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Comparative Effects of Organic Amendments on Soil Physicochemical Properties

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ABSTRACT: *Soil degradation caused by intensive cultivation and overreliance on chemical fertilizers has led to declining fertility, poor structure, and reduced productivity. Organic amendments such as biochar, poultry manure, and cow dung are increasingly applied to restore soil health by improving its physicochemical properties. This study evaluated the effects of these amendments on soil collected from the Lafia axis of Nasarawa State, Nigeria. The amendments were incorporated at 10% (w/w), and soil samples were analyzed for particle size distribution, pH, organic carbon (OC), cation exchange capacity (CEC), and electrical conductivity (EC) using standard methods. Results revealed that while soil texture remained sandy across all treatments, poultry manure and cow dung slightly increased the clay fraction, enhancing aggregation. Biochar significantly raised CEC (14.3%) and EC (262%), whereas cow dung contributed the highest increases in OC (28%) and pH (12.68%). Poultry manure provided moderate but consistent improvements across parameters. Analysis of variance (ANOVA) indicated significant treatment effects on CEC, EC, and OC, but not on pH. These improvements suggest that organic amendments enhance soil fertility, nutrient retention, and buffering capacity, while also reducing the mobility of agrochemicals. The findings highlight that biochar, poultry manure, and cow dung provide distinct but complementary benefits, making them valuable for sustainable soil management. Their application has the potential to restore degraded soils, improve crop productivity, and promote environmentally sound agricultural practices.*

Keywords: Organic amendments, Biochar, Poultry manure, Cow dung, Soil physicochemical properties, Soil fertility management

INTRODUCTION

Soil is the foundation of agricultural productivity, yet its quality is often compromised by intensive cultivation, excessive dependence on chemical fertilizers, and unsustainable management practices. These pressures reduce organic matter, disturb nutrient balance, and weaken soil structure, which in turn lowers fertility and limits crop performance (Lal, 2015). Addressing these challenges requires approaches that not only replenish nutrients but also restore the natural physicochemical balance of soils. One of the most sustainable strategies is the application of organic amendments, which improve soil health while reducing reliance on synthetic inputs (Agegnehu et al., 2016).

Organic amendment materials derived from plant or animal sources that, when incorporated into soil, enhance its physical, chemical, and biological qualities. Their effects, however, differ according to their composition and interaction with soil type. Biochar, for example, is a carbon-rich material produced through the pyrolysis of biomass. Its porous structure and high surface area enable it to improve cation exchange capacity, water retention, and long-term carbon storage (Lehmann & Joseph, 2015; Jin et al., 2016). Poultry manure, in contrast, provides a readily available source of nitrogen, phosphorus, and other nutrients, while also raising soil pH and stimulating microbial activity (Mkhabela & Warman, 2005; Li et al., 2020). Cow dung, a traditional amendment widely used in smallholder farming, contributes to soil aggregation, increases organic matter, and enhances nutrient mineralization through microbial action (Ghosh et al., 2012; Sharma et al., 2017).

Beyond fertility restoration, organic amendments have important implications for soil chemical processes and environmental quality. By increasing soil organic matter and improving cation exchange capacity, amendments can reduce the leaching of nutrients and agrochemicals, limit heavy metal mobility, and lower the risks of groundwater contamination (Beesley et al., 2011; Hussain et al., 2017). They also improve buffering capacity, stabilize soil pH, and encourage beneficial microbial communities that facilitate organic matter decomposition and pollutant degradation (Glaser et al., 2002; Zhang et al., 2021).

The use of biochar, poultry manure, and cow dung, therefore, represents a practical and sustainable means of enhancing soil physicochemical properties. However, the magnitude of their effects varies with amendment type, application rate, and soil conditions (Agegnehu et al., 2017). An understanding of these variations is essential to inform management practices that optimize soil fertility, enhance crop yields, and ensure long-term sustainability in agricultural systems.

MATERIALS AND METHODS

Sampling/sample location

A composite surface soil sample from the Lafia axis of Nasarawa State, Nigeria, was collected at a depth of 0-15 cm using a hand trowel, air-dried for five days, and sieved through a 2 mm mesh. The samples were transported to the laboratory in covered aluminum buckets.

Soil sample preparation

The soil samples were modified by uniformly incorporating cow dung, poultry manure, and biochar at a rate of 10% (w/w) on a dry weight basis. For each treatment, triplicate portions of 5 kg soil were thoroughly mixed with 500 g of the respective organic material (biochar, poultry manure, or cow dung); the untreated portion served as the control ("Organic Matter and Soil Amendments," 2023). After fortification, the mixtures were homogenized and allowed to stabilize for two weeks before further use (Carpio et al., 2021).

