



Aggregate Stability in Relation to Hydrolysable Organic Carbon in Humid Tropical Ultisol under Manure-Fertilizer Amendments

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Abstract: Improving soil aggregate stability (AS) and soil organic carbon (SOC) through manure and fertilizer management is a well-established agricultural practice. This study investigates the impact of poultry manure (PM) and inorganic fertilizers (IFs) applied at varying rates to hybrid maize on AS and soil organic carbon fractions (SOCFs) in Nsukka, Nigeria. Both PM and IF, whether separately or together, enhanced mean weight diameter (MWD) in 2013, notably in PM-treated plots in subsequent years, supported by positive potential structural enhancement index (PSEI). PM decreased clay dispersion index (CDI) and dispersion ratio (DR) while increasing aggregated silt plus (ASC), especially with higher PM rates. Aggregate density (AD) decreased with increasing PM rates, while non-hydrolysable soil organic carbon (NHC) and hydrolysable soil organic carbon (HOC) increased. Both NHC and HOC showed significant positive correlations with MWD and PSEI, with only HOC exhibiting a negative association with AD. The SOCFs correlated negatively with CDI and DR, and positively with ASC, except for the non-significant association of NHC with DR. Overall, the positive effects of manure-fertilizer applications on AS indices, and SOCFs, highlighted the importance of enhancing HOC and NHC through organic inputs for soil structural stability and long-term SOC and labile C stabilization.

Keywords: Aggregate stability, Non hydrolysable carbon, Hydrolysable carbon, Poultry manure inorganic fertilizer

Tropical soils, known for their high weathering and fragility, often suffer from low soil organic carbon (SOC) and poor aggregate stability due to factors such as climate change, continuous cultivation, and inadequate agronomic practices (Zhang et al., 2016, Guo et al., 2019). Soil aggregates, which are crucial for soil health, consist of macro-aggregates (>250 μm) formed from smaller micro-aggregates (<250 μm) bound together by organic materials. The stability of these aggregates impacts soil functions, including erosion resistance and compaction and high organic carbon storage (Berhe and Kleber 2014, Wang et al., 2015).

Fertilization practices, particularly the application of organic manure and inorganic fertilizers, show influence on SOC and aggregate stability. Studies indicate that organic manure can improve micro-aggregate stability and overall SOC in fragile tropical soils and demonstrated that sustainable soil management that allow restoration of SOM have the potential to reduce DR and CDI while increasing ASC and CFI (Udom and Anozie 2018). The addition of organic manure alone or combined with inorganic fertilizers has been reported to enhance macro-aggregate stability, as opposed to the application of inorganic fertilizers alone. (Sadiq et al., 2018) However, other research suggests that organic amendments may not always improve aggregate stability (Gardenas et al., 2011). The contribution of fertilization to increased SOM in bulk soil is well researched

(Xu et al., 2016), but few have evaluated the effect of fertilization on the soil organic carbon fractions (SOCFs). Chemical fractionation methods separate SOC into hydrolysable (labile) and non-hydrolysable (passive) fractions, with the latter being more resistant to decomposition and critical for long-term SOC storage (Sanni et al., 2020). Understanding how these SOC fractions affect aggregate stability can inform better soil management practices. Thus, this study aims to evaluate the effects of poultry manure and inorganic fertilizers on aggregate stability and SOC fractions in tropical Ultisols of Nigeria, addressing gaps in the current understanding of how SOC fractions influence soil aggregate stability.

MATERIAL AND METHODS

Site description: The experiment was conducted at Nsukka situated in the derived Savannah agro-ecological zone of Southeastern Nigeria. It is located on latitude 06° 51' N and longitude 07° 29' E and at an altitude of about 447 masl. It has a bimodal annual rainfall pattern with annual precipitation of about 1600 mm, mean annual temperature of 28 °C and average relative humidity is rarely below 60%. Soils in Nsukka are Ultisol, formed from Nsukka formation (Ezeaku et al., 2015) and derived from false bedded sandstone. The soil is classified as Typic Kandistults in soil Taxonomy. The experimental site is in the University of Nigeria Teaching and

Research Farm and was under cultivation for 20 years. It was under fallow for eight years prior to the commencement of the field experiment. Common crops grown were maize (*Zea mays* L), garden egg (*Solanum* spp.) and cowpea (*Vigna unguiculata*).

