RESEARCH ARTICLE

Residual effects of heavy application of poultry-droppings manure on aggregation, P-fertility and hydraulic properties of well-drained tropical soils

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Abstract: Manure effects on soil organic matter (SOM) and related physicochemical fertility indices wane rather fast in the tropics due mainly to the prevailing high temperatures. In texturally similar soils, SOM-mediated aggregation controls hydraulic properties including rainfall-to-field-capacity time (FC_{time}) and field capacity water content (FC_{water}) that relate to water/nutrients availability to crops. This study assessed the residual effects of poultry-droppings manure at 25, 50 and 75 t/ha on SOM and aggregation, P-fertility and hydraulic properties of sandy-loam Ultisols in southeastern Nigeria. Mulch-protected treatment plots were water-saturated weekly during the dry season. Sampling for immediate effects was done one month after treatment; that for residual effects in the subsequent rainy season, 7-8 months after treatment, when FC_{time}/FC_{water} was monitored at 3-24 h intervals after three rainfall events each $\geq$ 30 mm. A given monitoring time was designated FC_{time} if the corresponding FC_{water} was similar to that of the succeeding one. Immediate effects of the manurial treatment showed higher soil pH, SOM, aggregates' mean-weight diameter and available P in 50 and 75 t/ha than unamended control, but similar sand-corrected water-stable aggregates and permeability indices among treatments. Residual effects toed similar trends except that aggregates' mean-weight diameter was unaffected, while soil bulk density was lower and microporosity higher in 75 t/ha than the rest. Across the three rainfall events corresponding to the sampling periods, FC_{time} averaged 42 and 26 h, respectively at $\leq$ 25 and $\geq$ 50 t/ha, while FC_{water} increased steadily (0.08-0.22 g/g) with manure rate. Beyond the season of its application to drought-prone Ultisols, poultry-droppings manure at heavy rates (50-75 t/ha) can still be promoting their SOM and P-fertility statuses but not macro-aggregation. Up to 75 t/ha of the manure may be required for similar residual effects on soil hydraulic properties (including FC_{time} and FC_{water}), with FC_{time} seemingly varying not just with SOM but also the associated rainfall's characteristics.
Keywords: Well-drained sandy loam, organic soil amendments, soil structure reformation, pore size distribution, soil hydraulic properties, variable field capacity

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1 Introduction

Soil organic matter (SOM) influences soil aggregate stability and hydraulic properties (including water retention) as much as it influences soil fertility and overall soil quality. It is often regarded as the single most important indicator of soil degradation (Obalum et al., 2017). The effects of changes in SOM status on soil structure and associated soil properties depend on soil textural attributes and the antecedent SOM content of the soil (Bhadha et al., 2017; Ezeaku et al., 2020), as well as the quantity (and certainly the quality) of organic matter added to the soil and time since its addition.

The SOM serves as an aggregating agent in soils. In coarse-textured tropical soils, SOM positively influences field capacity (FC), the amount of water retained against gravitation-driven drainage (Obalum et al., 2020a; Obalum and Obi, 2013), information of which finds application in irrigation scheduling (Obalum and Azuka, 2021). The influence of SOM on FC is partly because SOM has a charged surface and hence affinity for water (Bhadha et al., 2017), and partly because of increased soil aggregation which could make FC to be attained faster. Water retention is more sensitive to SOM in coarse-textured than fine-textured soils. The higher the SOM content is, the more water is absorbed and retained in the soil (Adeyemo et al., 2019), and this is particularly true in coarse-textured soils as opposed to fine-textured ones where increases in SOM concentration often led to decreases in water retention (Sheppard et al., 2022).

Manures are often used by farmers worldwide to boost SOM and store carbon in a bid to improve soil fertility. They improve soil tilts and porosity and increase soil infiltration rates and crop yields (Eusufzai and Fujii, 2012; Rayne and Aula, 2020), and this is mostly through increases in SOM (Maillard and Angers, 2013; Amorim et al., 2022) which translates into increased aggregation and decreased soil bulk density (Suja and Sreekkumar, 2014). Added organic matter promotes soil aggregation by stimulating microbial/fungal activity for increased production of exudates that serve as natural binding agents between soil particles (Zhou et al., 2020). Improved soil aggregation and structure results in good drainage (Eusufzai and Fujii, 2012; Li et al., 2021).

