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Evaluation of the Physicochemical Properties of Vermicompost from Red Californian Worm (*Eisenia foetida*) and Bocashi

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ABSTRACT

The physicochemical properties of two types of organic fertilizers bocashi and vermicompost from red Californian worm (*Eisenia foetida*) were evaluated to determine their effectiveness as soil amendments. The study was conducted at the agroecological module of the Facultad Maya de Estudios Agropecuarios, Universidad Autónoma de Chiapas. The variables analyzed included pH, electrical conductivity, total organic carbon (TOC), total nitrogen (N total), carbon/nitrogen ratio (C/N), moisture content, and cation exchange capacity (CEC). Results showed that bocashi exhibited an alkaline pH (8.02), a high TOC content (13.85%), and total nitrogen (1.12%), demonstrating its strong potential to enhance soil fertility. Its water retention capacity and diverse nutrient profile make it particularly suitable for sustainable agriculture.

The vermicompost from *Eisenia foetida* displayed a pH of 6.31 and a TOC of 10.79%, indicating its effectiveness in improving agricultural soils, especially for vegetable cultivation, although with slightly lower nutrient content than bocashi. Both organic fertilizers presented favorable physical properties, such as low bulk density and high porosity, which are essential for improving soil structure and water retention. Additionally, the cation exchange capacity of bocashi (37.47 cmol/kg) and vermicompost (33.21 cmol/kg) reflects a high nutrient retention capacity, beneficial for plant growth.

Keywords: Organic fertilizer, Humus, Bocashi, Phosphorus, Calcium, pH.

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INTRODUCTION

Organic fertilizers are a key tool in the development of sustainable agricultural systems due to their proven benefits in enhancing the physical, chemical, and biological properties of soil (Cancino, 2022). These inputs increase the amount of organic matter in the soil, promoting greater water retention and a more stable structure, which improves the soil's ability to resist erosion and the effects of climate change (López *et al.*, 2019). Their incorporation into agricultural management has shown positive effects on soil fertility and helps reduce dependency on chemical inputs, which often cause negative side effects in ecosystems (Gupta *et al.*, 2023). Organic fertilizers contain a broader range

of nutrients compared to chemical fertilizers, including micronutrients, trace elements, and physiologically active compounds (FAO, 2024). These amendments enhance plant metabolic processes, promote growth, and increase nutrient uptake efficiency (Sánchez, 2024). Moreover, this type of fertilization significantly stimulates soil microbial activity —an essential component in organic matter decomposition and nutrient recycling (Fang *et al.*, 2021). Recent studies highlight the high potential of organic fertilizers to regenerate degraded soils and contribute to the stability of biogeochemical cycles within agroecosystems (Wang *et al.*, 2022). The intensive use of chemical fertilizers over recent decades has led to detrimental effects, including soil acidification, nitrate leaching into water bodies, and the loss of microbial biodiversity (Arévalo, 2019). In contrast, organic fertilizers have proven effective in mitigating these issues by restoring soil balance and enhancing its cation exchange capacity. This results in improved nutrient retention and creates a more favorable environment for plant development (Zhou *et al.*, 2023). Proper management of organic fertilizers promotes more efficient use of natural resources and reduces greenhouse gas emissions associated with the production and application of synthetic fertilizers (Wan *et al.*, 2021). Vermicompost, derived from the process of worm composting, is a particularly valuable organic fertilizer due to its high concentration of essential nutrients (Higa, 2023). It contains nitrogen, phosphorus, soluble potassium, calcium, and magnesium in levels that often surpass those of synthetic fertilizers. Its application improves water retention and supports the development of more robust root systems, increasing crop yields under both conventional and organic farming conditions (Velasco-Velasco *et al.*, 2021). Recent studies have also shown that vermicompost functions as a natural pathogen suppressant in the soil, reducing the incidence of crop diseases (Salinas-Vásquez *et al.*, 2014). Bocashi is an organic fertilizer known for its production method based on aerobic fermentation of organic materials (Sandoval *et al.*, 2022). Its composition includes a wide range of nutrients such as nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese, zinc, copper, and boron. The availability of these nutrients depends on the materials used and the fermentation conditions (Álvarez *et al.*, 2016). This fertilizer contributes to the regeneration of degraded soils and enhances their infiltration and water-holding capacity, which is particularly beneficial for crop development in regions affected by water stress (Brady, 2014). The microbial activity stimulated by Bocashi facilitates the mineralization of organic compounds, promoting a gradual release of nutrients and minimizing losses due to leaching (Mendivil *et al.*, 2019). A detailed analysis of the physical and chemical characteristics of organic fertilizers is essential to understanding their impact on soils and crops. The use of these fertilizers improves the availability of macro- and micronutrients in nutrient-deficient soils and enhances agricultural productivity in small- and medium-scale production systems (González *et al.*, 2023). Such analysis supports the optimization of management strategies and ensures sustainability in agricultural systems (Plaza-Bonilla *et al.*, 2021). This study investigates the physicochemical properties of Bocashi and vermicompost derived from red Californian worms (*Eisenia foetida*), two of the most widely used organic fertilizers in sustainable agriculture. The analysis includes the chemical and physical characterization of both inputs, aiming to evaluate their capacity to meet plant nutritional demands and their potential as viable alternatives to synthetic fertilizers (Gupta *et al*., 2023). The findings of this study will contribute to a deeper understanding of organic fertilizer management and their role in promoting more sustainable agricultural practices (Zhou *et al*., 2023).

