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Effects of organic fertilizers on oil palm (*Elaeis guineensis* Jacq.) in Colombian soil

Efectos de fertilizantes orgánicos sobre el cultivo de palma de aceite (*Elaeis guineensis* Jacq.) en suelos colombianos

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ABSTRACT

Colombia is the leading oil palm producer in the Americas, with an area exceeding 520,000 hectares. Favorable prices and the long-term stability of this crop are driving an expansion in cultivated areas. However, concerns about environmental degradation caused by oil palm cultivation have increased, mainly due to the negative impact on the soil's physical, chemical, and biological properties. The use of organic fertilizers in oil palm cultivation improves soil fertility, helps maintain stable production levels, increases the plants' resistance to disease, and is more environmentally friendly. This study aims to evaluate the impact of applying three organic fertilizers: palm rachis compost, poultry manure compost, and bovine manure compost, as a strategy to mitigate the problem of low fertility and chemical degradation of soils under oil palm cultivation in the municipality of Tibú, Norte de Santander, Colombia. The work consisted of a field experiment with a quantitative approach based on a block experimental design. Both bovine and poultry manure composts increased oxidizable organic carbon and total nitrogen in the soil. All sources of organic matter proved to be promising and suitable alternatives for improving the chemical properties of the soil under oil palm cultivation.

Key words: bovine manure; compost; fertilization; poultry manure; regenerative agriculture; soil fertility

RESUMEN

Colombia es el principal productor de palma de aceite en las Américas, con una superficie que supera las 520.000 hectáreas. Los precios favorables y la estabilidad a largo plazo de este cultivo están impulsando la expansión de las áreas cultivadas. Sin embargo, han aumentado las preocupaciones sobre la degradación ambiental asociada al cultivo de palma de aceite, principalmente debido al impacto negativo en las propiedades físicas, químicas y biológicas del suelo. El uso de fertilizantes orgánicos en el cultivo de palma de aceite mejora la fertilidad del suelo, ayuda a mantener niveles de producción estables, aumenta la resistencia de las plantas a las enfermedades y resulta más respetuoso con el medio ambiente. Este estudio tiene como objetivo evaluar el impacto de la aplicación de tres fertilizantes orgánicos -compost de raquis de palma, compost de gallinaza y compost de estiércol bovino- como estrategia para mitigar los problemas de baja fertilidad y degradación química de los suelos cultivados con palma de aceite en el municipio de Tibú, Norte de Santander, Colombia. El trabajo consistió en un experimento de campo con enfoque cuantitativo, basado en un diseño experimental de bloques. Tanto el compost de estiércol bovino como el avícola incrementaron el carbono orgánico oxidable y el nitrógeno total en el suelo. Todas las fuentes de materia orgánica demostraron ser alternativas prometedoras y adecuadas para mejorar las propiedades químicas del suelo en cultivos de palma de aceite.

Palabras clave: agricultura regenerativa; bovinaza; compostaje; fertilización; fertilidad de suelo; gallinaza

INTRODUCTION

Oil palm is highly significant due to rising global demand for vegetable oils (Salgado-García *et al.*, 2023). According to the Colombian Federation of Oil Palm Farmers (Fedepalma, 2024), the estimated *per capita* consumption of vegetable oils in the country is 40 kg per year, distributed across various products that use vegetable oil as a raw material. This information indicates the high national demand for this product. However, its production has a series of environmental impacts that threaten crop sustainability.

Salgado-García *et al*. (2023) stated that oil palm cultivation is associated with problems such as the displacement of livestock systems, deforestation, and natural habitat destruction; therefore, it is necessary to implement alternative practices for this crop to mitigate these problems.

Oil palm production has increased steadily over the past decade, and by January 2023, a historical high of 168,900 tons of oil palm was reached (Fedepalma, 2023), indicating strong national demand for this product. It is important to note that although 99% of oil palm crops in Colombia are free of deforestation (Fedepalma, 2023), certain practices associated with palm cultivation can degrade the soil in which the palms are planted and, consequently, reduce productivity, thereby generating economic, social, and environmental problems.