One problem, however, with manures generally is their little or no residual effects on SOM content and related soil properties and processes in the tropics due mainly to the prevailing high temperatures. This is true mostly for animal manures whose carbon content defines their mineralisation rates and hence residual effects in soils (Uzoh et al., 2015). For instance, cattle dung is typically richer in carbon than manures from monogastrics such as pig dung and poultry droppings (Uzoh et al., 2015; Adubasim et al., 2018); yet its residual effects on structure-related properties of humid tropical soils are often not evident (Ezenne et al., 2019; Obalum et al., 2020a). Improving the structure of these soils can also help to minimize excessive leaching of the base-forming cations that provokes soil acidity and P-fixation.

As an effective manure, poultry droppings can improve soil aggregation (Chukwuma et al., 2024) for enhanced water retention and hence FC. At 10 t/ha, this manure could improve soil hydraulic properties of the Alfisols of southwestern Nigeria (Adeyemo et al., 2019), and those of the drought-prone Ultisols of the Derived Savannah of southeastern Nigeria whose full productivity restoration would need higher rates (Obi and Ebo, 1995). In this regard, application rate of 20 t/ha has been proposed for these soils (Ogunezi et al., 2019; Nnadi et al., 2020; Azuka and Idu, 2021). At this modest rate, their SOM content and hydraulic properties represented by soil bulk density are sometimes not significantly affected (Onunwa et al., 2016), and some other times affected (Nwite and Alu, 2019; Obalum et al., 2020b). This casts doubt on the residual effects of this relatively low-carbon manure on structure-related properties of the soils.

With or without poultry-droppings manure at a heavy rate of 70 t/ha, tillage-loosened coarse-textured tropical soils would have their aggregation status improved after about five months when, however, the manure-amended ones would show increased densification due to the manure's over-liming effect increasing the soil pH to and above near-neutral values (Obalum et al., 2024). These soil pH-driven concurrent increases in soil aggregation and bulk density as from five months after heavy application of poultry-droppings manure suggest that such a practice may have desirable residual effects on P availability and hydraulic properties of these low P-fertility and drought-prone soils. In the present study, our interest was mostly on drainability of the soils, indexed by time from soil-saturating rainfall to FC (FC_{time}) and soil water content at FC (FC_{water}). Any residual effects of this manure on these two hydraulic properties for the soils could have some agronomic and ecological significance. So too would its residual effects on P sorption and precipitation of these oxide-rich, largely acid soils (Chukwuma et al., 2024). The objective of this study, therefore, was to assess the effects of previous heavy manuring with poultry droppings on SOM content and the imprint on macro-aggregation, P-fertility and hydraulic properties of oxide-rich and coarse-textured acid soils that are dominant in the humid tropics.

2 Materials and Methods

2.1 Site description

The field experiment was carried out near the central sewage at the north-eastern end of Nsukka campus of the University of Nigeria (UNN), approximately 800 m from the Junior Staff Quarters (06° 52'N, 07º 24'E) (Echiegu et al., 2016). The site which is at the lowest point on the campus is located on a plateau (approximately 280 m asl). Mean annual rainfall, temperature and relative humidity are 1600 mm, 27.1 ºC and 75.5%, respectively. Rainy season usually extends from April to October. The area experiences a bimodal rainfall with peaks in July and October. The soil is sandy loam, slightly brown and porous with low saturation water holding capacity (Obalum and Obi, 2014). The vegetation of the area is dominated by grasses of different species such as elephant grass, centro (*Centrosema pubscens*), guinea grass, etc.

Table 1. Some physicochemical and structure-related properties of the coarse-textured acid soil under investigation before heavy application of poultry-droppings manure

Soil property	pH-H_2O	pH-KCl	SOM (g/kg)	AvP (mg/kg)	MWD (mm)	% WSAcfs	BD (g/cm^3)	% TP	K_s (cm/h)
Value	5.3	4.0	9.80	27.36	1.29	44.29	1.40	47.15	14.16

SOM - soil organic matter, AvP - available phosphorus, MWD - mean-weight diameter of soil aggregates, WSA_{cfs} - water-stable aggregates corrected for sand, BD - bulk density, TP - total porosity, K_s - saturated hydraulic conductivity.

