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Soil chemical properties as influenced by poultry manure source and application rates

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Abstract

Poultry manure application to soil has been a good way to restore and improve soil health. However, it is mostly used in combination with inorganic fertilizer, which in the long run, the inorganic fertilizer may have a negative effect on soil health. Therefore, a laboratory experiment (incubation study) was conducted at the Federal University of Technology, Minna, Nigeria, to investigate how soil chemical properties are affected by different sole poultry manure sources and application rates. The experiment was a 3 x 5 factorial experiment laid out in a Completely Randomized Design (CRD), consisting of three poultry manure sources, including deep litter, battery cage, and local, and five application rates (0, 5, 10, 15 and 20 tons/ha) in three replications. Data were subjected to analysis of variance (ANOVA), and treatment means were separated using least significant difference (LSD) at 5% probability level. Results showed that poultry manure exerted a significant effect on available soil phosphorus, organic carbon, and total nitrogen. Additionally, greater improvements in all soil chemical properties were observed with increasing manure application rates, with application at 20 tons/ha being the most effective. However, future research is needed to better understand the practical application of different manure sources and various application rates on soil and crop performance.

Keywords: Poultry manure, phosphorus, organic carbon, total nitrogen, chemical properties

1. Introduction

Soil fertility depletion is one of the major constraints to sustainable agricultural production in many regions of the world, particularly in areas where intensive continuous cultivation, overuse of inorganic fertilizer, and inadequate nutrient replenishment have resulted in nutrient imbalance and degraded soil properties (Adeyemo *et al.*, 2019; Agbede, 2025) [3, 4]. Overall, these issues lead to deterioration in soil quality and crop yield (Yu *et al.*, 2025; Zhang *et al.*, 2024a) [31, 32]. To alleviate the negative impacts associated with long-term use of inorganic fertilizers, it is important to consider organic amendments such as manure (Adekiya *et al.*, 2020; Yu *et al.*, 2025) [2, 31]. The use of organic amendments has been recognized as an effective and eco-friendly approach to restoring soil fertility and improving soil properties (Kareem *et al.*, 2025b; Liman *et al.*, 2024b) [17, 20]. Among the various organic amendments available, animal manure, particularly poultry manure, stands out due to their high nutrient content, rapid nutrient release, and long-term benefits for soil health (Pangaribuan *et al.*, 2020; Schmidt & Knoblauch, 2020; Ismael *et al.*, 2021) [25, 27, 13].

Poultry manure is widely valued as an organic fertilizer because it contains essential plant nutrients, including nitrogen (N), phosphorus (P), potassium (K), and micronutrients, which are often present in readily available forms (Kobierski *et al.*, 2017) [18]. Global poultry manure production is projected to reach 457 million tons by 2023 (Zhang *et al.*, 2021b) [33], highlighting the need for appropriate utilization strategies that recycle nutrients back to the soil while mitigating environmental risks (Adekiya *et al.*, 2020) [2]. Compared to other animal manures, poultry manure generally contains higher concentrations of nutrients, making it an attractive option for enhancing crop productivity (Chukwuma *et al.*, 2024) [10]. In addition to supplying plant nutrients, poultry manure contributes to soil organic matter (SOM) accumulation, which

improves soil structure, water infiltration, aggregate stability, and cation exchange capacity, while also stimulating soil biological activity (Ojeniyi *et al.*, 2013; Prasai *et al.*, 2018) ^[23, 26].

Among the essential nutrients influenced by manure applications, phosphorus (P), organic carbon (OC), and total nitrogen (TN) are of particular importance. Phosphorus is a critical macronutrient involved in energy transfer, root development, and overall plant growth, yet it is often a limiting nutrient in tropical soils due to fixation in insoluble forms (Alengebawy *et al.*, 2024) ^[6]. Organic carbon serves as the foundation of soil organic matter, supporting microbial populations, enhancing soil aggregation, and improving soil structure and water-holding capacity (Zhou *et al.*, 2020) ^[34]. Total nitrogen, a key component of amino acids, proteins, and chlorophyll, is frequently deficient in tropical soils, and its availability largely determines vegetative growth and yield performance (Liman, 2024a) ^[19]. Application of poultry manure has been shown to increase the levels of these critical nutrients, although the composition of poultry manure varies widely and the extent of improvement depends on factors such as poultry housing system, feed composition, bedding materials, manure type, and handling practice (Hossain *et al.*, 2017; Soremi *et al.*, 2017) ^[12, 28].

