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Short-term impacts of heavy poultry manure addition on the properties of loamy-sand Alfisols later evaluated using okra

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ABSTRACT

The uncontrolled disposal of large quantities of poultry waste onto the soil surface by poultry farmers poses significant long-term risks to soil health. While long-term concerns remain, this study focused on the implications of short-term impacts of heavy application of poultry manure on soil chemical and hydraulic characteristics, as well as its subsequent effects on okra growth indices. Poultry manure was applied to 10 kg potted soil at varying rates of 0, 20, 40, and 60 kg/ha, designated as PM_0, PM_{20}, PM_{40}, and PM_{60}, respectively, with five replicates per treatment. The experiment was arranged in a completely randomized design (CRD). Disturbed and undisturbed soil samples were collected from the experimental units at 8 and 12 weeks after incorporation (WAI) for determination of chemical and hydraulic properties using standard methods. Okra seeds were sowed in the experimental units at 12 WAI, and plant growth data were collected at 2, 4, and 6 weeks after sowing (WAS). Treatment affected all chemical and hydraulic properties measured at 5% probability level except total N at 12 WAI. Overall, the different manure rates showed similar values amongst one another, suggesting that the optimal benefits of poultry manure addition was achieved at the lowest application rate of 20 t/ha. The agronomic parameters, including plant height, leaf area, and leaf numbers, were affected by the treatments across the sampling periods.

Keywords: Poultry manure rates, chemical properties, hydraulic properties, okra growth, disturbed soil, undisturbed soil

1. INTRODUCTION

The application of animal manure in agriculture has gained significant attention due to its potential to enhance soil fertility, increase crop yields, and improve both soil structure and hydraulic properties (Obalum et al., 2024a). Farmers worldwide use animal manure to improve soil fertility by increasing soil organic matter (SOM) and

DISCOVERY SCIENTIFIC SOCIETY

storing carbon. This improves soil tilt, porosity, infiltration rates, and crop yields (Rayne and Aula, 2020). Increased SOM increases aggregation and decreased soil bulk density (Amorim et al., 2022; Suja and Sreekkumar, 2014).

Added organic matter strengthens soil aggregation by stimulating microbial/fungal activity, resulting in increased production of exudates that act as natural binding agents between soil particles (Zhou et al., 2020). Enhanced soil aggregation and structure result in optimal drainage (Li et al., 2021). Among animal manures, poultry manure stands out as a valuable source of nutrients for plants (Joseph et al., 2017; Obalum et al., 2020). According to Chandrashekara et al., (2000) and Chukwuma et al., (2024), poultry manure is richer and more effective than other types of manure, such as cattle, goat, and pig dung, in improving soil quality. Poultry manure is in high demand among farmers due to its ability to increase crop productivity (Joseph et al., 2017; Ogunezi et al., 2019; Obalum et al., 2024b).

According to Onah et al., (2023), the organic matter in poultry manure enhances soil structure by improving aggregation, leading to enhanced water infiltration and root penetration. Poultry manure is a valuable source of essential nutrients, including nitrogen, phosphorus, and potassium, as well as other micronutrients. According to Onah et al., (2023), the release of these nutrients into the soil through poultry manure decomposition can substantially enhance soil fertility. These nutrients have a lingering impact due to their gradual release and persistence in the soil over an extended period. The effects of manures on SOM and soil productivity quickly wane in the tropics because of the prevalent high temperatures (Onah et al., 2022).

A significant loss of SOM due to tropical temperatures might lower the soil's fertility and productivity. However, excessive application might result in nutrient imbalances and environmental issues. Optimal crop growth and productivity require a balanced nutrient profile. This manure, at 10 t/ha, could improve soil hydraulic properties in the Alfisols of southwestern Nigeria Adeyemo et al., (2019), as well as in the drought-prone Ultisols of the Derived Savannah in southeastern Nigeria; an application rate of 20 t/ha has been suggested for these soils (Ogunezi et al., 2019; Nnadi et al., 2020; Azuka and Idu, 2021). However, at this low rate, their SOM content and hydraulic properties, as indicated by soil bulk density, remain inconsistent.

While some studies have reported no significant effects Onunwa et al., (2016), others have found alterations in these soil properties (Nwite and Alu, 2018; Obalum et al., 2020). Research on the use of poultry manure has focused on its synergistic effect with NPK fertilizers on crop performance and fertility indices Joseph et al., (2017), Omalle et al., (2022), but no data exists in works of literature regarding its sole impact on soil properties in our study area. The lack of data on the sole use of poultry manure in our study area is particularly concerning, as excessive application of poultry manure can alter soil properties, affecting water infiltration, aeration, and root growth.