Oil palm (*Elaeis guineensis* Jacq.) is considered a perennial crop with a productive life of 25 years. It extracts large amounts of nutrients from the soil and requires land with good topographical and agroecological conditions for normal growth, development, and productivity (Fedepalma, 2023). Oil palm crops require agronomic practices to be implemented, taking into consideration the factors that enhance the sustainability of the crop.

On the other hand, the profitability of this crop depends on sound nutritional management, which requires the application of large amounts of fertilizer. Wulandari *et al.* (2025) indicated that excessive use of synthetic chemical fertilizers on oil palm crops degrades soil quality, including decreased fertility, damage to soil structure, and depletion of organic matter, which negatively affects productivity and yield quality. Reliance on synthetic chemical fertilizers can also lead to imbalances in soil and foliar nutrients, reduce palm productivity, and cause environmental pollution.

This situation causes soil degradation, an essential renewable resource for producing the food necessary to sustain human beings; therefore, when it occurs, it is considered a complex and global problem (Gomiero, 2016). Soil degradation is also associated with decreases in soil organic matter and biological activity, destruction of soil structure, formation of crusts, reduced fertility, and changes in soil acidity (Lahmar & Ruellan, 2007).

Additionally, soils used for oil palm cultivation are typically low in fertility, which limits their capacity to provide a continuous supply of nutrients for the growth and production of oil palm (Hasputri *et al.*, 2017).

Limitations in nutrient availability must be offset by sustainable soil management practices that include optimized fertilizer management for oil palm (Goh *et al.*, 1999), which provide benefits beyond preventing nutrient deficiency and maintaining plant health, such as improving chemical, physical, and biological conditions that increase overall soil fertility (Magdoff & Weil, 2004).

Fertilizing oil palm with organic fertilizers can improve soil fertility, making the crop's production level more stable and increasing plant resistance to disease and adverse environmental conditions. The application of organic fertilizers can also increase the effectiveness of inorganic fertilizers and boost plant production in the long term (Hasputri *et al.*, 2017).

Organic fertilizers, including poultry manure, bovine manure, and plant-residue composts, improve soil fertility by increasing the availability of essential nutrients such as nitrogen, phosphorus, and potassium (Maryani *et al.*, 2021; Purwanto *et al.*, 2022). This results in better nutrient uptake by plants and improved plant growth (Ogboghodo *et al.,* 2004).

Impacts on the physical and chemical properties of the soil have also been reported. According to Adeyemo *et al.* (2019), organic fertilizers improve soil structure, promote better infiltration, increase water retention, and improve soil aeration. Kobierski *et al.* (2017) reported that organic fertilizers increase the cation exchange capacity and elevate soil pH.

In Colombia, soil management and crop nutrition have not received the attention they require, despite their high impact on productivity and sustainability in oil palm cultivation (Munévar, 1998).

Therefore, the main goal of this study is to evaluate the impact of applying three organic fertilizers: palm rachis compost, chicken manure compost, and bovine manure compost, as a strategy to mitigate the problem of low soil fertility and chemical degradation of soils destined for oil palm cultivation in the municipality of Tibú, Norte de Santander, Colombia.

MATERIALS AND METHODS

Study area

This study was conducted on soils cultivated with oil palm (*Elaeis guineensis* Jacq.) at the Villa Teresa farm in the Petrolea village of Tibú, Norte de Santander, Colombia. The site is part of the Catatumbo Tropical Rainforest, with an average annual rainfall of 3900 mm and an annual mean temperature of 32°C. The research was descriptive and experimental, using a quantitative approach based on an experimental design with a block arrangement.

Population and sample

The experiment was conducted on a farm representative of the local oil palm farmers' union, selected using convenience sampling. It has a planted area of 69 hectares, cultivated with oil palm trees over seven years old.

Experimental design

For the experiment, an area of one hectare (10,000 m^2) with a plant density of 124 palm trees per hectare was delineated, and a block design was implemented in the form of rectangular east-west strips, each consisting of 16 plants.