Table 1 shows the physicochemical and structure-related properties of the soil before the heavy application of poultry manure to raise SOM and heavy surface mulching to protect it. The soil was slightly acidic and showed low pre-manuring SOM content. It also showed low values of some soil structure-related parameters, including mean-weight diameter (MWD) of soil aggregates, water-stable aggregates corrected for sand (WSA_{cfs}), and saturated hydraulic conductivity (K_s). However, soil content of available P, soil bulk density, and total porosity indicated moderate values.

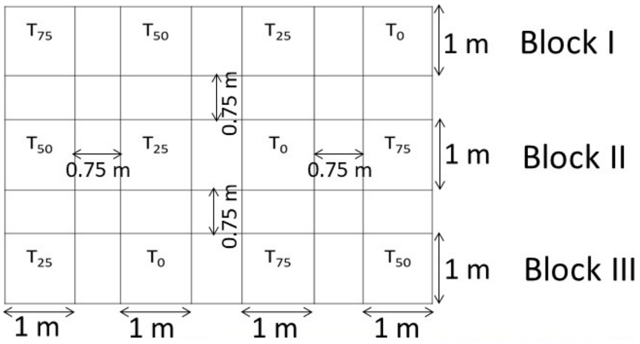

Figure 1. Field layout of the experiment showing the investigated four treatments of varying application rates of poultry-droppings manure (T_0, T_{25}, T_{50} and T_{75}).

2.2 Experimental design and treatment set-up

The field study involved, as treatments, addition of poultry-droppings manure at four rates namely 0, 25 50 and 75 t/ha, designated T_0 (or the unamended control), T_{25}, T_{50} and T_{75}, respectively. At the experimental site, the land delineated for the field study measured approximately 28 m^2 (6.25 m × 4.50 m). It was manually cleared and demarcated into treatment plots using earthen bunds. Treatments were replicated three times in a randomized complete block design, giving 12 bunded mini-plots each of dimension 1 m × 1 m, with a 0.75-m space among them in blocks and also between blocks (Figure 1).

The poultry-droppings manure, sourced from the battery cage system of the Poultry Unit of Animal Science Farm of the UNN, was cured by air-drying amidst regular turning for four weeks, homogenized, crushed and sieved before use. The manure used exhibited an extremely alkaline pH and a relatively high content of organic carbon, and moderate concentrations of nitrogen, phosphorus, calcium, magnesium and sodium (Table 2). It was applied at the different rates to the plots meant to receive them. Thereafter, the plots were tilled by hoeing to about 20 cm depth, incorporating the manure into the soil and making flatbeds within each bunded plot to ensure uniform water distribution during irrigation/rainfall. They were watered to FC at two-day intervals for two weeks to facilitate decomposition of the added manure.

Table 2. Some chemical properties of the poultry-droppings manure

pH-H_2O	pH-KCl	OC§	N§	Phosphoru	Potassiu	Calcium	Magnesiu	Sodium
		(g/kg)						
9.5	8.9	326	18.2	3.66	5.50	120	48	1.10

OC - organic carbon, N - nitrogen; Carbon-nitrogen ratio of 17.91.

Two weeks after manuring, a thick translucent polythene material of about the size of the individual plots was used to cover them. In the study environment, surface grass mulch could conserve soil water in the root zone when applied at a low rate of 5 t/ha (Obalum et al., 2012), but might not have residual effect on SOM content even when used at a higher rate of 20 t/ha (Ezenne et al., 2019; Obalum et al., 2020a).

Figure 2. The treatment plots that received poultry-droppings manure at varying rates as first covered with transparent polythene material [left], followed by heaping of dry grass material as protective surface mulch at the rate of 100 t/ha [right].

