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RESEARCH ARTICLE

SHORT-TERM COMPARATIVE EFFECTS OF DIFFERENT SOURCES OF ORGANIC RESIDUE ON SOIL ORGANIC CARBON AND AGGREGATE STABILITY

***,[1]Ezema, R. A., [2]Onunwa, A. O. and [1]Igbonekwu, J. E.**

[1]Department of Agricultural Technology, Enugu State Polytechnic, Iwollo, Nigeria
[2]Department of Soil Science and Land Resources Management, Nnamdi Azikiwe University, Awka, Nigeria

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ABSTRACT

Identifying specific organic amendments that can maximize stable aggregates and increase soil organic carbon (C) recovery is a critical component of soil management. In this study, we investigated comparatively, the short- term effects of poultry droppings (PM), cow dung (CD),swine slurry (SS), rice chaff (RF), boiler ash (BA) and control (no amendment) on significant soil properties such as aggregate stability, organic carbon fractions, pH and soil temperature. The research, which involved incubation of a mixture of each organic residue with soil in the laboratory for 90 days, adopted a completely randomized design (CRD). Results indicated that mean weight diameter – an index of aggregate stability and strength was highest (1.26 mm) in RF treated soil followed by BA, which did not differ significantly from SS. Aggregate stability in CD treated soils did not differ significantly from that of PM. The soil organic carbon was higher in all amended soils and ranked in the order of RF > CD >SS >PM > BA > Control and highest at 30 days sampling. Soil pH was highest (pH 7.0) in CD and PM treated soils and least (5.7) in SS treated soil and generally at 90 days sampling. There were significant (p=0.05) interactions between applied organic waste and incubation time on soil pH and organic carbon content. The organic residues differed in their effect on soil temperature at different sampling dates with PM treated having the highest.

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INTRODUCTION

Stability of soil aggregates when in contact with water and quantity of organic carbon have been ranked among the critical indicators of soil vulnerability (Supriyadi *et al*., 2014). Reduced ability of soil aggregates to resist destruction mechanisms decrease soil fertility and increase the risk of soil erosion (Barthes and Roose, 2002). Soil aggregate stability exerts significant influence on soilinfiltration capacity, hydraulic conductivity, solute transport, carbon cycling and sequestration, erodibility and degradation, root distribution and uptake of water and nutrients by plants (Tisdale and Oades, 1982; Haynes and Swift, 1990, Bronick and Lal, 2005, Plaza-Bonilla, 2013). Research has also shown that soil organic carbon (SOC) plays significant role in soil pH buffering, stabilization of soil aggregates (Chenu, 2000), and as well provides substrate and nutrients for microbes.Organic wastes of various origins have been used to increase or regulate organic carbon content of soil (Bahtiyar, 1999; Wapa *et al.* 2013). Their qualities have also been noted to influence aggregate stabilization, accumulation and dynamics of organic carbon in the soil and a means by which carbon is protected against microbial degradation (Andreux, 1996; Piccolo *et al.*, 2004; Yamashita *et al.,* 2006).Organic amendments with low lignin content and C: N ratio coupled with abundant labile C fraction rapidly degrades and almost disappears often within few months when incorporated into to the soil (Benbouali*et al.,* 2013). In addition, they stimulate microbial mineralization of more stable recalcitrant soil organic C fractions through priming effect (Fontaine *et al*., 2007). This organic input provides only a rather marginal contribution for the maintenance of soil organic carbon stock, Similarly, Lucas *et al*. (2014) observed that organic amendment containing high amount of bioavailable C derived from cellulose could promote fungal proliferation and improve stabilization of soil aggregates. Milad *et al*. (2015) reported differences in mean weight diameter (MWD) an index of aggregate stability and strength in soil amended with alfalfa and wheat straw. Alfalfa straw efficiently produced more OC than wheat straw. Understanding how organic amendments affect aggregate stability and organic carbon stock with time is crucial for planning farming system focused on maintaining soil quality. Adequate comparative information for predicting change in soil aggregate stability and organic carbon stock with time due to different organic residue management options is

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****Corresponding author:*** **Ezema, R. A.**
Department of Agricultural Technology, Enugu State Polytechnic, Iwollo, Nigeria.

insufficient.Hence, this comparative approach aims to establish differences and similarities among boiler ash, rice chaff, poultry droppings, cow dung and control (no amendment) in maximizing soil organic carbon quantity and soil aggregate stability of an Ultisol over- time.