The rationale for using higher application rates up to 60 t/ha in our study stems from common farming practices in our region, where animal manure is often disposed of in heaps on the soil surface, remaining there for extended periods before decomposition. This study simulated these conditions and investigated the consequences of such practices on soil health and okra productivity. Therefore, this study investigated the short-term impacts of heavy poultry manure application on soil chemical and hydraulic properties, and its impact on okra growth performance in a well-drained acid Alfisols within the Derived Savannah agroecological zone of Nigeria.

2. MATERIALS AND METHODS

Study area

This study was conducted at Prince Abubakar Audu University (PAAU), Anyigba, Kogi State, Nigeria (Latitude 7° 06'N and Longitude 6° 43'E). The region falls within the North-Central Derived Savannah agroecological zone of Nigeria (Kowal and Knabe, 1972). The study area experiences a distinct dry and wet season, characterized by a bimodal rainfall pattern that peaks in July and September. The location experiences a warm, humid climate, and annual rainfall varies between 1560 to 1808 mm (Amhakhian et al., 2010).

The average monthly temperature ranges from 17^{0}C to 36.2^{0}C, with variation occurring throughout the year. At 65% and 85% annually, relative humidity is still moderately high (Amhakhian et al., 2010). The geology is part of Nigeria's Cretaceous to recent sediments and falls within the Anambra Basin (Amhakhian and Osemwota, 2012). It is predominantly composed of the Ajali formation. The soils in the area are formed from the sandstone mineralogy, and classified as Alfisols.

Soil sampling, treatment and experimental design

Soil samples were collected from a continuously cultivated land located at the Faculty of Agriculture, Prince Abubakar Audu University, at a depth of 0 to 20 cm. The soil was sieved through a 2-mm mesh sieve to remove stones, gravel, and debris. Sieved soil samples (10 kg each) were measured into 10 L plastic pots. A subsample was taken before sowing for routine analysis at the laboratory. The treatments consists four rates of poultry manure application: 0, 20, 40, and 60 t/ha, termed heavy application, and designated as PM_0, PM_{20}, PM_{40}, and PM_{60}, respectively. We replicated the treatments five times, resulting in 20 experimental units, and arranged them in a completely randomized design (CRD). We obtained the okra seed (*Abelmoschus esculentus*) from the National Cereals Research Institute, Badegi, Kogi State.

We obtained the poultry manure from the deep litter system of the Poultry Unit of the Animal Production Section of the PAAU Teaching and Student Research Farm, and then cured by air-drying for four weeks, crushed, sieved, and thoroughly mixed to ensure homogeneity before application. Thereafter, we thoroughly incorporated the poultry manure into the 10 kg soil in each pot. Immediately after adding manure, we covered the individual pot by surface mulching using dry grass material at a uniform height of 15 cm, to minimize mineralization of the added manure and prevent water loss to evaporation. We watered the set-up experiment with 1 liter of water at a 4-day interval for 12 weeks. At 12 weeks after incorporating amendments into the soil, we sowed three okra seeds in each pot, and thinned to one plant per stand at 2 weeks after germination. We conducted the experiment from March to July 2024.

Soil sample and agronomic data collection

Soil samples were collected at 8 and 12 weeks after amendment incorporation using core samplers of 123.2 cm^3 by volume. Two undisturbed samples were taken per pot for the determination of hydraulic properties, and corresponding soil samples were collected for the determination of chemical properties. Okra growth data were collected at a 2-week interval, starting from the second week after sowing okra, corresponding to 14 WAI. Agronomic data was collected on vegetative growth, including plant height, using a ruler to measure from soil level to the youngest outgrowth at the tip, leaf area where leaf area (LA) = L × W × 0.45 (cm^2) Ogoke et al., (2003), and number of leaves by counting.

Laboratory analysis

The particle size distribution was determined using the hydrometer method, as described by (Gee and Or, 2002). Soil pH was determined potentiometrically using a pH meter, with a soil–liquid ratio of 1:2.5 suspensions of soil in distilled water and KCl, following (McLean, 1982). Soil organic carbon was determined using the Walkley–Black wet oxidation procedure (Nelson and Sommers, 1996). The percentage of organic matter was computed by multiplying the percentage organic carbon by the Van Bemmelen factor of 1.724. Total nitrogen was determined by the salicylic acid-thiophosphate digestion method, followed by distillation using a modified Macro-Kjeldhal apparatus, as described by (Juo, 1979). The available phosphorus was extracted by the Bray No.2 and Bray No. 1 methods (Murphy and Riley, 1962).