There was thus a need to guard against evaporative loss of water so as to enhance the accuracy of FC data while also reducing mineralisation of the added organic matter whose residual effect on FC was sought. Because of these concerns, the surface coverage with polythene material was followed by further surface mulching at a very high rate of 100 t/ha, done by heaping 10 kg of dry grass per 1-m^2 plot (Figure 2).

The plots were set up in early Dec. 2019. After the mulching, they were water-saturated artificially on weekly basis for five months before the full return of rains in May 2020. Natural rains sustained the plots from May till Jul. 2020 when the experiment was terminated.

2.3 Data collection and analysis

Soil sampling was done twice; early Jan. and early Jul. 2019, corresponding to 1 and 7 months after treatment (MAT) when immediate and residual effects of treatment were tested, respectively. The choice to wait till 7 MAT to assess treatment residual effects was adopted after Ezenne et al. (2019) who studied the effects of cattle-dung manure on hydraulic properties of the coarse-textured soils under investigation. Undisturbed and disturbed soil samples were collected from the topsoil (0-10 cm) at both sampling times to determine soil structure-related and physicochemical properties.

The disturbed soil samples were air-dried at room temperature to constant weight, passed through nested 4.7 and 2 mm-mesh sieves. The 4.7-2 mm soil aggregates that were retained on the 2-mm sieve were used to assess the treatments for aggregate stability, while the <-2 mm fine earth materials were used for soil physicochemical analysis. Soil macro-aggregate formation and aggregate stability were assessed, following wet sieving of 4.7-2 mm aggregates, by the popular MWD of soil aggregates and percent WSA_{cfs}, respectively, adopting the procedures described in Obalum et al. (2011b). Soil physicochemical properties determined on the <-2 mm fine earth materials were soil pH-H_2O, SOM and Bray-2 available P, following standard laboratory procedures (Sparks, 1996).

Using the undisturbed soil samples, some hydraulic properties including soil bulk density, total porosity, macro-/microporosity and saturated hydraulic conductivity (K_s) were determined by standard procedures. In brief, the steady state volume of water flowing through the soil was first measured by the constant head permeameter method (Klute and

Dirksen, 1986), after which K_s was calculated using the transposed Darcy's equation for vertical flows of liquids through porous media. Then, the undisturbed soil samples (soil cores) were re-saturated and weighed before subjecting them to drainage under 60-cm water-tension for 24 h; macroporosity was determined as the volume of water drained out of them, taken as hypothetically occupying the macropores, expressed as a ratio of the soil core holder's volume (Obalum et al., 2011b). Subsequent oven drying of the soil cores to enable the computation of soil bulk density was done at 105ºC for 24 h (Grossman and Reinsch, 2002).

The FC_{time} and FC_{water} were monitored thrice during 7-8 MAT, when each topsoil sampling was synchronized with sufficient rainfall (rainfall events $\geq$ 30 mm). Moist soil samples for this purpose were collected at 3-h intervals on the first day, 6-h intervals on the second day, 12-h intervals on the third day, and 24-h interval on the fourth and the fifth day. Depending on the time of the day when desired rainfall event occurred, this schedule for FC monitoring was not always strictly followed, as such monitoring at nights was impossible in this study. However, in the three sampling periods, no two monitoring times had a time lag larger than 12 h.

At a given monitoring time regarded as FC_{time}, the corresponding water content was inferred to be FC_{water} if this water content was similar to that of the succeeding one, i.e., the one determined in the next monitoring time. This FC_{water} was expressed on gravimetric basis.

Data were analyzed using the software *R*. The data for the soil hydraulic properties (including FC_{water} but not FC_{time}) and chemical properties were subjected to one-way analysis of variance done by the Kruskal Wallis test, to compensate for the rather small number of observations (n = 12) in the study. In this test, differences were accepted to be significant at 5% probability level ($P < 0.05$). Mean separation was by the Bonferonni test and means that differed significantly were denoted by different letters of the alphabet.