Experimental design and treatment layout: The study was a field experiment laid as randomized complete block design (RCBD) replicated four times with twelve fertilizer treatment combinations. The treatment combinations were derived from three rates of poultry manure (0, 5 and 10 t ha⁻¹; represented as PM₀, PM₅ and PM₁₀, respectively) combined with four rates of inorganic fertilizer (0, 50, 100 and 150%, coded IF₀, IF₅₀, IF₁₀₀ and IF₁₅₀, respectively) being the recommended dose of IF for hybrid maize (400 kg ha⁻¹ NPK 20-10-10, containing 80 kg N - 40 kg P₂O₅ - 40 kg K₂O ha⁻¹) plus 150 kg ha⁻¹ Urea, containing 69 kg N ha⁻¹). Sample of the air-dry poultry manure, sourced from deep litter poultry houses in the study location, was analyzed for their contents of N, P, K, Ca, Mg, Na and organic C.

The site was cleared and demarcated into plots. Each plot size was 1.5 m x 3.6 m. Plots and blocks were separated by 1m buffer strip amounting to total area of 30 m x 18.4 m. Stipulated PM rates were applied in 2013 and 2014 to plots one week before planting, and hybrid seeds (*Zea mays* L. var. M9211 Yellow) from Manoma Seed Company Abuja, Nigeria were sown on 2nd September, 23rd May and 3rd June in 2013, 2014 and 2015, at two seeds/hole at an inter row spacing of 60 cm, and plant- to-plant distance of 25 cm. Inorganic fertilizers were applied in three splits. The stipulated dose of 400 kg/ha NPK 20:10:10 at the rate of 0, 50, 100 and 150%, of 400 kg ha⁻¹ NPK 20-10-10 was applied at one week after planting, while 150 kg ha⁻¹ Urea, containing 69 kg N ha⁻¹ at the rate of 0, 50, 100 and 150% was applied in two equal splits, at four (4) weeks after planting and at tasseling. The quantity of fertilizer per plant (NPK and Urea) was calculated and placed 5-8 cm away from each plant, and at 2-3 cm depth below the soil surface. In 2015, the residual effects of the fertilizer treatments were evaluated, hence there was no re-application of the treatments.

Soil sampling: Prior to bed preparation for planting, soil samples were taken at random from 20 points at 0-20 cm depth and mixed homogeneously to get a composite sample. The samples were air dried and passed through a 2mm sieve for the determination of available phosphorous, exchangeable calcium (Ca²⁺), exchangeable magnesium (Mg²⁺), exchangeable sodium ((Na⁺), exchangeable potassium (K⁺), soil organic carbon (SOC), total nitrogen, pH and particle size distribution. Ten core samplers were used to take samples at random for determination of soil bulk density. At the end of maize maturity in each planting season, soil

samples were taken within the net plot of each bed at three points in a zig-zag pattern and mixed to get a composite sample. They were air dried and a part was passed through an 8 mm sieve for the evaluation of aggregate density while another part was passed through a 4.75mm sieve for determination of aggregate stability. The remaining part was passed through a 2-mm sieve for the determination of total soil organic carbon, non-hydrolysable organic carbon (NHC) and hydrolysable organic carbon (HOC).

Soil analysis: Soil particle size distribution was determined by the hydrometer method (Kalra and Maynard, 1982). The core method, by Blake and Hartge (1986) was used in the determination of bulk density. Soil pH was measured in 0.10N potassium chloride solution at ratios of 1:2.5 soil/ water suspension (McClean, 1982). The soil organic carbon was determined by the Walkley- Black wet-oxidation as modified by Nelson and Sommers (1982). Total N was determined using the micro Kjeldahl digestion-distillation method (Bremner, 1996). The available P was determined by Mehlich-3 extractant method (Mehlich, 1984). The exchangeable bases (K⁺, Ca²⁺, Mg²⁺ and Na⁺) were extracted by leaching the soil using ammonium acetate (NH₄OAc) solution after neutralizing this reagent (pH 7) to standardize the analysis. The K⁺ and Na⁺ in the extract were determined using a flame photometer while Ca²⁺ and Mg²⁺ were determined using Atomic Absorption Photo-spectrophotometer.