Parameter	Control	Modified soils		
		Biochar	Poultry droppings	Cow dung
Clay (%)	6.00 ± 0.100	6 .00± 0.300	8.00 ± 0.200	8.00 ± 0.050
Silt (%)	5.40 ± 0.100	5.40 ± 0.100	5.40 ± 0.100	5.40 ± 0.100
Sand (%)	88.60 ± 0.100	88.60 ± 0.060	86.60 ± 0.090	86.60 ± 0.700
Texture	Sand	Sand	Sand	Sand

Physicochemical analysis of a soil sample

Soil samples and their amendments were subjected to physicochemical analysis using standard methods.

Determination of soil particle size

The soil particle size was determined by the Bouyoucos hygrometer method (1962).

Determination of soil particle size

The pH was determined using a glass electrode method with a 1:1 ratio of soil to distilled water (Sparks, 1996).

Determination of soil organic carbon (OC)

The determination of soil organic matter was carried out using the Walkley-Black wet oxidation method (Walkley and Black, 1934).

Determination of cation exchange capacity (CEC)

The cation exchange capacity (CEC) of the soil samples was determined using the ammonium acetate titration method as described by Thomas (1982).

Determination of electrical conductivity

Electrical conductivity was determined using a standard method (Rhoades, 1996).

Statistical Analysis

Data obtained from the study were subjected to statistical analysis using analysis of variance (ANOVA) to determine significant differences among treatments.

RESULTS

Tables 1 and 2 show the physicochemical properties of unamended and organically amended soils, including parameters such as organic carbon, pH, electrical conductivity, cation exchange capacity, and soil texture, while the statistical analysis is presented in Tables 3 and

Table 1: Textural results for modified and control soils

Table 2: Chemical properties of modified and control soils

Parameter	Source	D	SS	MS	F-Value	P-Value
CEC	Between Groups	3	0.0192	0.0064	320.00	0.0000
	Within Groups	8	0.00016	0.00002		
	Total	11	0.01936			
EC	Between Groups	3	1,059,248.33	353,082.78	64,169.80	0.0000
	Within Groups	8	44.02	5.50		
	Total	11	1,059,292.35			
OC	Between Groups	3	0.7928	0.2643	6.33	0.0170
	Within Groups	8	0.3341	0.0418		
	Total	11	1.1269			
pH	Between Groups	3	0.5367	0.1789	3.37	0.0780
	Within Groups	8	0.4249	0.0531		
	Total	11	0.9616			

Table 3: ANOVA of the physicochemical properties of soil under different amendments (control, biochar, poultry manure, and cow dung)

Parameter	Control	Modified soils		
		Biochar	Poultry droppings	Cow dung
CEC (mol/kg)	0.84 ± 0.008	0.96 ± 0.019	0.86 ± 0.009	0.90 ± 0.011
EC (µs/cm)	345.00± 0.100	1250.00 ± 2.00	573.00 ± 3.000	201.00 ± 3.000
OC (%)	1.89 ± 0.015	2.32± 0.020	2.40 ± 0.400	2.42 ± 0.080
pH	7.10 ± 0.050	7.50 ± 0.200	7.90 ± 0.100	8.00 ± 0.400

ANOVA= Analysis of variance; DF= Degrees of Freedom; SS= sum of squares; MS= Mean Square; CEC= Cation exchange capacity; Electrical conductivity; Organic carbon

DISCUSSION

The textural analysis (Table 1) revealed that the control soil and soil modified with biochar, poultry manure, and cow dung were of sandy texture. This is attributed to the predominance of sand particles, which remained above 86 % in all treatments. Similar values (6.00 %) were recorded for both the control and biochar-amended soils, suggesting that biochar did affect the soil's particle size distribution. Conversely, poultry manure and cow dung amendments marginally increased the clay fraction to 8.00%, accompanied by a slight reduction in sand content from 88.60% to 86.60%. This shift likely reflects the incorporation of finer organic particles or improved soil aggregation due to the added organic matter. The silt content remained constant at 5.40%, indicating a minimal impact of the amendments on this fraction. Despite these subtle changes, all soils remained texturally classified as sandy. These changes in particle size distribution could nonetheless influence key soil functions such as water retention, nutrient holding capacity, and structure. Agbede (2025) reported that poultry manure improves soil physical properties by contributing fine particles and enhancing porosity and bulk density. Likewise, Lima et al. (2021) emphasized the role of organic inputs in improving aggregation and structure. Although biochar may not substantially alter soil texture (Lehmann et al., 2011), it plays an important role in improving soil physical conditions by enhancing structural stability and preserving organic matter. The unchanging silt content aligns with the findings of Oyekunle et al. (2025), who noted that poultry manure had little effect on silt but significantly influenced other texture-related properties. Thus, the observed rise in clay and drop in sand content in poultry and cow dung treatments suggested that organic amendments enhanced the physical quality of sandy soils, albeit without altering their textural class. The slight textural shift, particularly in increased clay content and organic input, may influence imidacloprid mobility and uptake in amended treatments. Soils with finer textures and higher organic content typically exhibit greater sorption and reduced pesticide leaching (McGinley et al., 2022).