Housing systems such as battery cage, deep litter, and bare ground methods produce manure with distinct physicochemical characteristics. For instance, Casas and Guerra (2020) ^[8] reported that battery cage systems often yield manure with little or no bedding materials, resulting in drier, more nutrient-dense manure. In contrast, deep litter and bare ground systems produce manure mixed with bedding materials and are subject to partial microbial decomposition before collection. Thus, these differences in manure composition can have significant impacts on soil fertility when the manures are used as an amendment (Casas and Guerra, 2020) ^[8].

Despite substantial research effort on poultry manure use, much of the focus has been on its combined use with mineral fertilizer, especially NPK formulations, to enhance crop performance (Joseph *et al.*, 2017; Omalle *et al.*, 2022) ^[14, 24]. However, limited information exists on how different poultry production systems and application rates influence the nutrient composition of the manure and, consequently, its impact on soil properties when applied as the sole amendment. This is an important knowledge gap because differences in manure composition among production systems may lead to varied outcomes in soil fertility restoration. Therefore, addressing this knowledge gap is critical for optimizing manure management strategies, improving soil fertility, and crop performance. Hence, this study evaluated the effects of poultry manure derived from three different production systems, including the battery cage system, deep litter, and bare ground, and various application rates on soil chemical properties, focusing on phosphorus, organic carbon, and total nitrogen. Additionally, understanding how these poultry manure sources influence key soil fertility parameters will contribute to better decision-making regarding application rates, and integration into sustainable nutrient management practices.

2. Materials and Methods

2.1 Experimental Site, Design, and Treatments

An incubation study was conducted in the Soil Science and Land Management Department Laboratory of Federal University of Technology Minna, Nigeria. The study region is situated at latitude 09°31'N and longitude 06°30'E in the southern Guinea

savannah agro-ecological zone of Nigeria (Liman *et al.*, 2025; Kareem *et al.*, 2025a) ^[21, 16]. With an average yearly rainfall of 1,284 mm, a dry season that lasts for four to five months from November to March, and an average temperature of 33 °C (Azeez *et al.*, 2025) ^[7]. Three levels of manure, including deep litter, battery cage, and bare ground from poultry housing systems and five levels of application (0, 5, 10, 15, and 20 tons/ha) were used in the study in a 3 × 5 factorial experiment, which was set up in a completely randomized design (CRD), replicated three times.

2.2 Soil and Manure Sample Collection

Representative soil samples were collected with the use of a shovel through 0 to 20cm in a diagonal direction at the Teaching and Research Farm of the Federal University of Technology Minna, Nigeria. Prior to the incubation phase, collected soil samples were analyzed for various properties and presented in Table 1. Manure samples for deep litter system were mainly from the broiler poultry birds, those of the battery cage systems were from layer birds, while those of the bare ground systems were also from broiler birds. Collected soil and manure samples were transferred into well-labeled and clean polythene plastic bags and taken to the laboratory. Soil samples were then air-dried, crushed, and passed through a 2 mm sieve, and used for various soil physical and chemical analyses.

2.3 Incubation

A 2 kg soil sample and 0 to 20t/ha poultry manure were weighed into polythene bags, while a 40% moisture-based soil mass was sustained for an incubation period of 2 weeks. At the conclusion of the second week, samples were allowed to cool after being oven-dried for 72 hours at 65 °C. Then, different soil chemical properties were ascertained after the samples were run through a 2 mm and 0.5 mm screen, respectively.

2.4 Soil pH (1: 2.5), Phosphorus, Organic Carbon, and Total Nitrogen Determination

The pH of the soil was determined through the potentiometric method, where 10 g of sieved soil sample was weighed into two 500 ml beakers. 25 ml of distilled water was then added to one beaker, and 25 ml of 0.01M CaCl₂ to the other beaker, and stirred for approximately 60 seconds before letting the mixture stand for fifteen minutes. After the fifteen-minute stand, the mixtures were stirred again for another 60 seconds and left to stand for a further fifteen minutes. Following the fifteen-minute pause, the pH meter was calibrated using a standard solution of Buffer. After calibration, each sample's pH in water and calcium chloride was then measured.