MATERIALS AND METHODS

Study area

The present study was conducted at the agroecological module of the Facultad Maya de Estudios Agropecuarios (FMEA), Universidad Autónoma de Chiapas, located on the Catazajá-Palenque Highway, Km 4, Catazajá, Chiapas, Mexico.

Sampling

The samples were collected from the composting area of the agroecological module of the FMEA, using sampling methods based on the guidelines established in the Mexican Official Standard NOM-021-RECNAT-2000 and other procedures recommended for the analysis of soils and organic materials (Figure 1). To ensure the representativeness and validity of the results, each type of material (soil, bocashi, and worm humus) was carefully collected in triplicate to avoid any possible contamination and to guarantee the integrity of the samples, which were transported and stored under controlled conditions until their analysis in the laboratory. This allowed for the preservation of their physical and chemical properties, ensuring the quality and reliability of the results obtained. The analysis of the samples was carried out at the Soil, Plant and Water Laboratory (LASPA) of the Colegio de Postgraduados, Tabasco Campus.

Sample processing at LASPA

For pH analysis, a digital pH meter was used following the procedure established in NOM-021-RECNAT-2000, which outlines the method for measuring pH in soils and organic materials. Electrical conductivity was determined using a conductivity meter, as this measurement provides insight into the content of dissolved salts and the material's ability to conduct electricity. Total organic carbon (TOC) content was quantified via the wet oxidation method using dichromate, which is essential for assessing the organic quality and fertility of the material (Sánchez, 2023). Total nitrogen (N total) was measured using

Figure 1. Physicochemical analysis of organic fertilizers in the Laboratory (LASPA) of the Colegio de Postgraduados, Tabasco Campus.

the Kjeldahl method, widely accepted for the analysis of soils and organic materials. The carbon-to-nitrogen ratio (C/N ratio) was calculated to assess the balance between carbon and nitrogen, which influences decomposition rates and nutritional quality. Moisture content was determined by drying samples at 105 °C, in accordance with NOM-021-RECNAT-2000, providing crucial information for the management and conservation of organic materials. To analyze nutrients and mineral elements such as Olsen phosphorus (P-Olsen), iron (Fe), manganese (Mn), sulfates ($S\text{-}SO_4$), boron (B), potassium (K), calcium (Ca), and magnesium (Mg), standardized gravimetric and volumetric techniques were employed. These methods ensure precision and reliability in accordance with NOM-021-RECNAT-2000 specifications. Cation exchange capacity (CEC) was determined via the salt adsorption method, also based on gravimetric and volumetric procedures recommended by the same standard. Bulk density (Bd) of organic material, including vermicompost, was measured using the graduated cylinder method as per NMX-FF-109-SCFI-2008, which sets the quality standards for vermicompost production and commercialization in Mexico. Additionally, the physical characteristics of the material such as clay, silt, and sand content were analyzed, and textural classification was performed. This helps to better understand the structure and physical properties of the material, which are essential for its application in agriculture and fertilization processes (Gómez, 2023). A Pearson correlation analysis was conducted to evaluate the relationships among the physicochemical properties of the soil, organic fertilizers (Bocashi and red Californian worm humus), and a reference untreated soil. This statistical test quantifies the strength and direction of the linear relationship between two continuous variables. Correlation values range from −1 to 1, where values close to 1 indicate a strong positive correlation, values near −1 indicate a strong negative correlation, and values close to 0 suggest no significant linear relationship between variables. The correlation analysis included measured soil properties such as pH, TOC, total nitrogen, CEC, electrical conductivity (EC), C/N ratio, and moisture. Analyses were performed using SPSS statistical software (Version 28.0), which allows for the generation of correlation matrices and visual representation of relationships among the various parameters.