Determination of SOC and SOC fractions: The soil organic carbon was determined by the Walkley and Black method as modified by Nelson and Sommers (1986). The method of Silveira et al. (2008) was used to fractionate SOC into NHC and HOC. In this procedure, 2 g of soil (< 2.00 mm) was mixed with 6 M HCl and heated at 105 °C for 3 h, washed three times with distilled water and then centrifuged for 10 min. to remove the HCl. The residue was dried and analyzed for organic carbon which represents the NHC. The HOC concentration was calculated as the difference between SOC in < 2.00 mm soil and NHC concentration (Mchlauchlan et al., 2004).

Bulk density and aggregate density: The core method of Blake and Hartge (1986) was used in the determination of bulk density. Aggregate density (AD) was measured using 5-8 mm aggregates by the clod method (Grossman and Reinsch 2002). Each aggregate was weighed (Ma), coated with wax and weight taken (Ma+w). Coated aggregate was immersed in distilled water at 20 °C and weight taken Ma1. The loss (Ma - Ma1) was equal to the volume of wax coated aggregate. All weights were expressed in Mg and the density (Mgm⁻³) was computed as

$$AD = \frac{Ma}{\left(\frac{Ma}{Pw}\right) - \frac{(Ma - Ma + w)f}{Ps}} \quad (1)$$

Where, P_w is density of water at 20 °C and P_s is density of wax coating (0.93 Mg m^{-3}).

The value of f was taken as 0.3 for 5 to 8 mm aggregates (Munkholm and Kay 2002).

Assessment of macro-aggregate stability of the soil: The distribution of water stable aggregates was estimated by the wet sieving technique described in detail by Kemper and Rosenau (1986). To separate water stable aggregate, 25 g samples of the > 4.75 mm air dried aggregates were placed on top of a nest of four sieves measuring 2 mm, 1 mm, 0.25 mm and < 0.25 mm and pre-soaked for 10 minutes in water. The sieves and their content were oscillated vertically, once per second in water 20 times using an amplitude of 4cm. Care was taken to ensure that the soil particles on the topmost sieve were always below the water. The resistant aggregates on each sieve were oven dried at 105 °C for 24 h and weighed. The mass of < 0.25 mm was obtained by difference between the initial sample weight and the sum of sample weight collected on the 2.00, 1.00, 0.50 and 0.25 mm sieve nests. Coarse fraction was corrected on each size fraction by soaking in sodium hexametaphosphate and washing back through the same sieve size and the sample retained on the sieve was oven dried, weighed and recorded as the coarse fraction (Hillel 1998). The mean weight diameter (MWD), was calculated.

$$MWD = \sum_{i=1}^n W_i X_i \quad (2)$$

where W_i is weight of aggregate in the i th aggregate size range as fraction of dry weight of sample and X_i is mean diameter of any particular size range of aggregates separated by sieving.

The potential structural enhancement index (PSEI) is used to measure the effect of the treatments on aggregate stability (Mbagwu and Bazzoffi 1989), and was computed as follows:

$$PSEI = 1 - \left(\frac{MWD_c}{MWD_t} \right) \times 100 \quad (3)$$

where MWD_c is mean weight diameter for control and MWD_t is mean weight diameter of treated soil.

Assessment of particle size distribution and micro-aggregate stability of the soil: Particle size distribution of less than 2-mm fine earth was measured by the hydrometer method as (Kalra and Maynard 1991) using sodium hexametaphosphate (calgon) as the dispersing agent. To determine the micro-aggregate stability indices the same procedure was followed but water was used in place of calgon.

The micro-aggregate stability indices were computed as follows:

$$DR = \% \text{ clay} + \% \text{ silt (water)} / \% \text{ clay} + \% \text{ silt (calgon)} \times 1004$$

$$CDI = \% \text{ clay (water)} / \% \text{ clay (calgon)} \quad 5$$

$$ASC = \% \text{ clay} + \% \text{ silt (calgon)} - \% \text{ clay} + \% \text{ silt (water)} \quad 6$$

where DR is Dispersion Ratio, CDI is Clay Dispersion Index and ASC is Aggregated Silt plus Clay.

Statistical analysis: The data generated were subjected to analysis of variance using GENSTAT Release 7.2 DE statistical software. Treatment means were separated using Fisher's least significant difference at 5% probability level. Simple linear correlation analysis between soil organic carbon fractions and aggregate stability indices were carried out for each year using Spearman correlation co-efficient (Rs).