The experiment consisted of four treatments distributed across five blocks. Each treatment included four palm trees, arranged in a zigzag pattern within each block, following the pre-existing planting system of the crop plot.

In this way, twenty palms were used per treatment, for a total of 80 plants in the experiment (Figure 1).

The effect of applying organic fertilizers on the chemical properties of the soil under study was evaluated using three composted organic sources (chicken manure, bovine manure, and oil palm bunch residues) and a control consisting of soil conventionally treated with chemical fertilizers. The treatments were as follows:

T1: Control, soil without application of organic matter

T2: Application of chicken manure compost (18600 kg/ha)

T3: Application of bovine manure compost (18600 kg/ha)

T4: Application of oil palm bunch residues compost (18600 kg/ha)

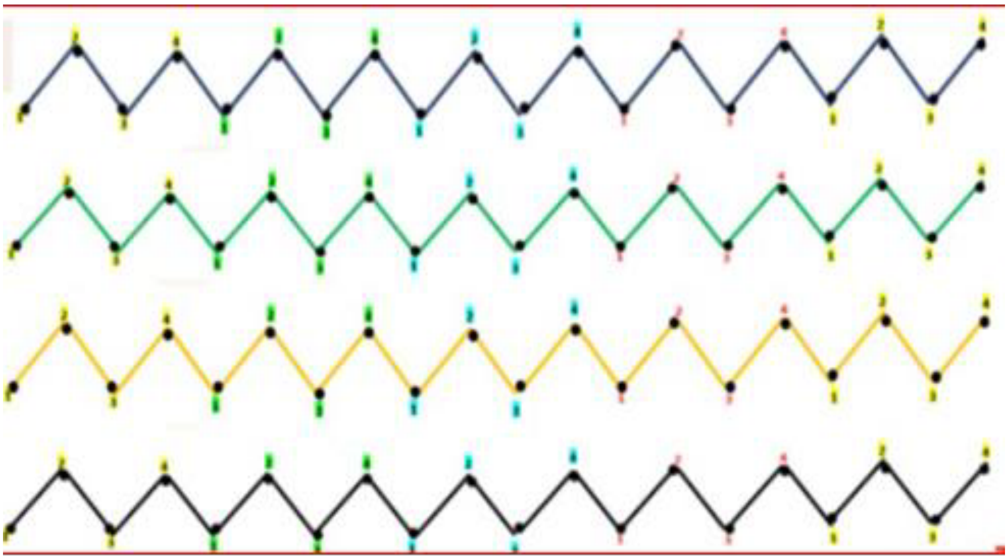

Figure 1. *Scheme of the experimental design of four treatments in the field of the Villa Teresa farm, Petrolea village, municipality of Tibu, Norte de Santander*

Study factors

This is a single-factor study that evaluated the application of 150 kg of organic matter per plant in one year, divided into three applications of 50 kg per plant spaced every four months. Three sources of compost were used (bovine manure, poultry manure, and palm bunch residues compost).

Phases of the experiment

Initial field phase. In this phase, the chemical properties of the soil under study were analyzed. Planting density, crop age, origin of the plant material, and its variety were identified. According to the general study of soils by IGAC (2006), in the northeastern part of Tibú, the predominant soil order is Inceptisol, with high exchangeable aluminum and low saturation of exchangeable bases due to low pH and low overall fertility. The landscape of the area is a slight flat slope that gives rise to the formation of valleys and terraces. The experimental plot was located in the central part of the plantation so that the blocks had homogeneous characteristics. Strips with zigzag rows were organized, ensuring homogeneity in the geomorphology and soil characteristics of each block.

Georeferencing Phase. Using the QGIS software (Figure 2), the georeferencing of each plant was carried out, and at the base of each palm stem, a mark was painted, where an alphanumeric code indicated the number of the palm and the organic source applied as fertilizer.

Figure 2. *Georeferencing of the area*

Organic fertilizer application phase. Composted organic matter was applied to the soil surface (Figure 3) at the plate area of each plant, 1.5 meters from the base of the stem, every 4 months for one year.