The exchangeable potassium (K^+) and sodium (Na^+) were extracted with HCl solution, and their levels determined by flame, and exchangeable magnesium (Mg^{2+}) and calcium (Ca^{2+}) by atomic absorption spectrophotometer (Senjobi and Ogunkunle, 2010). The exchangeable acidity was extracted in 1 N KCl using the titrimetric method (McLean, 1982). The total exchangeable bases (TEB) are calculated by summating exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, Na^+). The effective cation exchange capacity (ECEC) was calculated by summing TEB and exchangeable acidity. The soil bulk density was calculated according to (Grossman and Reinsch, 2002). Total porosity was calculated according to. Water holding capacity was calculated according to (Piper, 1966). Saturated hydraulic conductivity (K_s) was determined using the method outlined by (Klute and Dirksen, 1986).

Data analysis

Data on all observations were subjected to one-way Analysis of Variance (ANOVA) using IBM SPSS Statistics version 27. The treatment means were compared using the least significant difference (LSD) test.

3. RESULTS AND DISCUSSIONS

Physicochemical properties of the soil and chemical properties of poultry manure used in this study

Table 1 shows the initial physicochemical properties of the soil and the chemical properties of PM used in this study. From the particle size distribution, the soil falls under the loamy sand category. The physicochemical properties of the soil show that it is an acid soil. This soil is most desirable for vegetable production with a pH of 6.0 to 7.0. With low contents of macro-nutrients (particularly total N and available P). The soil exhibits inherently low fertility characteristics, rendering it unsuitable for sustaining productive arable crop production (Joseph et al., 2017). The PM showed low values for organic carbon and total nitrogen but high values for pH, phosphorus, sodium, potassium, magnesium, and calcium compared to those used in the studies of (Joseph et al., 2017).

Table 1 Initial physicochemical properties of the soil and chemical properties of poultry manure used in this study

Parameter	Pre-soil analysis	Poultry manure
Sand (g/kg)	850.80	-
Silt (g/kg)	43.0	-
Clay(g/kg)	106.20	-
Textural class	Loamy Sand	-
Soil pH in H_2O	6.60	7.00
Soil pH in KCl	-	6.00
% Soil organic carbon, SOC	1.39	3.76
% Soil organic matter, SOM	2.40	6.48
% Total nitrogen, N	0.09	0.25
Available phosphorus, P (mg/kg)	1.07	23.80
Exchangeable potassium, K^+ (cmol/kg)	1.89	3.42
Exchangeable calcium, Ca^{2+} (cmol/kg)	4.01	6.52
Exchangeable magnesium, Mg^{2+} (cmol/kg)	2.39	3.69
Exchangeable sodium, Na^+ (cmol/kg)	0.27	0.62
Exchangeable Acidity	-	1.06

Effect of poultry manure on soil chemical properties at 8 and 12 weeks after incorporation (WAI) of amendments

Table 2 shows the effect of poultry manure on soil chemical properties at 8 and 12 weeks after incorporation of amendments. Treatment affected all chemical parameters evaluated across the sampling period except total N at 12 WAI. It was observed that PM_{60} had a higher and significant effect on pH (in water and KCl), Na (0.5 cmol/kg) and Available P (3.82 mg/kg) at 8 WAI, while PM_{40} had a higher and significant effect on Mg (2.48 cmol/kg), Ca (4.96 cmol/kg), K (2.24 cmol/kg), total N (0.16%), SOM (3.82%), ECEC (11.30 cmol/kg) and TEB (10.14 cmol/kg).

Although the difference is not noticeable with other poultry-manure-amended soil, it indicates that as poultry manure decomposes, nutrient elements are released into the soil, thereby improving the fertility status of the soil (Awais et al., 2022). The higher value of pH in the treatment shows that poultry manure raised the soil pH and encouraged the availability of exchangeable bases, which would encourage the availability of more soil organic matter and increase the fertility of the soil (Awais et al., 2022). The significant and a higher SOM observed in the treatment shows that with mineralization comes higher release of organic carbon to the soil, stored as organic matter.

At 12 WAI, pH (water and KCl), Mg, Na, Ca, K, SOM, total N, ECEC, and TEB were significantly affected by PM_{20}, while PM_{60} had a higher and significant effect on available P. It was also observed that PM_0 had the lowest values on all parameters measured, except on EA at both sampling periods. The higher value of EA observed in PM_0 suggests that poultry manure application decreases soil acidity. It was also observed that the measured parameters fluctuated without a definite pattern between 8 WAI to 12 WAI of amendments. This could result from further mineralization or temporary stabilization of poultry manure decomposition.