Table 2 further elucidates the impact of organic amendments on key soil chemical characteristics, including cation exchange capacity (CEC), electrical conductivity (EC), organic carbon (OC), and pH. The CEC of the control soil was 0.84 mol/kg. After amendment, biochar significantly increased CEC to 0.96 mol/kg (14.3% increase), cow dung to 0.90 mol/kg (7.1% increase), and poultry manure to 0.86 mol/kg (2.4% increase). These changes reflect the amendments' contributions of organic matter and reactive surfaces that facilitate nutrient retention. Biochar's enhancement of CEC is supported by Liang et al. (2006), who attributed similar increases to the development of carboxylic and phenolic functional groups. Lehmann and Joseph (2024) also identified the high CEC potential of biochar due to its structural complexity. Meanwhile, contributions, due to poultry manure and cow dung, primarily occur through microbial stimulation and humus formation, consistent with findings by Alves et al. (2021).

Electrical conductivity (EC), as an indicator of soluble salts and nutrient availability, varied markedly across treatments. The control soil had an EC of 345.00 µS/cm. Biochar amendment elevated EC to 1250.00 µS/cm (a 262% increase), followed by poultry manure at 573.00 µS/cm (66% increase), while cow dung had the lowest EC, which was 201.00 µS/cm (a 42% decrease). The rise in EC for biochar and poultry manure was likely linked to their ash and mineral contents. Wang et al. (2024) documented similar trends in biochar-treated soils. Agbede & Oyewumi (2023) observed high EC from poultry manure but comparatively low effects from cattle manure, which is consistent with the results in this study. These findings emphasize the importance of amendment selection, as excessive EC could lead to salinity issues if not managed properly.

Organic carbon (OC) content improved substantially with amendment. The control soil had an OC of 1.89 %, while cow dung raised it to 2.42 % (28 % increase), poultry manure to 2.40 % (27 %), and biochar to 2.32 % (22.8 %). These increases reflected the organic matter contributions of each amendment. Kätterer et al. (2011) and Obia et al. (2016) reported that both stable (biochar) and labile (manure) organic amendments promote OC accumulation. While biochar contributes to long-term carbon stabilization, poultry manure and cow dung enhance microbial activity and rapid organic matter turnover. Olowoboko et al. (2018) documented similar percentage increases for these amendments, reinforcing their carbon-enriching effects. Thus, the combined benefit of OC enhancement and structural improvement supports sustainable soil fertility.

Soil pH values increased progressively with organic amendments from biochar through poultry to cow dung-amended soils. A pH of 7.10 was recorded for the control soil samples. Amendments with biochar raised the pH to 7.50 (5.63% increase), 7.90 with poultry manure (11.27%), and 8.00 with cow dung (12.68%). The liming effect observed is due to the base cation content in these materials, which neutralizes soil acidity. These findings correspond with the studies by Abdul-Aziz et al. (2025), Yuan and Xu (2011), and Agbede & Oyewumi (2023). The order of increase in pH was cow dung > poultry manure > biochar, an indication that cow dung has stronger buffering capacity due to its higher calcium and magnesium ion contents (Van Dang et al., 2021).

Integration of organic amendments generally improved soil chemical properties relative to the unamended control. Biochar provided the greatest enhancement of CEC (14.3%), cow dung most significantly raised OC (28 %) and pH (12.68 %), while biochar also caused the highest EC increase (262 %). These improvements, while varying by amendment, may collectively enhance soil fertility, structure, and buffering capacity. Moreover, the alterations in soil texture and chemistry may contribute to reducing pesticide mobility and uptake, validating the effectiveness of amendments in promoting sustainable and safe agricultural practices. The findings confirm that biochar, poultry manure, and cow dung can each serve distinct but complementary roles in improving soil quality and mitigating agrochemical risks in sandy soils.