Figure 3. *Application of organic fertilizers in oil palms for each treatment in the study area*

Sampling phase and analysis of soil properties. Four soil sampling cycles were conducted, one before the first fertilizer application and one every four months thereafter. A composite surface soil sample was collected around the stem of each oil palm at a depth of 30 centimeters in all repetitions of each treatment. These composite soil samples were collected according to the sampling protocols at a depth of 30 cm, as this is the soil layer where oil palms concentrate tertiary and quaternary roots.

The soil properties analyzed in the laboratory were: pH and electrical conductivity (EC) in a 1:1 soil-water suspension; effective cation exchange capacity (ECEC) measured by the 1N ammonium acetate method at pH 7; oxidizable organic carbon (COOx) measured by the modified Wakley & Black method; and total nitrogen (total N) estimated from OM.

The soil physical variables measured were the bulk density (Bd) using the waxed aggregate method and the soil water content at saturation using the gravimetric method.

Statistical analysis

Data were organized and tabulated in Microsoft Excel. Descriptive statistics and analysis of variance (ANOVA) were performed using Statgraphic Centurion statistical software. ANOVA was conducted after verifying the assumptions of normality (Shapiro-Wilk) and homogeneity of variances (Levene). In cases of noncompliance with these assumptions, the nonparametric Kruskal-Wallis test was used.

The comparison of the first and last soil samples allowed for the evaluation of the effectiveness of organic fertilizer treatments on soil properties. Additionally, the analysis of different applications was conducted to determine the effect of fertilizer dose fractionation.

RESULTS

The soil analysis at the initial phase of the experiment reported a pH below 5.0, described as strongly acidic. After the first application, the soil in the control treatment and in treatments with bovine manure compost and palm bunch residues compost had a pH between 4.5 and 5.5. After the third application of organic fertilizers, a notable increase in pH was observed; only the control treatment maintained the initial soil pH, which aligns with several studies reporting an increase in soil pH with the application of organic fertilizers (Kobierski *et al.*, 2017; Soremi *et al*., 2017; Bakayoko *et al*., 2009).

After the first application of organic fertilizer, the soil pH and electrical conductivity (EC) were statistically heterogeneous across the sources of organic fertilizer applied. Chicken manure compost produced a neutral pH, whereas bovine and palm bunch residues raised the pH to moderately acidic, while the control treatment remained strongly acidic (Table 1). The EC was lowest in the soil without compost application (control). The three composts evaluated showed statistically higher EC than the control (Table 1), which is associated with the contribution of soluble salts contained in organic fertilizers, as pointed out by Liebhardt (1976).

After the third application of composts, pH, EC, and effective cation exchange capacity (ECEC) showed significant differences. The chicken manure treatment had a higher pH (neutral), followed by bovine manure and palm bunch residues treatments.

At the end of the study, the ECEC was higher when applying chicken manure, compared to the control soil, and the use of bovine manure and palm bunch residues. This variable was homogeneous after the first application of the composts (Table 1).

Table 1. *Effect of the application of three sources of composted organic fertilizer on pH, EC, ECEC, and Moisture Saturation*

	Variable	pH	EC (dS/m)	ECEC (meq/100)	Saturation H (%)
Initial analysis	***p*-value**	0.0006	0.0003	0.1558	0.5875
	Chicken manure	6.27 ± 0.19 b	1.44 ± 0.39 b	23.24 ± 5.20 a	34.00 ± 5.87 a
	Bovine manure	5.24 ± 0.11 a	1.77 ± 0.61 b	18.80 ± 3.68 a	33.78 ± 6.16 a
	Oil palm bunch residues	5.50 ± 0.78 a	1.46 ± 0.36 b	19.46 ± 6.52 a	31.88 ± 6.38 a
	Control	4.81 ± 0.28 a	0.25 ± 0.02 a	14.54 ± 6.79 a	28.08 ± 10.10 a
	***p*-value**	0.0001	0.0001	0.0004	0.2426
Final analysis	Chicken manure	6.73 ± 0.03 c	1.77 ± 0.51 b	30.92 ± 6.78 b	31.54 ± 4.58 a
	Bovine manure	5.58 ± 0.31 b	0.78 ± 0.33 a	17.32 ± 6.00 a	30.20 ± 5.68 a
	Oil palm bunch residues	5.80 ± 0.44 b	0.98 ± 0.31 a	19.56 ± 7.74 a	29.78 ± 5.39 a
	Control	4.91 ± 0.44 a	0.46 ± 0.11 a	11.85 ± 6.73 a	26.14 ± 5.60 a