RESULTS AND DISCUSSION

Initial soil properties in experimental location and chemical properties of poultry manure: The soil was sandy clay loam and highly acidic (4.1), which may result to nutrient fixation. The bulk densities were below the critical limit for root growth based on Morris and Lowery (1988) on critical limits for different soil textures (Table 1, 2). Hence soils of the study location may support root growth and development. Soil nitrogen, soil organic carbon, exchangeable K, exchangeable sodium and magnesium were all below critical limit for maize production except available phosphorus that was above the critical limit (FMANR, 1990). The results apparently depicted the need for external sources of nutrient to support optimum maize yield and soil sustainability.

Effect of poultry manure and inorganic fertilizers on soil properties: In 2013, all amended plots showed significant increases in mean weight diameter (MWD), with the highest was with 5 t/ha of poultry manure (PM5+ IF0(2.45 mm)), compared to 1.56 mm in the control (PM0+ IF0) (Table 3). This increase may be attributed to the effects of iron and aluminum oxides and root biomass, as these oxides are known to stabilize soil in tropical and semi-tropical regions (Igwe and Obalum 2013). The addition of artificial fertilizers also enhances soil structural stability by increasing soil organic carbon (SOC) (Sainju et al., 2003, Álvaro-Fuentes et al., 2012, Plaza-Bonilla et al., 2013). In 2014, MWD declined in plots with only inorganic fertilizers (IF) due to increased cultivation but remained stable with PM. The highest MWD was in PM10+ IF100 (1.42 mm), similar to other PM treatments. This suggests that higher manure inputs improve aggregate stability. Residual MWD was highest in PM10+ IF50, reflecting the role of microbial decomposition of organic material in macro aggregation (Mikha et al., 2010, Rasoulzadeh and Yaghoubi 2010, Mandal et al., 2013, Sadiq 2018). The potential structural enhancement index (PSEI) was positive in most treatments, indicating improved macro

Table 1. Initial soil properties at the experimental station

Parameter	Unit	Nsukka
Soil organic C	g/kg	9.13
Total N	%	0.09
Mehlich available P	mg/kg	18.43
Exchangeable K	cmol/kg	0.12
Exchangeable Ca	cmol/kg	0.38
Exchangeable Mg	cmol/kg	0.13
Exchangeable Na	cmol/kg	0.14
pH	,	4.1
Bulk density	Mg/cm ³	1.53
Sand	g/kg	630
Silt	g/kg	101.
Clay	g/kg	269.
Texture		Sandy clay loam

Table 2. Chemical properties of poultry manure at Nsukka

Parameter (%)	2013	2014
Organic carbon	32.42	30.80
Nitrogen, N	2.01	1.99
Phosphorus, P	0.81	0.77
Potassium, K	1.44	1.56
Calcium, Ca	1.56	1.49
Magnesium, Mg	0.48	0.55
Sodium, Na	0.16	0.16
pH	7.70	7.50

Table 3. Effect of poultry manure and inorganic fertilizers on aggregate properties at Nsukka

Year	2013			2014			2015		
	MWD	PSEI	AD	MWD	PSEI	AD	MWD	PSEI	AD
Parameter									
Fertilizer Treatment	Mm		Mgm ⁻³	Mm		Mgm ⁻³	mm		Mgm ⁻³
PM ₀ + IF ₀	1.56	0.00	1.63	0.82	0.00	1.64	0.57	0.00	1.67
PM ₅ + IF ₀	2.45	0.36	1.43	0.94	0.13	1.57	0.73	0.19	1.66
PM ₁₀ + IF ₀	2.20	0.25	1.47	1.24	0.31	1.58	0.79	0.24	1.58
PM ₀ + IF ₅₀	2.10	0.21	1.61	1.03	0.09	1.70	0.82	0.11	1.68
PM ₅ + IF ₅₀	2.27	0.31	1.50	1.12	0.23	1.57	0.67	0.28	1.64
PM ₁₀ + IF ₁₀	2.12	0.26	1.47	1.28	0.29	1.51	0.75	0.19	1.59
PM ₀ + IF ₁₀₀	1.95	0.21	1.64	1.01	0.11	1.59	0.72	0.2	1.64
PM ₅ + IF ₁₀₀	2.37	0.34	1.52	0.99	0.16	1.58	0.84	0.29	1.61
PM ₁₀ + IF ₁₀₀	2.22	0.29	1.48	1.42	0.35	1.57	0.68	0.16	1.57
PM ₀ + IF ₁₅₀	1.99	0.22	1.64	0.81	0.08	1.71	0.71	0.20	1.68
PM ₅ + IF ₁₅₀	2.14	0.26	1.52	0.98	0.13	1.59	0.61	0.06	1.65
PM ₁₀ + IF ₁₅₀	2.27	0.31	1.52	1.23	0.27	1.58	0.84	0.32	1.57
LSD (0.05)	0.34		0.13	0.24		0.09	0.13	0.13	NS