Specifically, the study intend:

i. To determine and compare effectiveness of poultry droppings, cow dung, rice chaff, swine slurry and boiler ash on macro aggregate stability, total soil organic carbon, pH and temperature,
ii. To gain more insights on short–term changes in total soil organic carbon, pH, temperature and aggregate stability in soil amended with poultry droppings, cow dung, rice chaff, swine slurry and boiler ash.

MATERIALS AND METHODS

Site description

The study was conducted at the Plant and Screen House of Department of Agricultural Technology, Enugu State Polytechnic Iwollo, Nigeria. It is located by Longitude 06^o 26.35' 'N and Latitude 07^o 16.83'E. The area has an annual rainfall of 1700mm-1800mm and a mean annual maximum (day) and minimum (night) temperatures of 31^{0}C and 21^{0}C respectively, while the average relative humidity is rarely below 60 %.

Screen House Study

The experiment was laid out using Completely Randomized Design (CRD). Soil samples were collected at 0-20 cm of an agricultural land, dried, sieved with a 2.0 mm mesh sieve and bulked. Eighteen (18) perforated poly bags were each filled with 20 kg of the soil. There were six treatments namely boiler ash, cow dung, poultry droppings, rice chaff, swine slurry and a control (untreated soil). These treatments were replicated three times to give eighteen experimental units. Subsequently, each poly bag containing 20 kg soil was mixed with 10 kg of each organic residue accordingly They were arranged at 0.5 m space between poly bags and 1 m between replications. The treated and untreated soils were incubated under constant soil moisture (60 % water holding capacity) for 90 days. Soil thermometer was inserted at a depth of 10 cm and the temperature read daily for the 90 days duration of the study. Soil samples from each poly bag were assayed for pH, total organic carbon and water stability of aggregates (mean weight diameter) at 30, 60 and 90 days of incubation.

Laboratory study

Aggregate fractionation

The procedure described by Kemper and Rosenau (1986) was used to separate water stable aggregates (WSA). In this method, 20g of the < 4.75mm air-dried aggregates were placed on top of a net of four sieves of 2, 1, 0.5, and 0.25mm mesh size and soaked in distilled water for 10 minutes. The sieves and their contents were then oscillated vertically for 20 times along a 4cm stroke at the rate of one oscillation per second. After wet sieving, the aggregates retained on the sieves were oven-dried at 105^{0}c. The mass of the < 0.25mm fraction was obtained by difference. Later, they were mixed together, placed in a (0.25mm) sieve, and washed with water to obtain the weight of sand fraction.

The respective dry masses were used to compute mean weight diameter (MWD)

$$MWD = \sum WiXi$$

Where xi = arithmetic mean diameter of the i-1
I= sieve openings (mm)
W (i) = proportion of the total sample weight (Uncorrected for sand and gravel, occurring in the fraction) (dimensionless).
n= total number of sieve fractions (in this case 5).
Larger MWD value indicates higher proportion of macro-aggregates and therefore, higher stability to water erosion.

The pH was measured in a 1:2.5 soil to water solution by using electrometric method. Particle size distribution was measured by the hydrometer method as described by Gee and Bauder (1986), soil organic carbon (OC) was determined by the Walkley and Black method described by Nelson and Sommers (1982). Total nitrogen was determined by semi-micro kjeldahl digestion method using sulphuric acid and CuSO4 and Na2SO4 catalyst mixture (Bremner, 1996).

Statistical analysis

The data were subjected to two-way analysis of variance (ANOVA). Using GENSAT Statistical package.

RESULTS AND DISCUSSION

The soil used for the experiment was loamy sand in texture, strongly acidic and low in carbonand nitrogen content (Table I). The soil is apt for the study since when organic C enters the soil, the amount retained depends not only on its biochemical quality but also on its interactions with soil mineral components i.e. sand, silt, and clay fractions as well as carbonate and organic C content (Piccolo, 1996; Clough and Skjemstad, 2000). In soils low in organic C content, exogenous organic matter is more easily absorbed and less exposed to microbial attack (Bonanomi *et al.,*2014). Analysis of the organic wastes indicate that CD, BA and SS were alkaline in nature while PM and RF were slightly acidic (Table 1). On the hand, CD, BA and RF had high C: N ratios indicating higher carbon content and lower mineralization potential.