Note. ANOVA Analysis of Variance Test (n = 20). Equal letters in the same column indicate homogeneity in the variable evaluated; different letters indicate that there are significant differences.

The results of oxidizable organic carbon (COOx), total nitrogen (Total N), and apparent density (Bd) showed statistically significant differences depending on the type of organic fertilizer applied to the soil, both at the beginning and at the end of the study, as seen in Table 2. These differences indicate that the COOx and total N levels in the soil were significantly influenced by the type of organic fertilizer applied, as well as its Bd.

Table 2. *Effect of the application of three sources of organic fertilizer on oxidizable organic carbon, total nitrogen, and soil bulk density*

	Variable	COOx (%)	Total N (%)	Bd (g/cm³)
Initial analysis	***p*-value**	0.0002	0.0002	0.038
	Chicken manure	2.16 ± 0.17 ab	0.18 ± 0.01 ab	1.22 ± 0.06 ab
	Bovine manure	2.85 ± 0.29 bc	0.24 ± 0.02 bc	1.15 ± 0.06 ab
	Oil palm bunch residues.	3.04 ± 0.69 c	0.25 c ± 0.06 c	1.13 ± 0.07 a
	Control	1.54 ± 0.28 a	0.12 ± 0.02 a	1.30 ± 0.11 b
	Variable	**COOx (%)**	**Total N (%)**	**Bd (g/cm³)**
Final Analysis	***p*-value**	0.0002	0.0002	0.0002
	Chicken manure	3.80 ± 1.25 b	0.31 ± 0.10 b	1.05 ± 0.11 a
	Bovine manure	4.22 ± 1.44 bc	0.35 ± 0.12 bc	1.03 ± 0.13 a
	Oil palm bunch residues.	5.97 ± 2.05 c	0.49 ± 0.17 c	0.92 ± 0.12 a
	Control	1.88 ± 0.62 a	0.15 ± 0.05 a	1.28 ± 0.11 b

Note. The table shows the results of the ANOVA Test (n = 20). The initial analysis was carried out independently of the data recorded at the end of the experiment. Equal letters in the same column indicate homogeneity in the evaluated variable, whereas different letters indicate significant differences after the application of composted organic matter on oxidizable organic carbon (COOx), total nitrogen (total N), and apparent density in soils cultivated with oil palm at the beginning (one application) and at the end of the experiment (three applications).

The control showed the lowest values for COOx and total N, while the soil treated with oil palm bunch residues recorded the highest values. Soils treated with chicken manure and bovine manure showed intermediate values between these extremes, confirming the benefit of organic fertilizers to increase soil organic matter (Babu *et al*., 2021).

On the other hand, soil Bd also showed significant differences depending on the type of organic fertilizer applied, both at the beginning and at the end of the study. The highest Bd was recorded in the control soil, indicating greater compaction in this treatment. In contrast, the application of organic fertilizers tended to reduce soil Bd, producing more homogeneous values among the three types of organic fertilizers at the end of the study.

Effect of fractioning the bovine manure fertilizer on the chemical characteristics of the soil

The data recorded for the variables pH, ECEC, COOx, total N, and Bd in the soil after the first, second, and third applications of cattle compost were statistically homogeneous, suggesting that these soil variables did not undergo significant changes due to the second and third applications of organic matter (Table 3).