Table 2 Effect of poultry manure on soil chemical properties at 8 and 12 weeks after incorporation

Treatment	pH-H2O	pH-KCl	%SOM	%TN	AP (mg/kg)	Mg	Na	Ca	K	EA	ECEC	TEB
						cmol/kg						
8 weeks after incorporation												
PM_0	6.03b	5.48b	2.49b	0.14a	3.71a	2.08b	0.38b	4.14b	1.91b	1.35a	9.86b	8.51b
PM_{20}	6.12b	5.48b	3.00ab	0.15a	3.15b	2.33a	0.46a	4.71a	2.17a	1.21b	10.88a	9.67a
PM_{40}	6.09b	5.42b	3.82a	0.16a	2.84b	2.48a	0.46a	4.96a	2.24a	1.16b	11.30a	10.14a
PM_{60}	6.28a	5.67a	3.47a	0.12b	3.82a	2.33a	0.50a	4.76a	2.13a	1.18b	10.90a	9.72a
12 weeks after incorporation												
PM_0	5.59b	4.48b	2.15b	0.19	4.15b	2.51b	0.37c	3.46a	2.41b	1.25a	10.00b	8.75b
PM_{20}	6.11a	4.86a	5.71a	0.22	13.94a	3.27a	0.45ab	3.31a	3.05a	1.17bc	11.25a	10.08a
PM_{40}	5.69b	4.66ab	5.55a	0.18	5.85b	3.21a	0.43b	3.28a	3.02a	1.19b	11.13a	9.94a
PM_{60}	5.64b	4.98a	5.86a	0.23	15.58a	3.31a	0.51a	2.80b	2.98a	1.14c	10.74a	9.60a

PM – Poultry manure; SOM – Soil organic matter; TN – Total nitrogen; AP – Available phosphorus; Na – Sodium; K – Potassium; Mg – Magnesium; Ca – Calcium; EA – Exchangeable acidity; TEB – Total exchangeable bases; ECEC – Effective cation exchange capacity; abcd – Significant difference at $p \leq 0.05$

Effect of poultry manure on soil physical and hydraulic properties at 8 and 12 weeks after incorporation (WAI)

Table 3 shows the effect of poultry manure on the physical and hydraulic properties of the soil. Treatment affected all hydraulic parameters measured, with PM_{20} having a higher and significant impact on *Ks* (32.93 cm/hr), and WHC (43.41%). In comparison, PM_{60} had a higher and significant impact on total porosity (51.27%) and a lower considerable impact on the bulk density (1.29 g/cm^3) at 8 WAI. At 12 WAI, PM_{60} had a higher and considerable impact on *Ks* (43.56 cm/hr), total porosity (50.46%) and a lower and considerable impact on the bulk density (1.31 g/cm^3), while PM_{40} had a higher and considerable impact on WHC (47.04%) at 12 WAI. In all measured parameters at both sampling periods, PM_0 had the lowest values except for the bulk density.

The significantly higher values observed in the treatment show that poultry manure can improve soil structure by enhancing *Ks*, total porosity, and WHC, while reducing bulk density. The higher value of the soil bulk density observed in PM_0 indicates compaction of the soil, although the bulk density of 1.44 and 1.46 g/cm^3 observed at 8 and 12 WAI, respectively, falls within suitable range of bulk density for arable crop production (Joseph and Ojomah, 2023). It was also observed that the bulk density and total porosity decrease, but other measured parameters increase over the sampling time. The significant effect of the treatment shows that the added organic matter can increase soil porosity, allowing for better water infiltration and aeration (Anyaoha et al., 2018; Adeyemo et al., 2019; Bashir et al., 2021).

A notable treatment effect was observed on WHC, which could suggest that the type and quantity of organic amendment used may have been sufficient to influence WHC significantly. Obalum et al., (2024a) reported that the addition of organic matter generally results in the improvement of soil organic matter content and soil stability. Obalum et al., (2024a) report that the manure applied significantly decreased the bulk density and increased the total and macro porosity, infiltration capacity, and available water capacity. Consistent with our findings, Agbede et al., (2008) and Obalum et al., (2024a) also reported considerable reductions in the soil bulk density and temperature, and increases in the total porosity and moisture content, following manure application in Nigerian soils. The application of waste manure resulted in increased soil organic matter and decreased bulk density.

Effect of poultry manure on okra growth indices at 2, 4, and 6 weeks after sowing (WAS)

Table 4 shows that treatment significantly affected most plant parameters across the data collection period, except for the number of leaves at 2 WAS and stem girth at 2 and 4 WAS. At 2 WAS, PM_{60} exhibited significantly higher values for plant height (24.62 cm) and leaf area (42.87 cm^2). At 4 WAS, PM_{60} had a higher and considerable value of 43.10 cm, 7.40, and 7 on plant height, number of leaves, and number of branches, respectively, while PM_{20} had a higher and considerable value of 134.18 cm^2 in leaf area.