RESULTS AND DISCUSSION

The results obtained from the analysis of the chemical and physical properties of the organic materials Bocashi and vermicompost provided crucial insights for their application as organic amendments in agricultural contexts. Both fertilizers exhibited key properties that positively influence soil fertility and structure. Bocashi recorded a pH of 8.02, making it an excellent option for neutralizing acidic soils. This characteristic is particularly important for optimizing crop development, as most crops thrive in soils with a pH near neutrality. Its electrical conductivity (EC) measured 1.89 dS/m, indicating a high concentration of soluble salts. This suggests a nutrient-rich organic material, especially in essential elements such as potassium, calcium, and magnesium, which are vital for plant growth and development. Similar results were reported by Pérez (2021) and Martínez *et al.* (2015), who highlighted Bocashi's effectiveness in enhancing soil fertility and nutritional content. Vermicompost exhibited a pH of 6.31 and an electrical conductivity of 2.25 dS/m. The higher conductivity reflects a more advanced stage of organic matter mineralization, enhancing the availability of essential nutrients for plant roots (Cordova, 2022). Martínez *et al.* (2015) and Plaza *et al.* (2021) emphasized vermicompost as a reliable nutrient source and a significant enhancer of the soil's physical and chemical structure. Furthermore, it contributes to water retention and soil stability crucial factors in sustaining crop productivity under variable climatic conditions (Brady & Weil, 2022). Regarding total organic carbon (TOC) and total nitrogen (N total), Bocashi showed a TOC content of 13.85% and a total nitrogen level of 1.12%. These values reflect its strong potential to enhance soil fertility and structure, as organic carbon contributes to aggregate formation and overall soil stability (Johnson *et al.*, 2016). Vermicompost, in comparison, recorded a TOC of 10.79% and a total nitrogen content of 0.95%. Despite being slightly lower, these values still indicate its effectiveness in soil improvement, particularly by aiding water retention and increasing nutrient availability to plant roots (Smith *et al.*, 2018). These findings are supported by Gómez *et al.* (2012) and Martínez *et al.* (2015), who emphasized the essential role of both Bocashi and vermicompost as organic amendments for soil enhancement. Both contribute to improved fertility, better physical structure, and increased biological activity in the soil. Combining these materials can offer synergistic benefits: Bocashi supplies additional nutrients, while vermicompost enhances physical stability and moisture retention. Comparison of the results with previous studies highlights the importance of selecting the appropriate organic material based on the specific needs of the soil and crop type. In soils characterized by high acidity and nutrient deficiencies, Bocashi may offer greater advantages, while vermicompost is preferable for soils with good physical structure and active biological activity (Pérez *et al.*, 2018). The carbon-to-nitrogen (C/N) ratio of Bocashi and vermicompost provides essential insight into their behavior as organic amendments and their influence on soil dynamics. Bocashi exhibited a C/N ratio of 12.37, indicating rapid decomposition and efficient nitrogen release, which is crucial for the nitrogen cycle in soil ecosystems and crop development (Gómez *et al.*, 2012; Martínez *et al.*, 2015). Vermicompost, on the other hand, had a C/N ratio of 11.36, suggesting greater organic matter stability and a favorable environment for soil microbial activity (Johnson *et al.*, 2016). This stability supports the formation of robust soil structure and prolonged nutrient retention, both of which are vital for crop growth and yield (Smith *et al.*, 2018). Regarding physical properties, both Bocashi and vermicompost exhibited low bulk densities, which are beneficial for enhancing porosity and water retention in compacted soils. Bocashi showed a bulk density of 0.84 g/cm^3, while vermicompost had an even lower value of 0.78 g/cm^3. These physical characteristics significantly improve root access to water and nutrients and ensure adequate soil aeration key elements for biological functioning and overall soil ecosystem health (Gómez *et al.*, 2012; Smith *et al.*, 2018). Cation exchange capacity (CEC) is another key parameter for evaluating the potential of Bocashi and vermicompost as organic amendments. Bocashi exhibited a CEC of 37.47 cmol/kg, compared to 33.21 cmol/kg in vermicompost. This indicates that Bocashi has a greater ability to retain and supply essential nutrients such as potassium, calcium, and magnesium, making it a more efficient option for enhancing soil fertility (Johnson *et al.*, 2016). This nutrient retention capacity supports a consistent supply of elements vital for plant growth and root system development both of which are critical for crop productivity and health (Martínez *et al.*, 2015). Gómez *et al.* (2012) and Martínez *et al.* (2015) emphasize Bocashi's effectiveness as a fast-acting and accessible nutrient source, as well as its ability to increase soil organic content. Johnson *et al.* (2016) highlight the importance of vermicompost in improving both the physical and biological structure of the soil, thereby contributing to long-term soil stability and functionality. Similarly, Smith *et al.* (2018) provide strong evidence that organic materials such as Bocashi and vermicompost enhance soil physical and chemical properties, ultimately leading to higher crop yields and promoting more sustainable and environmentally friendly agricultural practices.