MWD, Mean weight diameter, PSEI, potential structural enhancement index, AD, Aggregate density

PM₀, PM₅, PM₁₀ is poultry manure at 0, 5, 10 t ha⁻¹, respectively; IF₀, IF₅₀, IF₁₀₀, IF₁₅₀ is inorganic fertilizer at 0%, 50% 100% and 150% recommended fertilizer dose, respectively, being 400 kg ha⁻¹ NPK-20:10:10 plus 150 kg ha⁻¹ urea

aggregation, except in PM₀+ IF₁₅₀ in 2014, where excessive IF application led to dispersion due to increased soil acidity (Mikha et al., 2010, Guo et al., 2019). Even after amendment withdrawal in 2015, structural stability was maintained, highlighting that it is not solely dependent on organic matter. For both years, PM reduced aggregate density (AD), with the best reductions observed in PM₅+ IF₀ (1.43 Mg/m³) in 2013 and PM₁₀+ IF₅₀ (1.51 Mg/m³) in 2014. The lack of residual effect from fertilizers on AD suggests it relies on SOC input (Munkholm and Kay 2002, Selvi et al., 2005, Karami et al., 2012). Enhanced aggregate properties improve soil aeration, hydraulic properties, and nutrient retention (Udom et al., 2018).

PM₀, PM₅, PM₁₀ is poultry manure at 0, 5, 10 t ha⁻¹, respectively; IF₀, IF₅₀, IF₁₀₀, IF₁₅₀ is inorganic fertilizer at 0%, 50% 100% and 150% recommended fertilizer dose, respectively, being 400 kg ha⁻¹ NPK-20:10:10 plus 150 kg ha⁻¹ urea

Effect of poultry manure and inorganic fertilizers on soil microaggregates stability indice: In 2013, fertilizer treatments did not significantly affect CDI, DR, or ASC compared to the control, likely due to the experiment's short duration of one year (Table 4). Nweke et al. (2013) also found no significant impact of manure and inorganic fertilizers (IF) on CDI, while Ogunwole et al. (2010) suggested that other stabilizing substances might influence aggregate stability differently. In 2014 and 2015, poultry manure (PM) generally exhibited lower CDI values (37.2% and 37.8%, respectively)

compared to the control, except for T11 in 2015. The highest CDI reduction in 2014 was with PM10+ IF100 (25.46%), and the best residual CDI in 2015 was in PM10+ IF50 (25.59%). These results indicate that soil organic matter (SOM), either alone or with IFs, can effectively reduce clay dispersion. Furthermore, PM, whether alone or combined with IFs, reduced DR and increased ASC in 2014 and 2015. This supports findings by Mba et al. (2010) and Ogunwole et al. (2010) of improved DR and ASC, respectively. Nweke et al. (2013) observed similar benefits with PM and NPK 20:10:10.

IFs, however, showed minimal impact on stability and might exacerbate soil acidity, increasing dispersion. Enhanced micro-aggregate stability, linked to organo-mineral interactions, reduces water erosion vulnerability (Udom and Anozie 2018, Osakwe et al., 2021).

Soil organic carbon, non-hydrolysable and hydrolysable soil organic carbon: In 2013, SOCb values ranged from 8.97 g/kg (PM0+ IF0) to 15.25 g/kg (PM10+ IF50), and in 2014, from 8.95 g/kg (PM0+ IF0) to 13.9 g/kg (T12: PM10+ IF150) (Table 5). Residual SOCb varied between 6.3 g/kg

Table 4. Effect of poultry manure and inorganic fertilizers on micro-aggregate stability indices at Nsukka