The Bray P1 method, which is used to measure the amount of accessible phosphorus in acidic soils, was used to extract the phosphorus after it was estimated using the colorimetric method. 7 ml of phosphorus extract (1N NH₄F, 1N HCL, and distilled water mixed together) was added to 1 g of 2 mm oven-dried soil samples that had been weighed into laboratory bottles. The mixture was then shaken for 60 seconds, filtered through Whatman 42 filter paper, and the supernatant solution was decanted into a clean bottle before being sent to a UV visible spectrophotometer for calorimetric analysis

To determine the amount of organic carbon through the Walkley-black procedure, 1 g of air-dried, sieved 0.5 mm soil sample was added to a 25 ml conical flask, followed by the addition of K₂Cr₂O₇. Solutions were swirled to disperse the soil. 10 ml of H₂SO₄ was further added, and the solution was left to stand for 30 minutes. Then 100 ml of distilled water was

added, followed by the addition of four drops of ferroin indicator. Then the solution was titrated against 0.5N ferrous ammonium sulphate (NH₄) FeSO₄ until it reached the green and brown endpoint.

The Kjeldahl or wet oxidation method, which consists of three stages (digestion, distillation, and titration), was used to calculate the total nitrogen. At the digestion stage, N was converted to ammonium nitrogen (NH₄-N) by heating the soil sample in a digestion tube with concentrated sulfuric acid (H₂SO₄) and copper sulfate combined with potassium sulfate as a catalyst in a digestion block at 300 °C - 400 °C. During the distillation phase, the ammonium was separated from the mixture (digested sample and NaOH) using Kjeldahl apparatus. As a result, ammonium nitrogen was transformed into ammonium gas and subsequently trapped in a boric acid solution. While at the titration stage, the sample was neutralized by the ammonia dissolving in the acid trapping solution. Then drops of nitrogen indicator were added, and the sample was titrated against a weak acid of 0.01N HCL, and the results were obtained through back titration.

2.5 Exchangeable Acidity

100 ml of 1N KCL was added to a reagent bottle containing 10 g of 2 mm sieved soil, which was then agitated for an hour in a mechanical shaker. The Whatman 42 filter paper was then used to filter the mixture into a volumetric flask. Five drops of phenolphthalein indicator were added to 25 ml of the filtered extract, which was then pipetted into a conical flask. The extract was then titrated against 0.1N NaOH until it reached the first endpoint of pink, and a blank was made without the soil sample to reach the same endpoint.

2.6 Particle Size Analysis

To determine the particle size, the Bouyoucous hydrometer method was used. 100 ml of 5% Calgon (sodium hexametaphosphate solution) was added to 50g of a 2 mm air-dried soil sample that had been weighed into sampling bottles. After an hour of shaking the solution in a mechanical shaker, the suspension was moved into a 1-liter measuring cylinder and replenished with water. After stirring the solution with a plunger, a hydrometer was placed inside the cylinder and readings were obtained at 40 seconds. The thermometer's readings were also recorded. After the suspension was left undisturbed for two hours, the suspension was submerged, and a thermometer and hydrometer readings were taken again.

2.7 Statistical Analysis

All data collected were subjected to analysis of variance (ANOVA) using the general linear model (GLM) on SAS V9.4. When the Global F values were found to be significant, the least significant difference (LSD) was used for mean separation.

3. Results and Discussion

3.1 Initial Physical and Chemical Properties of the Soil

Results from the initial soil properties showed that the soil textural class is sandy loam. The pH of the soil was 6.3, suggesting that the soil had a neutral pH. Organic carbon of the soil was low, suggesting that the soil had low organic matter concentration (Table 1). The available soil phosphorus as well as the potassium and calcium levels, were low (Table 1). The magnesium and sodium concentrations were moderate (Table 1). The exchangeable acidity was low as well, while the effective cation exchange capacity (ECEC) was 6.65 cmol/kg, and saturation base was 60.04% (Table 1). Similar findings were

reported by Kareem *et al.* (2025a) ^[21], who reported that the concentration level of most properties of the initial soil sample collected at the Teaching and Research Farm of Federal University of Technology was low.

The Exchangeable acidity of the soil was very low, having a value of 0.77 cmol/kg, the Effective cation exchange capacity of the soil was 6.65 cmol/kg, and the percentage base saturation of the soil was 60.04% (Table 1). Similarly, Azeez *et al.* (2025) ^[7], also reported that most properties of the initial soil sample from the Teaching and Research Farm of Federal University of Technology Minna, were low.