3 Results and Discussion

3.1 Immediate and residual effects of treatments on SOM and soil macro-aggregation

Table 3 shows the effects of heavy rates of poultry-droppings manure on SOM as well as on the macro-aggregation and aggregate stability indices of the study at 1 and 7 MAT. At both sampling times, treatment affected SOM status concentration in the soil which was generally higher in T_{75} and T_{50} compared with T_{25} and T_0. These results show that poultry-droppings manure needs to be applied at rates above 25 t/ha for its residual effect on SOM to be evident 7 months after application. From these data, the optimum rate of this manure as regards SOM appears to be 50 t/ha; beyond this rate, no further increases in SOM would be expected.

Table 3. Soil organic matter, macro-aggregation indices, soil pH and available P at 1 and 7 months after application of poultry-droppings manure at different – including heavy – rates

Treatment	SOM (g/kg)	MWD (mm)	% WSAcfs	Soil pH	Available P (mg/kg)
	Immediate effects (1 month after treatment)				
T_0 (0 t/ha)	9.91 ^{a}	1.09 ^{a}	34.29 ^{a}	5.27 ^{a**}	27.36 ^{a}
T_{25} (25 t/ha)	14.52 ^{ab}	1.07 ^{a}	35.26 ^{a}	7.50 ^{b}	70.57 ^{b}
T_{50} (50 t/ha)	26.44 ^{b}	1.51 ^{b}	43.63 ^{a}	7.43 ^{b}	108.19 ^{bc}
T_{75} (75 t/ha)	27.88 ^{b}	1.57 ^{b}	50.73 ^{a}	7.90 ^{b}	123.11 ^{c}
Sig. Level	*	§	ns	§	*
	Residual effects (7 months after treatment)				
T_0 (0 t/ha)	7.95 ^{a}	0.65 ^{a}	18.12 ^{a}	7.8 ^{a**}	32.02 ^{a}
T_{25} (25 t/ha)	11.98 ^{ab}	0.59 ^{a}	16.28 ^{a}	7.8 ^{a}	57.82 ^{ab}
T_{50} (50 t/ha)	23.96 ^{bc}	0.67 ^{a}	17.77 ^{a}	8.0 ^{ab}	85.18 ^{b}
T_{75} (75 t/ha)	23.27 ^{c}	0.60 ^{a}	17.95 ^{a}	8.1 ^{b}	92.96 ^{bc}
Sig. Level	*	ns	ns	*	*

T_0, T_{25}, T_{50} and T_{75} represent poultry-droppings manure at 0, 25, 50 and 75 t/ha, respectively. SOM - soil organic matter, MWD - mean-weight diameter of soil aggregates, WSA_{cfs} - water-stable aggregates corrected for sand; *significant at $P \leq 0.05$, significant at $P \leq 0.10$, ns - not significant.

Table 3 also shows treatment effects on the two aggregate stability indices of the study, soil pH and available P at 1 and 7 MAT. The MWD of soil aggregates discriminated the manure rates as producing dissimilar immediate effects ($P \leq 0.10$) in the soil at 1 MAT. The values were higher in T_{50} and T_{75} compared with T_0 and T_{25}. These effects, however, waned with time as the MWD of soil aggregates showed similar values for the residual effects tested at 7 MAT.

3.2 Immediate and residual effects of treatments on soil pH and available P

Treatment affected soil pH and available P (Table 3). The soil was more acidic in T_0 compared with the manure-amended plots at 1 MAT but in T_0 and T_{25} compared with T_{75} at 7 MAT. Manures are known to reduce soil acidity (Obalum et al., 2012; Han et al., 2016; Chukwuma et al., 2024). Similar to the observation made for SOM content, soil available P at both 1 and 7 MAT increased with increase in the application rate of manure. This suggests that the manure addition increased not just SOM content and soil available P, but also the population of microorganisms responsible for P solubility and availability. The increases in soil content of available P with increasing rate of manure agree with similar studies (Kumar and Nair, 2011; Yu et al., 2013; Yang et al., 2019), and the present study shows that such effects could linger beyond the season of manure application. It also points at the linear relationship often found between SOM and P contents of soils (Han et al., 2016; Chukwuma et al., 2024).