Year	2013			2014			2015		
	CDI (%)	DR (%)	ASC (g/kg)	CDI (%)	DR (%)	ASC (g/kg)	CDI (%)	DR (%)	ASC (g/kg)
PM ₀ + IF ₀	23.5	33.1	249.2	37.2	43.2	206.8	37.8	44.5	190.5
PM ₅ + IF ₀	22.9	35.6	241.0	26.7	40.4	217.2	26.7	40.0	213.6
PM ₁₀ + IF ₀	22.2	35.1	246.4	28.1	37.6	236.4	26.9	39.1	227.4
PM ₀ + IF ₅₀	26.4	35.2	244.6	35.9	41.7	209.3	37.8	44.6	189.6
PM ₅ + IF ₅₀	23.8	34.8	249.6	27.8	36.6	225.6	27.9	39.8	215.4
PM ₁₀ + IF ₁₀	22.0	34.7	251.0	26.1	36.7	233.0	25.6	39.6	217.2
PM ₀ + IF ₁₀₀	23.8	36.5	233.4	30.5	39.2	217.4	36.1	41.5	204.8
PM ₅ + IF ₁₀₀	22.5	35.3	245.0	29.9	38.9	231.4	30.7	39.6	210.0
PM ₁₀ + IF ₁₀₀	22.5	34.6	251.4	25.5	36.2	241.9	26.2	38.5	233.6
PM ₀ + IF ₁₅₀	24.1	36.3	234.0	38.8	42.5	206.4	42.8	43.3	204.0
PM ₅ + IF ₁₅₀	23.5	36.0	236.4	29.1	40.2	226.4	33.7	41.2	213.6
PM ₁₀ + IF ₁₅₀	23.5	35.9	236.4	29.1	40.2	226.4	29.6	39.6	217.2
LSD (0.05)	1.70	NS	NS	3.01	2.39	10.6	4.50	2.40	9.80

See Table 3 for treatment details

Table 5. Effect of poultry manure and inorganic fertilizers on soil organic carbon in bulk soil and soil organic carbon fractions (g/kg)

Year	2013			2014			2015		
	SOCb	NHC	HOC	SOCb	NHC	HOC	SOCb	NHC	HOC
PM ₀ + IF ₀	8.97	1.53	7.45	10.1	2.03	8.08	6.49	0.75	5.65
PM ₅ + IF ₀	12.52	3.33	9.2	10.42	2.49	7.93	8	1.65	6.35
PM ₁₀ + IF ₀	13.85	4.25	9.6	12.38	3.4	8.98	9.2	2.18	7.02
PM ₀ + IF ₅₀	9.53	1.78	7.75	8.95	0.91	8.04	6.13	0.65	5.48
PM ₅ + IF ₅₀	14.3	4.4	9.9	12.75	3.15	8.6	8.2	1.68	6.52
PM ₁₀ + IF ₁₀	15.25	5.2	10.1	13.3	4.63	8.67	10.23	2.38	7.85
PM ₀ + IF ₁₀₀	9.45	0.93	8.52	9.13	0.6	8.53	6.4	0.66	5.74
PM ₅ + IF ₁₀₀	12.2	3.53	8.68	11.75	3.37	8.38	7.68	1.58	6.1
PM ₁₀ + IF ₁₀₀	15.2	5.95	9.25	13.75	4.81	8.94	10.28	2.55	7.74
PM ₀ + IF ₁₅₀	9.4	0.9	8.5	9.15	0.55	8.6	6.3	0.88	5.42
PM ₅ + IF ₁₅₀	13.95	3.95	10	12.8	4.08	8.73	7.88	1.75	6.13
PM ₁₀ + IF ₁₅₀	15.1	5.75	9.35	13.9	4.88	9.02	8.33	2.23	6.1
LSD (0.05)	1	0.85	1.12	0.7	0.53	0.83	0.78	0.46	0.42

See Table 3 for treatment details

Table 6. Correlation of soil organic fractions with aggregate stability indices

Year	2013		2014		2015	
	NHC	HOC	NHC	HOC	NHC	HOC
MWD	0.64*	0.56*	0.59*	0.75**	0.13ns	0.13ns
PSEI	0.75**	0.64*	0.55ns	0.80***	0.17ns	0.25ns
AD	-0.47ns	-0.60*	-0.37ns	-0.74**	0.76**	-0.85***
CDI	-0.63*	-0.56ns	-0.36ns	-0.75**	-0.76**	-0.86***
DR	0.21ns	-0.16ns	-0.47ns	-0.61*	-0.71**	-0.87***
ASC	0.15ns	0.43	0.62*	0.82***	0.73**	0.90***

NHC, non-hydrolysable carbon, HOC, hydrolysable organic carbon, * Significant at $p=0.05$, **Significant at $p=0.01$

