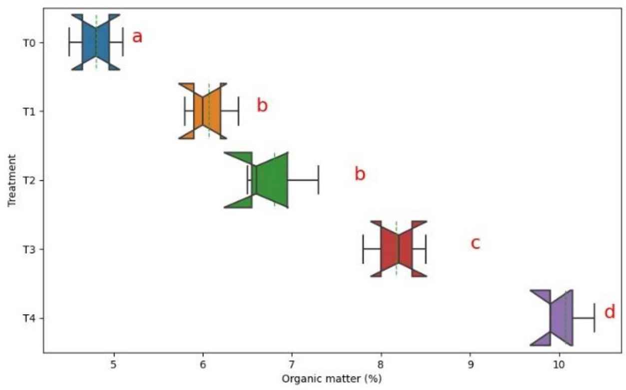

Letters (a, b, c, d indicate significant differences between treatments, providing a visual representation of the variations in % organic matter.

Figure 5 Organic matter (%)
Source: Own, Google Colab-Python

ANOVA and Tukey's test confirm significant differences between treatments for the variable OM ($p < 0.05$). These detailed results highlight the differential response of the soil to different proportions of biocompost, providing valuable evidence of the benefits of this organic amendment on the physical and chemical properties of the soil of the Huasteca Norte. These findings have crucial implications for the design of sustainable agricultural practices and effective soil management in the region.

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Conclusions

In conclusion, the results of this research highlight the transformative potential of biocompost derived from sugarcane cachaza in substantially improving soil physical properties in the Northern Huasteca region. The reduction of bulk and real density, the significant improvement in porosity and water retention, as well as the enrichment of organic matter content, validate the effectiveness of this organic amendment. These findings, in line with the stated objectives and hypotheses, not only contribute to the scientific understanding of sustainable agricultural practices, but also offer practical and ecological insights.

The practical implications of this study suggest that the application of biocompost can not only increase crop productivity, but also has the potential to improve the resilience of agricultural systems to extreme weather events. Increased soil organic matter not only contributes to soil fertility, but can also support microbial biodiversity and long-term soil health. However, it is crucial to recognise the limitations of the study, such as the sample size and the duration of the experiment. More extensive and detailed future research is required to consolidate and extend these results, which will strengthen the scientific basis for effective implementation of sustainable agricultural practices in regions vulnerable to climate change and soil degradation. This study not only supports the viability of biocompost as a strategy for sustainable soil management, but also underscores the importance of continued research in promoting agricultural resilience and mitigating adverse environmental impacts.

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