3.3 Immediate and residual effects of treatments on soil hydraulic properties

Table 4 shows the effects of heavy rates of poultry-droppings manure on some soil hydraulic properties of the drought-prone Ultisols determined on undisturbed samples at 1 and 7 MAT. Treatment had no immediate effects on these soil properties; the residual effects showed, however, marginally significant ($P \leq 0.10$) differences in soil bulk density and microporosity, with T_{75} giving better values of these two hydraulic properties than the other manure rates (Table 4).

Table 4. Some hydraulic properties of the coarse-textured acid soil at 1 and 7 months after application of poultry-droppings manure at different – including heavy – rates

Treatment	BD (Mg/m^3)	%Total Porosity	% Macro-porosity	% Micro-porosity	K_s (cm/h)
	Immediate effects (1 month after treatment)				
T_0 (0 t/ha)	1.40 ^{a}	33.79 ^{a}	9.24 ^{a}	24.55 ^{a}	3.16 ^{a}
T_{25} (25 t/ha)	1.49 ^{a}	35.35 ^{a}	7.73 ^{a}	27.61 ^{a}	8.32 ^{a}
T_{50} (50 t/ha)	1.48 ^{a}	35.47 ^{a}	9.04 ^{a}	26.43 ^{a}	6.97 ^{a}
T_{75} (75 t/ha)	1.55 ^{a}	35.67 ^{a}	9.94 ^{a}	25.73 ^{a}	2.12 ^{a}
Sig. Level	ns	ns	ns	ns	ns
	Residual effects (7 months after treatment)				
T_0 (0 t/ha)	1.63 ^{b}	64.98 ^{a}	21.66 ^{a}	43.32 ^{a}	8.25 ^{a}
T_{25} (25 t/ha)	1.56 ^{b}	52.73 ^{a}	16.88 ^{a}	35.84 ^{a}	14.97 ^{a}
T_{50} (50 t/ha)	1.53 ^{b}	50.12 ^{a}	5.98 ^{a}	44.14 ^{a}	12.79 ^{a}
T_{75} (75 t/ha)	1.11 ^{a}	73.26 ^{a}	8.29 ^{a}	64.98 ^{b}	11.28 ^{a}
Sig. Level	§	ns	ns	§	ns

T_0, T_{25}, T_{50} and T_{75} represent poultry-droppings manure at 0, 25, 50 and 75 t/ha, respectively. BD - bulk density, K_s - saturated hydraulic conductivity; significant at $P \leq 0.10$, ns - not significant.

Despite the differences in SOM, bulk density indicated similar values (1.40-1.55 Mg/m^3) at 1 MAT, probably because of frustration of SOM structure-stabilising effect in disturbed as opposed to natural ecosystems (Obalum and Obi, 2014). For this immediate effect, bulk density values even tended to increase with manure rate. Adekiya et al. (2014) reported increases in bulk density after three years of soil application of varying rates of poultry manure. That microporosity was also unaffected contrasts with the decreases in this soil hydraulic property due to poultry and livestock manures in a Chinese soil (Li et al., 2011). The K_s remained unaffected, suggesting that the heavy rates of manure dispersed the soil and reduced K_s, as reported for a loamy sand podzol (Wanniarachchi et al., 2019). But because the treatment-induced differences in SOM content were expected to reflect in K_s in this soil (Oguike et al., 2023), analytical error, especially with the highly variable nature of K_s, might be implicated.

The residual effects of treatment on soil bulk density and higher microporosity as determined 7 MAT showed to be marginally significant ($P \leq 0.10$), with lower and higher values, respectively in T_{75} than the rest. These results are remarkable and suggest that heavy application of poultry-droppings manure makes for enough SOM that allows aggregation to take place alongside excessive mineralisation. With this situation and SOM's affinity for water (Obalum and Obi, 2013; Bhadha et al., 2017; Lal, Rattan, 2020), soil structure becomes improved over time which manifests as reduced compaction and enhanced water retention capacity.