(PM0+ IF0) and 10.28 g/kg (PM10+ IF100). SOC generally increased with higher poultry manure (PM) rates, but inorganic fertilizers (IF) alone (PM0+ IF50, PM0+ IF100, PM0+ IF150) did not improve SOC compared to the control. The highest SOC_b was consistently observed with 10 t/ha PM combined with 50% IF, showing no additional benefit from higher IF levels. SOC decreased with subsequent cultivation. Previous studies also report enhanced SOC with manure and crop residues combined with inorganic fertilizers (Mbah et al., 2017, Alishar Sharma et al., 2023, Mbah et al., 2023). Continuous PM application is crucial for maintaining soil quality, as loss of SOC can reduce soil structure, microbial activity, and nutrient availability.

In 2013, NHC increased in all poultry manure (PM) treated plots, with PM10 + IF50 showing the highest contribution at 10.1 g/kg, similar to other PM treatments (except PM5 + IF100). This increase is likely due to the recalcitrant nature of PM and root biomass, as NHC is influenced by the organic material's inherent properties and the decomposition process (Six et al., 2002, Rovira and Vallejo 2002). In 2014, NHC rose with 10 t/ha PM, while other treatments were comparable to the control. Ding et al. (2012) also found lower NHC in control and NPK plots compared to those with NPK + manure. Residual NHC was highest in PM10 + IF50 (7.83 g/kg), indicating a synergy between PM and IF, though IF alone did not improve NHC across the three years, suggesting it does not contribute to stabilized SOC sequestration (Six et al., 2002, Wiesenberget al., 2010).

PM consistently improved hydrolysable organic carbon (HOC) in 2013, 2014, and 2015, with greater increases observed with higher manure rates (Table 5). Combinations of PM and IF were more effective than sole applications, supporting findings by Adeniyani et al. (2005), Ojo et al. (2015), and Soremi et al. (2017). IF alone did not significantly affect HOC compared to the control and may deplete labile organic carbon. HOC supports microbial activity and nutrient availability.

Correlation of soil organic fractions with aggregate stability indices: The correlation between soil organic

fractions and aggregate stability indices. In 2013 and 2014, non-hydrolysable carbon (NHC) and hydrolysable organic carbon (HOC) was positively correlated with mean weight diameter (MWD) and percentage stable aggregates (PSEI) ($r = 0.56-0.80$), though NHC had a non-significant relationship with PSEI in 2014 (Table 6). Fertilization significantly influenced both carbon fractions and aggregate stability, but correlations were non-significant when amendments were removed in 2015. HOC showed a negative correlation with aggregate density (AD) in 2013, 2014, and 2015 ($r = -0.60$ to -0.85), with the relationship strengthening over time, indicating changes in soil organic carbon (SOC) quality. Conversely, NHC had a positive relation with AD in 2013 and 2014, suggesting that increased NHC might reduce aggregate porosity and affect soil aeration and hydraulic properties. In 2013, micro-aggregate stability indices showed no significant correlations with either carbon fraction, except a negative correlation of NHC with clay dispersion index (CDI) ($r = -0.68$). In 2014, NHC positively related to aggregated silt plus clay (ASC), while HOC negatively related to CDI and dispersion ratio (DR), but positively related to ASC. In 2015, both fractions negatively correlated with CDI and DR ($r = -0.71$ to -0.87) and positively with ASC ($r = 0.73$ to 0.90). HOC exhibited a stronger relationship with aggregate stability indices compared to NHC.

CONCLUSION

Manure-fertilizer applications affected aggregate stability and soil organic carbon fractions at Nsukka. Both IF and PM applied alone or combined, improved the MWD and PSEI. The increase by only IF application may suggest other background agents of stabilization other than SOC from PM. Furthermore, the micro aggregate stability indices, hydrolysable carbon and non-hydrolysable carbon significantly improved at the application of poultry manure and with added benefit when in combination with IFs. But with regards to treatment combinations and the control, PM alone at 10 t/ha (PM₁₀+IF₀) or in combination with IF especially at reduce IF rate (PM₁₀+IF₅₀) indicated best

positive contribution, contrary to sole application of IF. Furthermore, NHC and HOC significantly correlated with aggregate stability indices, hence continuous application of PM in combination with 50 % IF will ensure both long term C storage and labile C in the tropical ultisol at Nsukka.

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