Table 1. Some properties of the soil and organic residues used for the study

Properties	Soil	Cow dung	Boiler ash	Poultry droppings	Rice chaff	Swine slurry
pH (H_2O)	5.6	7.7	8.9	6.7	6.8	7.2
Organic carbon (%)	2.3	14.3	12.9	10.8	29.0	19.0
N (%)	0.28	0.36	0.24	1.38	0.81	1.32
C :N	8.2	39.7	53.7	7.8	35.8	14.4
Sand (g Kg^{-1})	800	-	-	-	-	-
Silt (g Kg^{-1})	90	-	-	-	-	-
Clay (g Kg^{-1})	110					
Textural class	Loamy sand					

Effects of different organic residues on pH, organic carbon and mean weight diameter

A significant positive influence of the organic residues was observed in the pH, content of organic carbon and mean weight diameter of the treated soil (Table 2). Adding organic residues decreased soil acidity in all the treated soils, but the decrease was greatest (7.0) with use of cow dung and least (5.7) with swine slurry. The pH of soil treated with poultry droppings did not differ significantly from that of cow dung. These changes may be attributed to the neutralizing effect of calcium carbonate contained in the organic waste (Mullins, 2002). Similarly, type of organic amendment significantly affected the carbon status of the soil. This observation corroborates that of Obi and Ebo (1995) who reported a significant increase in organic matter (p=0.05) with application of poultry droppings Soil organic carbon ranged from 1.72% in control to 4.36 % in rice chaff and came in the order of RF > CD >SS >PM > BA > Control. The RF treated soil however did not differ significantly from that of CD. The organic carbon concentration of soils treated with SS, PM and BA did not differ significantly from each other. The high carbonaceous nature of the RF and CD; and their likely resistance to decomposition and subsequent mineralization compared to the other amendments may have explained the observed high organic carbon content of the soil (Rajcan and Tollen, 1999).The results also demonstrated a significant effect of organic residues in improving aggregate stability; the effectiveness was however, related to the type of organic residue applied.

Aggregate stability as measured using mean weight diameter index show that incorporation of BA, CD, PM, and RF into the soil increased aggregate stability significantly (p=0.05) by 83, 55, 76 and 110 % respectively, relative to the control. The rice chaff proved to be more efficient in soil aggregate stabilization followed by BA, which did not differ significantly from SS. Aggregate stability in CD treated soils did not differ significantly from that of PM. The result is in agreement with the findings of Aziz and Karim (2016) who observed highly significant (P < 0.0l) correlation coefficient for the relationship between aggregate stability and organic matter. The higher aggregate stability in the RF may be due to its recalcitrant nature and slow decomposition, which allowed significant quantity of residues on the soil surface. This agrees with the findings of Tisdall and Oades (1982) that SOC is closely related to the formation and stability of soil aggregates which are higher in soil management system that leave more plant residues on the soil surface.. Similarly, Benbouali *et al*. (2013) observed thatwheat straw proved to be more efficient in soil aggregation than cattle manure. The increased aggregate stability in the BA amended soil may be ascribed to its high polyvalent cations such as Ca^{2+} which protects total organic carbon as well as serve as binding agent by forming cationic bridges between organic matter and clays (Six *et al*. 2004). In addition, high salinity and toxic heavy metal often present in BA may reduce the efficacy of microbial and enzymatic attack on flocculated and condensed organic mineral complexes. The observation is contrary to that of Faleiros *et al.* (2014) that application of bagasse ash to soil at the rates of 5, 10, 20 and 40 $Mgha^{-1}$ (dry basis) caused no significant difference on soil aggregate stability index values.

Table 2. Comparison of pH, organic carbon and mean weight diameter in soil amended withdifferent organic residues

Organic waste	pH	% organic carbon	Mean weight diameter (mm)
Boiler ash	6.4	2.24	1.10
Cow dung	7.0	4.22	0.93
Poultry droppings	6.9	2.86	1.05
Rice chaff	6.7	4.36	1.26
Swine slurry	5.7	3.03	1.08
Control	5.1	1.72	0.60
F –LSD	0.298	1.218	0.1318

F-LSD =Fisher's least significant difference

Effect of duration of incubation on organic carbon concentration, pH and mean weight diameter of organic waste amended soil

Table 3 shows the pH, organic carbon concentration and mean weight diameter of soil amended with organic residues as affected by duration of incubation. Result of pH determination showed that pH increased with time. The highest pH value of 6.4 was observed from 90 days sampling but it did not differ significantly from that of 60 days. The increase in pH with time may be attributed to the release of basic cations contained in the residues. The decrease in pH observed after 60 days of incubation agree with the findings of Eneje and Uzoukwu (2012) who observed that application of organic amendments increased soil pH level as sampling duration increased with the highest value obtained at two months sampling.Soil organic carbon was highest at the 30 days sampling, but reduced significantly (P= 0.05) at 60 and 90 days samplings. The findings agrees with that of Tisdall and Oades (1982) that polysaccharides act as transient binding agents which are rapidly decomposed by microorganisms The fluctuation in organic carbon concentration of the soil may be attributed to microbial activities during decomposition. The MWD of the soil did not differ significantly with time within the 90 days of incubation. This may be attributed to the short period of the experiment, which may have not allowed sufficient time for stabilizing and destabilizing agents to exert significant influence.