In contrast, EC and saturation moisture content showed significant changes over time, correlated with the number of bovine manure applications. Both variables gradually decreased with the second and third applications of this organic fertilizer (Table 3). This trend suggests that bovine manure affects soluble salts and moisture retention in the soil.

Table 3. *Effect of bovine manure fractionation on pH, EC, ECEC, saturation moisture content, COOx, total N, and Bd.*

Variable	Test	*p*-value	Results		
			Initial	Intermediate	Final
pH	ANOVA Esfericity	0.230 0.626	5.24 ± 0.11 a	5.22 ± 0.15 a	5.58 ± 0.31 a
EC (dS/m)	ANOVA Esfericity	0.024 0.396	1.77 ± 0.61 b	0.95 ± 0.39 ab	0.78 ± 0.33 a
ECEC (meq/100)	ANOVA Esfericity	0.637 0.824	18.80 ± 3.68 a	16.96 ± 6.10 a	17.32 ± 6.00 a
Saturation (%)	ANOVA Esfericity	0.015 0.063	33.78 ± 6.16 b	31.04 ± 6.18 ab	30.20 ± 5.68 a
COOx (%)	ANOVA Esfericity	0.113 0.392	2.85 ± 0.29 a	2.55 ± 0.75 a	4.22 ± 1.44 a
N total (%)	ANOVA Esfericity	0.114 0.392	0.24 ± 0.02 a	0.21 ± 0.06 a	0.35 ± 0.12 a
Bd (g/cm3)	ANOVA Esfericity	0.059 0.609	1.15 ± 0.06 a	1.19 ± 0.10 a	1.03 ± 0.13 a

Note. The table shows results of the ANOVA Test for the fractionation of treatments. The analysis was carried out independently for each group of data obtained for the fractions of bovine organic fertilizer applied (n = 5). Equal letters in the same row indicate homogeneity in the variable evaluated, whereas different letters indicate significant differences for the pH, EC, effective cationic exchange capacity (ECEC), moisture saturation, oxidizable organic carbon (COOx), total nitrogen (Total N), and bulk density (Bd) of the soil. Source: Authors.

Effect of fractioning the chicken manure fertilizer on the chemical characteristics of the soil

The analysis of moisture content at saturation (%), COOx, and total N in relation to the repeated application of chicken manure fertilizer showed no significant differences throughout the study (Table 4). This indicates that moisture saturation, COOx, and total N remained stable regardless of the number of fractions of chicken manure fertilizer applied to the soil.

However, statistically significant differences were observed for the variables pH, EC, ECEC, and Bd depending on the number of chicken manure fertilizer fractions applied (Table 4). This suggests that soil reaction, soil salt concentration, and bulk density were affected by the number of applications of chicken manure fertilizer.

At the end of the study, after the final application of chicken manure fertilizer, an increase in soil pH, EC, and ECEC was recorded compared with the data obtained after the first application.

Table 4. *Effect of chicken manure fractionation on pH, EC, ECEC, saturation moisture content, COOx, total N, and bulk density*

Variable	Test	*p*-value	Results		
			Initial	Intermediate	Final
pH	ANOVA Esfericity	0.008 0.181	6.27 a ± 0.19 a	6.61 ± 0.35 ab	6.73 ± 0.03 b
EC (dS/m)	ANOVA Esfericity	0.007 0.043	1.44 ± 0.39 a	0.86 ± 0.18 a	1.77 ± 0.51 a
ECEC (meq/100)	ANOVA Esfericity	0.030 0.496	23.24 ± 5.20 a	25.12 ± 6.93 ab	30.92 ± 6.78 b
Saturation H (%)	ANOVA Esfericity	0.212 0.798	34.00 ± 5.87 a	33.50 ± 4.68 a	31.54 ± 4.58 a
COOx (%)	ANOVA Esfericity	0.150 0.357	2.16 ± 0.17 a	2.36 ± 0.70 a	3.80 ± 1.25 a
N total (%)	ANOVA Esfericity	0.149 0.356	0.18 ± 0.01 a	0.19 ± 0.05 a	0.31 ± 0.10 a
Bd (g/cm3)	ANOVA Esfericity	0.026 0.304	1.22 ± 0.06 a	1.18 ± 0.09 ab	1.05 ± 0.11 b