3.4 Residual effects of treatments on time to attain field capacity and moisture content at field capacity

The FC_{time}, shown in Table 5, varied among treatments at the three sampling periods during 7-8 MAT in a way suggesting soil moisture (as defined by rainfall intensity) and SOM status as the controlling factors. The data suggest that poultry-droppings manure at ≥50 t/ha might cause a reduction in FC_{time}. Considering the afore-mentioned affinity of SOM for soil water not just universally (Lal, Rattan, 2020), but also for the well-drained soils of Nsukka (Onah et al., 2023), plots with high SOM content are expected to attain FC faster than those with low SOM content. The increases in FC_{time} at higher rates of the poultry-droppings manure were due to improvement in soil structure (Obalum et al., 2020a). This phenomenon could be linked to the positive relationship between SOM and precisely the soil drainability index of K_s (Oguike et al., 2023), and this lends credence to the afore-mentioned analytical error with K_s of the soil.

Table 5. Residual effects of poultry-droppings manure on time to attain field capacity (h) and soil gravimetric water content at field capacity as determined during 7-8 months after treatment

Treatment	1st Sampling		2nd Sampling		3rd Sampling		*Mean*	
	FC_{time}	FC_{water}	FC_{time}	FC_{water}	FC_{time}	FC_{water}	FC_{time}	FC_{water}
T_0 (0 t/ha)	30	0.06 ^{a}	48	0.11 ^{a}	48	0.08 ^{a}	*42*	*0.08*
T_{25} (25	30	0.10 ^{a}	48	0.12 ^{a}	48	0.11 ^{a,b}	*42*	*0.11*
T_{50} (50	24	0.09 ^{a}	24	0.16 ^{a}	30	0.17 ^{b}	*26*	*0.14*
T_{75} (75	24	0.14 ^{a}	24	0.14 ^{a}	30	0.38 ^{c}	*26*	*0.22*
Sig. Level		ns		ns		§		

T_0, T_{25}, T_{50} and T_{75} represent poultry-droppings manure at 0, 25, 50 and 75 t/ha, respectively. FC_{time} - time to attain field capacity, FC_{water} - field capacity water content; significant at $P \leq 0.10$, ns - not significant.

Residual effects of treatment on FC_{water} at the three rainfall events corresponding to the sampling periods are also shown (Table 5). The FC_{water} generally increased with manure rate; the differences were marginally significant ($P \leq 0.10$) only at the 3^{rd} sampling period. These results align with the fact that SOM accretion promotes water retention in coarse-textured soils (Sheppard et al., 2022).

4 Conclusion

This study assessed the immediate and residual effects of heavy application rates of poultry-droppings manure on soil organic matter (SOM), aggregation and P-fertility of well-drained acid Ultisols. Treatment residual effects on structure-dependent hydraulic properties of these drought-prone tropical soils, including time between soil-saturating rainfall and field capacity and water content at field capacity, was also assessed. The SOM was lower in 'control' plots compared with those amended with the manure at 50 and 75 t/ha which showed similar values. These two application rates initially enhanced the mean-weight diameter of aggregates, but this was not sustained 7 months after application when the residual effects were tested. Soil pH and available P increased with increasing manure rate at both sampling times, being higher with 50 and 75 t/ha than the control. The desired residual effects on soil bulk density and microporosity were evident only with the highest rate (75 t/ha). The time to attain field capacity was variable and generally decreased with manure rates, contrary to water content at field capacity.

For the residual effects of poultry-droppings manure on SOM to be evident in these soils, it has to be applied at a minimum heavy rate of 50 t/ha. At this and even a higher rate of 75 t/ha, its residual effects on aggregate stability of the soils would not be expected to be evident, as opposed to P-fertility and hydraulic properties of the soils. Overall, realising the residual effects of this animal manure on SOM and P-fertility would require 50 t/ha as the optimum application rate; similar effects on soil hydraulic properties leading to reductions in soil compaction and enhancements of water retention at field capacity would require above 50 t/ha and up to 75 t/ha as the minimum rate. From the variable nature of time to attain field capacity and with its decreases with increasing manure rates, it would appear to depend on both the characteristics of the associated rainfall and manure-induced SOM status, while soil content at field capacity which generally increased with manure rate could be said to depend only on SOM status of well-drained and drought-prone tropical soils.

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Conflict of Interest

The authors have not declared any conflict of interests.

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