The use of organic materials such as Bocashi and vermicompost not only improves the chemical and physical properties of the soil but also enhances microbial and biological activity key elements for maintaining the balance of the soil ecosystem (Peralta, 2019). The selection of the appropriate organic material depends on the specific characteristics of the soil and the particular needs of the crop, highlighting the importance of tailoring agricultural practices to the unique conditions of each site and farming environment (Johnson *et al.*, 2016; Smith *et al.*, 2018).

The results of this study confirm the importance of organic amendments, such as Bocashi and vermicompost, in improving the physicochemical properties of soil. Bocashi demonstrated a high total organic carbon (TOC) and nitrogen content, consistent with the findings of Sánchez *et al.* (2017), who emphasized its ability to significantly enhance soil fertility and improve organic structure. Fernández *et al.* (2018) also noted that Bocashi promotes the availability of essential nutrients by increasing their retention capacity, which in turn supports crop growth and development. However, the elevated electrical conductivity of Bocashi associated with its high soluble salt content suggests that regular monitoring is necessary to prevent potential salinity issues that could negatively affect crops (Peralta *et al.*, 2019).

Vermicompost showed a neutral pH and notable water retention capacity, supporting the findings of Ramírez *et al.* (2017), who highlighted its ability to improve soil physical structure and stabilize organic matter over time. Additionally, vermicompost exhibited efficient cation exchange capacity (CEC), in line with results reported by González *et al.* (2023). These authors pointed out that, due to its higher degree of mineralization, vermicompost facilitates the availability of essential cations such as potassium, magnesium, and calcium enhancing soil fertility and contributing to long-term stability and productivity. Hernández *et al.* (2019) suggest that the continuous use of vermicompost not only supplies essential nutrients but also enhances the biological balance of the soil by promoting microbial activity and the formation of more resilient and stable soil structures. This underscores the role of vermicompost not merely as an organic amendment but as a fundamental component in sustainable and environmentally friendly agricultural systems.

Pearson correlation analysis

A comparative analysis was conducted based on the obtained physicochemical property data. This approach enabled the evaluation of the direct impact of these organic amendments on specific soil properties, in contrast to the natural behavior of untreated soil. The Pearson correlation matrix quantified relationships among various soil properties, offering a detailed perspective on how organic fertilizers can alter soil structure and composition in terms of pH, cation exchange capacity (CEC), total nitrogen (N total), total organic carbon (TOC), and other key parameters.