Note. The table shows the results of the ANOVA Test for the fractionation of treatments. The analysis was carried out independently for each group of data obtained for the fractions of chicken organic fertilizer applied (n = 5). Equal letters in the same row indicate homogeneity in the variable evaluated, whereas different letters indicate significant differences for pH, EC, effective cationic exchange capacity (ECEC), moisture saturation, oxidizable organic carbon (COOx), total nitrogen (Total N), and bulk density (Bd) of the soil.

Apparently, chicken manure fertilizer has a higher decomposition and mineralization rate compared to bovine manure, since it generates a smaller increase in the COOx content and total N throughout the application periods.

Effect of fractioning the oil palm bunch residues fertilizer on the chemical characteristics of the soil

The results indicate that the fractionation of oil palm bunch residue fertilizer did not cause significant changes over time for the variables of pH, EC, moisture saturation level, COOx, total N, and Bd (Table 5).

However, the ECEC presented significant differences over time, specifically, an increase after the second application (Table 5). This increase may indicate an improvement in the soil's ability to retain and exchange cation ions essential for plant growth.

It is worth noting that the ECEC recorded after the second application of composting remained constant in the third and final soil analysis. This suggests that the positive effect of the oil palm residue fertilizer on the ECEC remained stable over time, which is a positive indication for soil health and fertility in the context of sustainable agriculture.

Table 5. *Effect of oil palm bunch residues fertilizer fractionation on pH, EC, ECEC, saturation moisture content, COOx, total N, and Bd.*

Variable	Test	*p*-value	Results		
			Initial	Intermediate	Final
pH	ANOVA Esfericity	0.632 0.627	5.50 ± 0.78 a	5.47 ± 0.80 a	5.80 ± 0.44 a
EC (dS/m)	ANOVA Esfericity	0.058 0.838	1.46 ± 0.36 a	0.51 ± 0.15 a	0.98 ± 0.31 a
ECEC (meq/100)	ANOVA Esfericity	0.033 0.077	19.46 ± 6.52 a	16.22 ± 6.71 b	19.56 ± 7.74 ab
Saturation (%)	ANOVA Esfericity	0.073 0.017	31.88 ± 6.38 a	30.88 ± 5.73 a	29.78 ± 5.39 a
COOx (%)	ANOVA Esfericity	0.097 0.129	3.04 ± 0.69 a	2.36 ± 0.70 a	5.97 ± 2.05 a
N total (%)	ANOVA Esfericity	0.096 0.127	0.25 ± 0.06 a	0.22 ± 0.08 a	0.49 ± 0.17 a
Bd (g/cm3)	ANOVA Esfericity	0.051 0.850	1.13 ± 0.07 a	1.19 ± 0.11 a	0.92 ± 0.12 a

Note. The table shows the results of the ANOVA Test for the fractionation of treatments. The analysis was carried out independently for each group of data obtained for the fractions of oil palm bunch residues organic fertilizer applied (n = 5). Equal letters in the same row indicate homogeneity in the variable evaluated, whereas different letters indicate significant differences for the pH, EC, effective cationic exchange capacity (ECEC), moisture saturation, oxidizable organic carbon (COOx), total nitrogen (Total N), and bulk density (Bd) of the soil.

With the above, it can be confirmed that the increase observed after the third application of oil palm bunch residue fertilizer in the COOx and total N parameters of the soil is relevant in demonstrating that this residue from the crop itself can be used as a soil improver.

Furthermore, oil palm bunch residue fertilizer was the treatment that showed the greatest increase in COOx and total N, indicating a greater humigenic factor in this organic matter, whereas chicken manure and bovine manure decompose and mineralize to a greater extent.