Table 1: Initial Physical and Chemical properties of the soil

Soil Properties	Values
Particle Size Distribution	
Sand (g/kg)	881
Silt (g/kg)	62.0
Clay (g/kg)	57.0
Textural class	Loamy sand
pH	6.30
Organic carbon (g/kg)	6.22
Available soil phosphorus (mg/kg)	7.31
Exchangeable Bases (cmol/kg)	
Ca 2+	3.79
Mg2+	2.00
K+	0.23
Na+	0.54
Exchangeable acidity (cmol/kg)	
Al3+ + H+	0.77
ECEC (cmol/kg)	6.65
Percentage base saturation (%)	60.04
ECEC: Effective cation exchange capacity	

3.2 The Main Effect of Poultry Manure Sources and Application Rates on the Soil Chemical Properties

The main effect of poultry manure sources and application rates on soil chemical properties showed significant differences in the available soil P, organic matter, and total N (Table 2). A greater amount of available soil phosphorus was recorded for the manure source from the battery cage system, followed by that of the deep litter system. In contrast, those from the bare ground system had the lowest concentration of available soil phosphorus (Table 2). The greater amount of phosphorus recorded for the manure source from the battery cage system may be a result of the manure having a higher concentration of nutrients than the manure source from the deep litter system and bare ground, which are diluted with bedding as in the deep litter or bare ground. It may also be associated with the battery cage system being enclosed, reducing nutrient losses during storage compared to the open-based systems (bare ground and deep litter) that experience greater losses of available soil phosphorus through runoff or bedding absorption (Casas and Guerra, 2020) ^[8].

For organic carbon, the deep litter system source had the greatest concentration, but was not statistically different from the battery cage system, while the bare ground system also recorded the lowest concentration. This finding may be attributed to the presence of lower moisture and faster removal of the manure from the deep litter and battery cage system, which stays relatively dry, thus decreasing microbial decomposition until after application (Casas and Guerra, 2020; Soremi *et al.*, 2017) ^[8, 28].

The total nitrogen was greatest for the manure source obtained from the bare ground system, followed by those obtained from the battery cage system, while the lowest concentration was

recorded for the deep litter system (Table 2). The greatest concentration of total nitrogen seen in the manure source from the bare ground system may be linked to soil contact and nitrate accumulation resulting from direct manure-soil contact, thus enhancing microbial mineralization, converting nitrogen to ammonium and nitrate. It may also be tied to reduced losses

from ammonia volatilization compared to exposed piles in the litter and battery cage system. A study by Kacprzak *et al.* (2022)^[15] also reported an improvement in the nitrogen concentration resulting from the application of manure from the bare ground system.

Table 2: Main Effect of Different Poultry Manure Sources and Application Rates on Soil Chemical Properties

Treatment	Phosphorus (mg/kg)	Organic carbon (g/kg)	Total nitrogen (g/kg)
Source			
Local	12.53c	13.21b	1.26a
Battery Cage	36.46a	13.77a	1.10b
Deep Litter	26.69b	13.83a	1.02c
SE ±	5.72	0.12	0.04
Rates (tons/ha)			
0	5.27e	3.33d	1.10bc
5	8.98d	13.40c	1.21a
10	15.17c	13.61b	1.14b
15	37.45b	13.52bc	1.07c
20	59.27a	14.16a	1.20a
SE ±	3.82	0.18	0.11
Source × Rate	*	*	*

Means with similar letters down the column are not significantly different at $p \leq 0.05$

*: significant source × rate effect was evident at $p \leq 0.05$

The treatment effect of application rates on the available soil phosphorus, organic carbon, and total nitrogen showed significant differences among the treatments (Table 2). For phosphorus and organic carbon, there was a consistent linear trend among the treatments with an increase in concentration as the application rates increased, with 20 ton/ha application rates recording the greatest concentration, whereas the 0 ton/ha or control treatment recorded the least concentration in both properties, suggesting that higher application rates leads to higher concentration of phosphorus and organic carbon since the microbial decomposition of higher application rates will be greater than those of lower application. For the total nitrogen, an inconsistent trend was recorded as the application rates increased. Greater concentration was recorded for the 5 ton/ha application rates, while the lowest was recorded for the 25 ton/ha treatment, which was anomalous (Table 2). And it may be linked to nitrogen immobilization when higher rates of manure are applied to the soil. A study by Liman (2024a)^[19], applied an amendment to the soil and discovered that at higher application rates, nitrogen concentration was reduced. Liman (2024a)^[19] attributed the reason to nitrogen immobilization at higher application rates.