The results revealed a moderately positive correlation between soil pH and both TOC and CEC, suggesting that soils with higher pH tend to have greater organic carbon content and a higher capacity to retain nutrients. This implies that treatment with organic fertilizers enhances soil structural stability, thereby improving long-term fertility. In contrast, the untreated soil exhibited lower values across these parameters, underscoring the significant role of organic amendments in improving soil quality (Figure 2).

The resulting correlation matrix provided insight into the interactions among different parameters, allowing for the identification of relevant patterns that help explain how organic fertilizer treatments alter soil properties. This analytical approach is widely used in agro-environmental studies to understand interdependencies among soil physicochemical variables (Zar, 2010).

Electrical conductivity (EC), an indicator of soil salinity, showed significant positive correlations with total nitrogen (N total) and total organic carbon (TOC) in the treated soils, particularly in those amended with Bocashi and vermicompost. This suggests that increases in soil salinity may be associated with higher nutrient content specifically nitrogen and carbon which are essential for plant growth. In untreated soil, EC levels were significantly lower, indicating a reduced availability of nutrients for plant uptake.

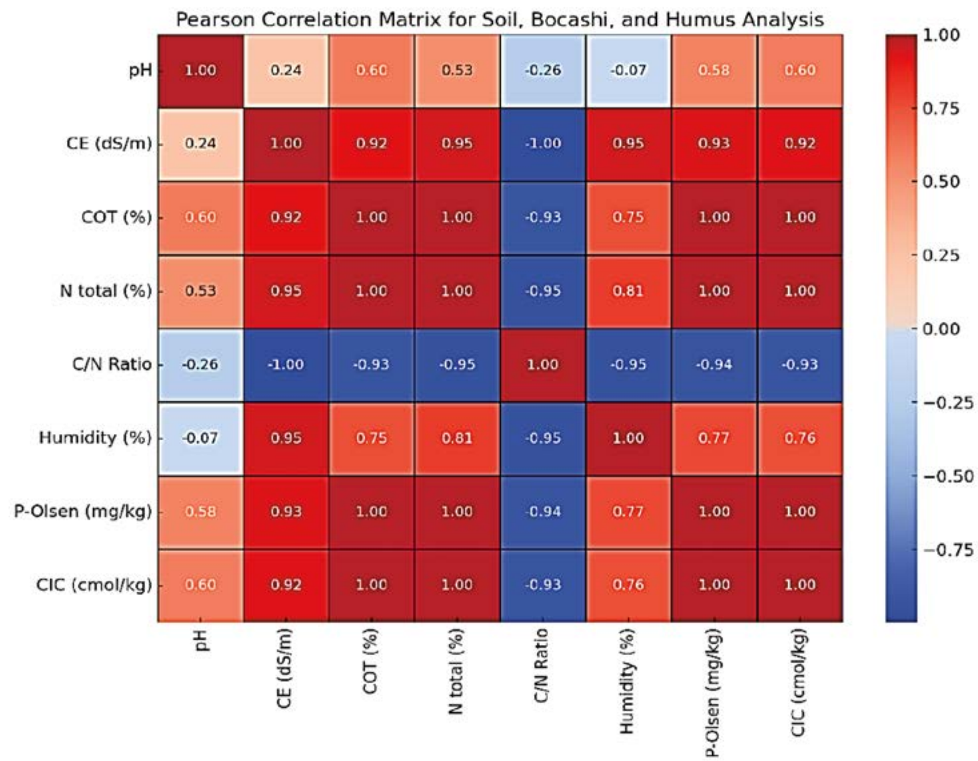

Figure 2. Pearson correlation matrix showing the relationships among various soil properties in treatments with Bocashi, vermicompost, and untreated soil.

The C/N ratio showed negative correlations with most of the analyzed variables, suggesting that soils with lower C/N ratios are more fertile and exhibit greater nutrient retention capacity. This trend was especially evident in soils treated with organic amendments, indicating enhanced microbial activity and more efficient organic matter decomposition. In contrast, untreated soils exhibited higher C/N ratios, reflecting lower levels of organic matter mineralization and, consequently, reduced nutrient availability.