Table 3. Mean comparison of pH and % organic carbon at different intervals in soil amended with organic wastes

Period of incubation (days)	pH	% organic Carbon	Mean weight diameter (mm)
30	6.1	5.22	1.03
60	6.4	1.92	1.01
90	6.4	2.07	0.97
F- LSD	0.21	0.86	n.s

F-LSD =Fisher's least significant difference, n.s = non-significant at 5% level of probability

Interactive effect of organic residues and time on soil pH, percentage organic carbon and mean weight diameter

Organic residues significantly (p=0.05) interacted with duration of incubation on soil pH and organic carbon content but not on soil aggregate stability measured as mean weight diameter (Table 4). Soil pH in soils amended with BA, SS and control did not differ with increase in incubation time. On the contrary, pH increased from 30 to 60 days of incubation in PM and CD amended soils but statistically remained the same up until 90 days of incubation. The highest % OC (8.41%) recorded in CD treated soil after 30 days of incubation declined to 2.11 % after 60 days but did not differ significantly at 90 days of incubation. It is worthy to note that the percentage OCcontent in BA and control did not significantly change with time. Similar observations were made in PM, RF, and SS treated soils. This observation agrees with that of Angers and Giroux (1996) that slake-resistant macro aggregates are stabilized by recently deposited residue.

Table 4. Interactive effect of organic waste and time on soil pH, percentage organic carbon and mean weight diameter

Organic wastes	Time (days)	pH	% carbon	Mean weight diameter
Boiler ash	30	6.1	2.72	1.16
	60	6.5	2.01	1.02
	90	6.6	1.98	1.11
Cow dung	30	6.2	8.41	0.89
	60	7.4	2.11	0.97
	90	7.3	2.15	0.93
Poultry droppings	30	6.4	4.40	1.06
	60	7.1	2.06	1.13
	90	7.2	2.12	0.97
Rice chaff	30	6.8	7.89	1.38
	60	6.7	2.24	1.13
	90	6.7	2.95	1.26
Swine slurry	30	5.7	4.91	1.07
	60	5.7	2.09	1.83
	90	5.7	2.09	1.00
Control	30	5.1	3.01	0.61
	60	5.0	0.99	0.62
	90	5.0	1.15	0.58
F –LSD (p=0.05)		0.515	2.110	n.s

F-LSD =Fisher's least significant difference, n.s = non-significant at 5% level of probability