3.3 Interaction Effect of Poultry Manure Source and Application Rates on Soil Chemical Properties

For the Poultry manure source × treatment (application rates) effect, significant differences occurred for available soil phosphorus, organic carbon, and total nitrogen (Table 3). The available soil phosphorus followed a positive linear trend as the manure from bare ground, battery cage, and deep litter application rates increases (Table 3), but the interaction between the manure sources showed that 20 tons/ha application rate of manure from battery cage system had the greatest concentration, followed by 20 tons/ha application rate of manure from deep litter system and 15 tons/ha application rate of manure from battery cage system. However, the lowest concentrations were recorded for the control or 0/ha application rates of manure from bare ground, battery cage, and deep litter system (Table 3). The improvement seen in the available soil phosphorus in treatments

containing poultry manure compared to the control treatments may be associated with the direct effect of manure present in those treatments, compared to the control treatments containing 0 tons/ha of manure. A study by Soremi *et al.* (2017)^[28], reported an improvement in available soil phosphorus following the application of poultry manure compared to the control treatment. Other studies also reported that manure contains a significant amount of available phosphorus (Aboltins and Kic, 2015; Cha *et al.*, 2020; Kacprzak *et al.*, 2022)^[1, 9, 15]. Thus, our findings are also consistent with those reported by Agbede *et al.* (2008)^[5], that P content almost doubled at an increased rate of manure application from 5.27 mg/kg to 8.98 mg/kg.

For the soil organic carbon, the 20 tons/ha manure application rates from the deep litter system gave the greatest concentration, while the lowest were recorded for the control treatment across all manure sources (Table 3). The improvement evident in the treatments containing poultry manure may be linked to the direct effect of the manure application (Mehdi-Khodadadi *et al.*, 2024)^[22]. Kacprzak *et al.* (2022)^[15] reported that poultry manure contains a significant amount of nutrients, including N, C, Ca, and P. Hence, the improvement seen in all the manure-containing treatments in our study is consistent with those reported by Kacprzak *et al.* (2022)^[15]. Additionally, Warren *et al.* (2006),^[30] stated that poultry manure aids in the improvement of soil organic matter, which is directly associated with organic carbon.

While for the total nitrogen, some treatments increased in concentration with the increase in application rate, while some decreased even as the application rates increased. However, the greatest concentration was recorded for the 20 tons/ha manure application rate from bare ground, which was similar to 10 ton/ha application rate from bare ground and 10 tons/ha application rate from the battery cage system (Table 3). Whereas the lowest total nitrogen concentration was recorded for the control treatment from battery cage system (Table 3). The improvement of nitrogen in all manure-containing treatments may be attributed to the fact that manure contains essential nutrients, including nitrogen. Other studies have shown that poultry manure increases the supply of macronutrients in the soil

(Garg and Bahla, 2008; Uweh *et al.*, 2012) ^[11, 29]. Hence, our results validated those reported by Uweh *et al.* (2012) ^[29], which states that the application of poultry manure increases the nitrogen content of the soil.

Table 3: The Poultry Manure Source × Application Rates Effect on Soil Chemical Properties

Rates (tons/ha)	Available Soil Phosphorus		
	Bare Ground	Battery cage	Deep litter
0	4.90h	5.90h	5.00h
5	5.60h	10.85g	10.50g
10	9.10g	17.15e	19.25e
15	14.00f	44.80b	25.55d
20	29.05c	47.60a	45.15b
Rates (tons/ha)	Organic Carbon		
	Bare Ground	Battery cage	Deep litter
0	2.96e	2.96e	3.06e
5	12.76d	13.60bc	13.84b
10	14.08b	13.62bc	13.12c
15	13.96b	13.72b	13.96b
20	13.36bc	13.96b	15.15a
Rates (tons/ha)	Total Nitrogen		
	Bare Ground	Battery cage	Deep litter
0	1.00c	0.76d	0.84d
5	1.26b	1.26b	1.12bc
10	1.40a	1.40d	1.26b
15	1.26b	0.98c	0.98c
20	1.40a	1.12bc	0.98c

Treatment values within an interaction followed by similar letters are not significantly different at $p \leq 0.05$

4. Conclusion

The different sources of poultry manure and application rates revealed significant improvement in the soil characteristics. The available soil phosphorus, organic carbon, and total nitrogen were mostly improved with increasing rates of manure application. However, some of the properties did not follow a consistent linear improvement with an increase in application rates. Additionally, it was evident that application of poultry manure, especially at 20 tons/ha proved to influence the soil characteristics significantly compared to other rates. Therefore, findings from this study highlight the benefits of using different poultry source manure and various application rates to enhance the soil chemical properties. Future research should focus on incorporating a test crop to further understand the effect of these different manure sources and application rates on both soil health and plant performance.

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6. Conflict of Interest

The authors declare no conflict of interest

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