Soil moisture in treated samples showed significant correlations with electrical conductivity (EC) and total nitrogen (N total), indicating that more humid soils tend to be more saline and have higher nitrogen content. According to Flores *et al.* (2013), the application of manure increased soil moisture from 5.09% to 6.52% and EC from 3.11 dS/m to 3.77 dS/m. Similarly, Pérez *et al.* (2018) observed a significant correlation between moisture and EC in agricultural soils. Phosphorus availability, measured using the Olsen method (P-Olsen), showed a strong positive correlation with total organic carbon (TOC) in treated soils. This suggests that higher organic carbon content enhances the release and availability of phosphorus, a vital nutrient for plant development. In untreated soils, phosphorus availability was lower, reinforcing the idea that incorporating organic amendments improves nutrient use efficiency.

The correlation analysis results revealed that soils treated with Bocashi and vermicompost exhibit significantly improved physicochemical properties compared to untreated soils. Correlations among parameters such as TOC, N total, and cation exchange capacity (CEC) suggest that these organic amendments significantly contribute to improving soil fertility, making it more suitable for agriculture. These findings are consistent with previous research conducted in various regions of Mexico, including Tabasco, where organic fertilizers have been shown to positively impact soil properties such as organic carbon content, nitrogen levels, and CEC. Hernández *et al.* (2022), in the Chontalpa region of Tabasco, reported that the use of Bocashi and vermicompost significantly increased TOC and N total, thereby enhancing soil quality and fertility for maize and vegetable crops. These findings align with the results of this study, in which TOC and N total showed strong positive correlations with other parameters like CEC, indicating that organic amendments contribute to more fertile and better-structured soils (Lee & Stoklosa, 2021). In soils treated with organic fertilizers in Veracruz, González *et al.* (2023) found a significant positive relationship between salinity (measured via EC) and nitrogen and carbon levels. In this study, samples with higher EC also showed higher concentrations of nitrogen and carbon, suggesting that increased salinity may be associated with greater availability of these essential nutrients. However, it is important to note that excessive salinity can negatively affect plant health (Zamora *et al.*, 2021), underscoring the need to balance the application of these amendments. The behavior of the C/N ratio observed in this study is also consistent with previous research. Ramírez *et al.* (2020), in agricultural soils of southern Mexico, found that a lower C/N ratio is associated with higher microbial activity and, consequently, greater organic matter mineralization. This helps explain the negative correlation observed between the C/N ratio and parameters like TOC and N total in soils treated with organic fertilizers in this study. Increased microbial activity contributes to more efficient organic matter decomposition, resulting in enhanced nutrient release and improved soil fertility. Moreover, the behavior of soils treated with Bocashi and vermicompost supports the idea that organic amendments not only improve soil structure but also enhance its capacity to retain essential nutrients such as phosphorus, which was positively correlated with TOC in our findings. This aligns with the results of Vega *et al.* (2022), who demonstrated that applying vermicompost increases phosphorus availability in degraded soils, improving their long-term fertility. Taken together, these studies highlight that organic amendments like Bocashi and vermicompost have a profound impact on soil physicochemical properties, reinforcing their potential for restoring agricultural soils across various regions of Mexico. The results obtained in this study not only corroborate previous findings but also provide valuable insights for future research on sustainable soil management and nutrient optimization in tropical agricultural systems.

CONCLUSIONS

In conclusion, the evaluation of the physicochemical properties of Bocashi and vermicompost demonstrated that both organic fertilizers significantly outperformed the native soil of the Catazajá region, Chiapas, which was used as the control in the analyses. Both Bocashi and vermicompost possess the necessary physicochemical properties for the restoration of degraded soils. Through continuous application, it is possible to improve nutrient content and availability, enhance soil texture, and support the recovery of beneficial microorganisms essential for the decomposition of organic matter. Bocashi stands out due to its high total organic carbon (TOC) and total nitrogen content, making it a highly effective amendment for increasing soil fertility. Its favorable TOC and nitrogen levels, combined with strong cation exchange capacity (CEC) and improved water retention, make it an ideal resource for agricultural soils that require rapid productivity enhancement. Although vermicompost contains slightly lower nutrient levels compared to Bocashi, it remains highly beneficial for improving soil structure, increasing water retention, and promoting microbial activity. Therefore, soils in the study area can be effectively enriched through the use of Bocashi and vermicompost, offering a sustainable approach to improving soil health and agricultural productivity.

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