Table 3 Effect of poultry manure on soil hydraulic properties at 8 and 12 weeks after incorporation

Treatment	*Ks* (cm/hr)	Bulk density (g/cm^3)	Total Porosity (%)	WHC (%)
8 weeks after incorporation				
PM_0	22.40b	1.44a	45.55b	31.11b
PM_{20}	32.93a	1.31b	50.21a	43.41a
PM_{40}	29.40a	1.30b	50.70a	39.09a
PM_{60}	22.77b	1.29b	51.27a	38.51a
12 weeks after incorporation				
PM_0	19.11c	1.46a	45.04b	39.90b
PM_{20}	31.40b	1.33b	49.75ab	46.07a
PM_{40}	26.17bc	1.33b	49.66ab	47.04a
PM_{60}	43.56a	1.31b	50.46a	42.91b

PM – Poultry manure; *Ks* – saturated hydraulic conductivity; WHC – water holding capacity; abcd – significant difference at $p \leq 0.05$

At 6 WAS, PM_{60} had a higher and considerable value on all plant parameters measured. This may be attributed to release of nutrients from the PM into the soil through mineralization. It was further observed that plant parameters increase over time, with gains between week 2 and 4, and further increases by week 6. Similar to the findings of this study, Gani et al., (2024) reported increases in plant growth parameters after the application of poultry manure to the soil.

Table 4 Effect of poultry manure on okra growth parameters at 2, 4, and 6 weeks after sowing corresponding to 14, 16, and 18 weeks after incorporating amendment, respectively

Treatment	Stem girth (cm)	Plant Height (cm)	Leaf Area (cm^2)	No of Leaf	No. of Branches
2 weeks after sowing					
PM_0	1.22	17.90b	17.93b	4.00	3.00b
PM_{20}	1.23	20.30b	29.46ab	5.20	3.80a
PM_{40}	1.10	19.58b	27.39ab	5.20	3.46ab
PM_{60}	1.12	24.62a	42.87a	4.60	3.55a
4 weeks after sowing					
PM_0	1.47	30.95b	58.72b	5.25b	4.65b
PM_{20}	1.50	38.90ab	134.18a	7.10a	6.10ab
PM_{40}	1.33	42.40a	85.05b	6.90a	6.60a
PM_{60}	2.10	43.10a	132.82a	7.40a	7.00a
6 weeks after sowing					
PM_0	1.70c	32.40c	46.24b	5.40c	4.70d
PM_{20}	3.40b	43.80b	141.60a	7.20b	6.40c
PM_{40}	4.10a	53.80a	154.00a	8.40b	8.50b
PM_{60}	4.55a	54.40a	176.00a	10.20a	9.60a

PM – Poultry manure; abcd – Significant difference at $p \leq 0.05$

4. CONCLUSION

This study evaluated the short-term effects of heavy poultry manure application on soil chemical and hydraulic properties, and its impact on okra growth performance, after 12 weeks of incorporation in a well-drained acid Alfisols. Treatment considerably affected all measured chemical and hydraulic properties measured at both sampling periods, except for total nitrogen at 12 WAI. No considerable differences were observed in SOM, Mg and K levels between PM_0 pots and those amended with poultry manure. While BD decreases, TP increases with increasing manure rate. Okra growth indices – plant height, leaf area, and number of leaf were affected by treatment across sampling periods.

Furthermore, all plant growth indices measured increase with sampling periods. Overall, the different manure rates showed similar values amongst one another, suggesting that the optimal benefits of manure amendment were achieved at the lowest application rate of 20 t/ha. This reveals that excessive manure application did not provide additional benefits, and may even pose environmental risks due to potential nutrient leaching or soil degradation. Therefore, the application rate of 20 t/ha appears to be sufficient for improving soil fertility and okra productivity.

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Author contributions

The authors confirm the study conception and design: Paul Omaye Joseph; data collection: Anejodo Eyojo Ejiga, John Babatunde Abioye; analysis and interpretation of results: Paul Omaye Joseph, Frank Ojochegbe Ojomah; draft manuscript preparation: Paul Omaye Joseph, Frank Ojochegbe Ojomah. The results were evaluated by all authors, and the final version of the manuscript was approved

Informed consent

Not applicable.

Conflicts of interests

The authors declare that there are no conflicts of interests.

Ethical approval

Not applicable.

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Data and materials availability

All data associated with this study are present in the paper.

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