Analysis of variance (ANOVA)

Analysis of Variance (ANOVA) was conducted to evaluate the impact of various soil amendments, unamended soil, and amended soils on selected soil physicochemical properties. Analysis was focused on four indicators of soil health: cation exchange capacity (CEC), electrical conductivity (EC), organic carbon (OC), and pH. The results, presented in Table 3, indicate that CEC, EC, and OC were significantly affected by the treatments, with p-values of 0.0000, 0.0000, and 0.0170, respectively. These findings demonstrate that organic inputs exert a considerable influence on essential soil properties. In contrast, soil pH showed no statistically significant variation across treatments ($p = 0.0780$), as the result did not meet the conventional 0.05 threshold for significance.

The significant enhancement in CEC suggests an improved nutrient-holding capacity in amended soils, a critical factor in promoting soil fertility and supporting plant growth. Among the amendments, biochar exhibited the most pronounced effect, probably due to its inherently porous structure and high surface area, which increase its ability to retain nutrients. This observation aligns with the findings of Omara et al. (2023), who observed a 20% increase in CEC following biochar application. Similarly, Sun et al. (2022) documented substantial improvements in CEC when biochar was applied to arid soils, underscoring the broader applicability of biochar as a soil-enhancing amendment.

Electrical conductivity, which reflects both soil salinity and nutrient availability, was also significantly influenced by the amendments. Biochar-amended soils recorded the highest EC values, as reflected in Table 4.1. This trend corresponds with Sun et al. (2022), although variations in EC values were noted to depend on initial soil type and biochar characteristics. Poultry manure and cow dung also contributed to EC increases, consistent with reports from Soremi et al. (2017), who found that poultry manure not only enhances EC but also boosts nutrient bioavailability, further confirming the fertility benefits of organic amendments.

Organic carbon content was another parameter significantly influenced by the soil treatments. The use of biochar, poultry manure, and cow dung led to higher OC values, reinforcing the positive contribution of organic inputs to soil organic matter. The rise in OC promotes better soil structure, moisture retention, and microbial activity, all of which are essential for sustainable soil health. These results align with the findings of Pandian et al. (2016) and Agbede (2025), both of whom highlighted the importance of organic amendments in maintaining and improving soil quality through increased carbon content.

Although soil pH did not exhibit statistically significant changes, a general trend of increased pH was observed in amended treatments. This trend is particularly evident in biochar-amended soils, which supports the notion that biochar may gradually buffer soil acidity over time. Research by Sun et al. (2022) emphasized the liming effect of biochar, which helps to neutralize soil acidity. Similarly, Omara et al. (2023) noted moderate increases in pH following biochar application, further suggesting potential long-term improvements in soil reaction with continued use.

The statistically significant improvements in CEC, EC, and OC as a result of soil amendment application highlight the critical role these properties play in influencing agrochemical behaviour and plant nutrient uptake. These changes contribute not only to enhanced soil fertility but also to the observed patterns of imidacloprid retention and plant absorption in earlier sections of this study. The findings affirm the value of integrating organic materials into soil management strategies to achieve both agronomic and environmental benefits.

CONCLUSION

This study demonstrated that the incorporation of biochar, poultry manure, and cow dung significantly enhanced key physicochemical properties of sandy soils relative to the unamended control. While soil texture remained sandy across treatments, poultry manure and cow dung marginally increased the clay fraction, indicating improved soil aggregation. Among the chemical properties, biochar provided the greatest increase in cation exchange capacity (14.3%) and electrical conductivity (262%), reflecting its porous structure and mineral content. Cow dung most effectively raised soil organic carbon (28%) and pH (12.68%), highlighting its strong buffering capacity and carbon-enriching effect. Poultry manure contributed moderate but consistent improvements in organic carbon, pH, and conductivity, supporting its role as a readily available nutrient source.

The ANOVA results confirmed that organic amendments had significant effects on cation exchange capacity, electrical conductivity, and organic carbon, but not on soil pH. These findings emphasize that while pH buffering may occur gradually, immediate improvements in nutrient-holding capacity and organic matter content are achievable through amendment application. Collectively, the amendments enhanced soil fertility, nutrient retention, and structural stability, thereby reducing the potential mobility of agrochemicals such as imidacloprid.

Overall, the integration of organic amendments into soil management practices offers a sustainable pathway for improving soil quality and mitigating agrochemical risks. Biochar, poultry manure, and cow dung each provide distinct but complementary benefits, and their combined use or site-specific application could optimize soil productivity and support long-term agricultural sustainability.

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