DISCUSION

This study underlines the importance of properly selecting organic amendments to improve soil properties. Chicken manure, by increasing ECEC, can offer substantial benefits in soil fertility, promoting greater retention of essential nutrients and improving their availability for plants (Adeyemo *et al*., 2019). This enhances the sustainability and productivity of oil palm farmers, especially in management systems that seek to reduce dependence on chemical fertilizers (Supriatna *et al*., 2023).

Each type of organic fertilizer brings specific benefits to agricultural soil. Oil palm bunch residues have been shown to be highly effective in enriching the soil with organic carbon and nitrogen. These elements are essential for improving soil fertility and providing the nutrients necessary for the growth of healthy crops (Waldrip *et al*., 2011; Inal *et al.*, 2015; Liu *et al.*, 2020). Furthermore, oil palm bunch residues can help improve soil water-holding capacity and promote better soil structure, which is crucial for erosion resistance and nutrient conservation (Marichal *et al*., 2019).

On the other hand, chicken and bovine manures also showed significant benefits. Although they can generate lower organic carbon and nitrogen levels compared to oil palm bunch residues, these composts have positive effects on soil structure, as observed in Bd reduction (Dunjana *et al*., 2012). They reduce soil compaction and improve aeration, which favors plant root development and facilitates the absorption of essential nutrients (Hojjati & Nourbakhsh, 2007).

On the other hand, the progressive accumulation of poultry manure in the soil can increase pH, improving the soil's nutrient exchange capacity (Waldrip *et al*., 2011). A significant decrease in soil compaction is also observed, as indicated by a reduction in Bd, which coincides with the study of Adeyemo *et al.* (2019).

An important consideration is the need to properly manage poultry manure fertilizer applications to optimize the soil's physical and chemical properties, thereby contributing to the sustainability and productivity of agricultural systems.

Furthermore, the analysis of the effect of the number of fractions in the application of each organic matter treatment indicates that chicken manure is the source of organic matter that showed a statistical difference in several parameters that increased with each application, whereas bovine manure and oil palm bunch residues fertilizer showed their greatest increase after the first application.

The application of any of the three organic sources to the soil, at an initial dose of 50 kg/plant, increases the soil pH and EC and decreases the Bd of the soil. The ability of chicken manure to raise the soil pH to neutrality is notable, representing a valuable opportunity to correct the extreme acidity present in the soils of the area.

While certain soil properties, such as pH, ECEC, COOx, Total N, and Bd, remained stable with multiple applications of bovine manure, EC and moisture saturation decreased, indicating a modification in soil dynamics with respect to these two specific parameters due to a greater residuality of this organic fertilizer (Ziogas *et al*., 2021).

CONCLUSIONS

The use of composted bovine and poultry manure can increase the soil's oxidizable organic carbon and total nitrogen content, but composting oil palm bunch residues as fertilizer is the source of organic matter capable of generating the greatest increases.

The three evaluated sources of organic matter proved to be promising alternatives for enhancing the chemical properties of soil under oil palm cultivation, mainly by raising the soil pH and thereby reducing the level of aluminum saturation.

Additionally, their capacity to improve soil physical conditions is demonstrated, since applying any of the three organic fertilizers evaluated produced a statistically significant decrease in the bulk density of the soil.

There was a differentiated response among the three sources of organic matter with respect to the number of fractions applied. Chicken manure had a significant effect on the higher number of parameters evaluated. This suggests a marked difference in the rate of decomposition and mineralization of chicken manure compared with the other sources.

AUTHOR CONTRIBUTIONS

Conceptualization, M.d. P.C. and J.P.T.; Methodology, M.d. P.C. and E.F.V.M.; Software, E.F.V.M. and J.P.T.; Validation, M.d. P.C., J.P.T., and E.F.V.M.; Formal Analysis, E.F.V.M.; Investigation M.d. P.C.; Resources, J.P.T.; Data Curation, E.F.V.M.; Writing-Original Draft Preparation, E.F.V.M.; Writing—Review & Editing, E.F.V.M.; Visualization, M.d. P.C.; Supervision, M.d. P.C.; Project Administration, M.d. P.C.; Funding Acquisition, J.P.T.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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