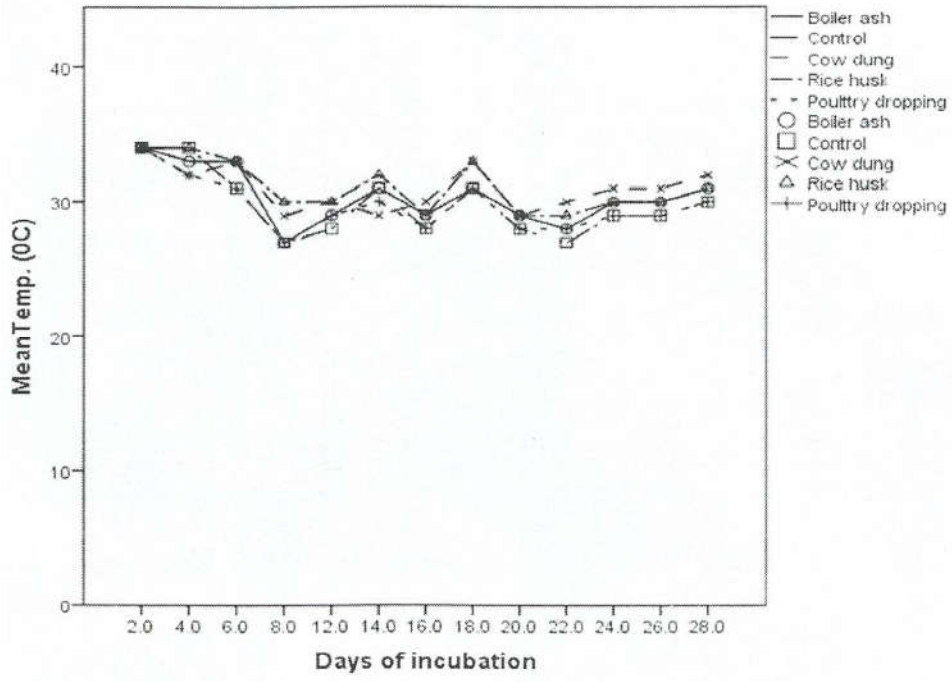

Fig.1. Mean temperature of soil-waste mixture during 0-30 days of incubation

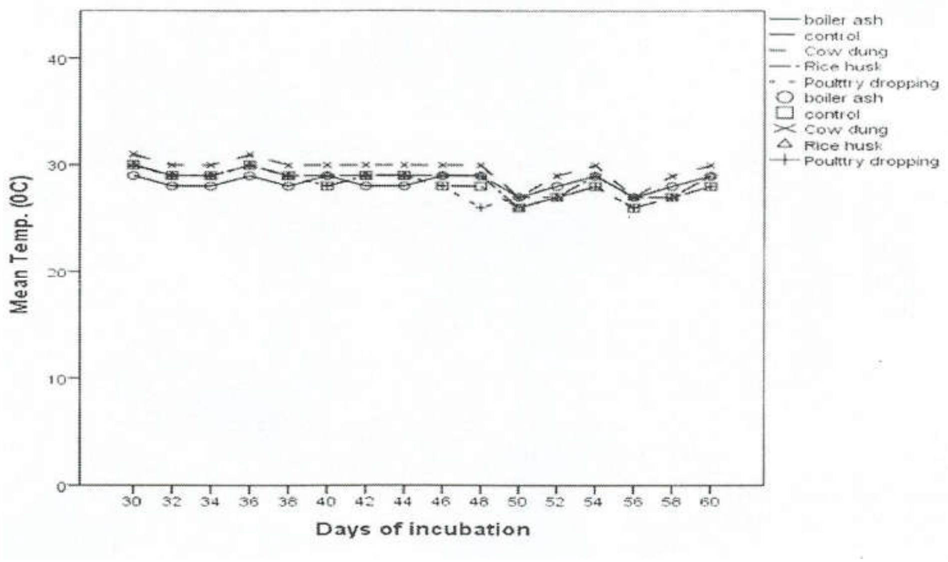

Fig. 2. Mean temperature of soil-wate mixture during 30-60 days of days of incubation

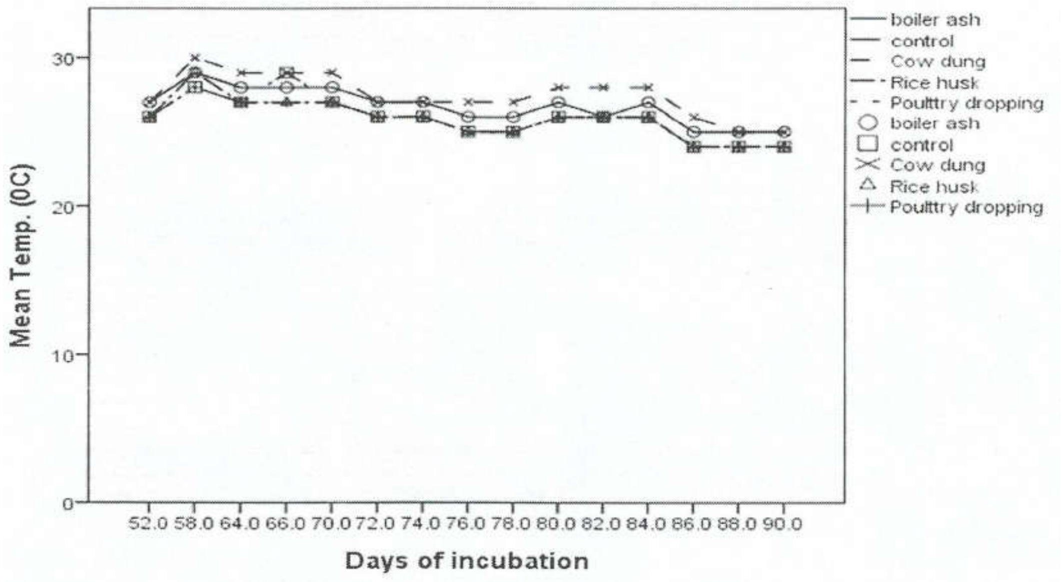

Fig.3. Mean temperature of soil-waste mixture during 60-90 days of incubation

Soil temperature variations as influenced by the organic residues overtime

The dynamics of soil temperature regimes as influenced by incorporation of the organic residues are shown in Figs 1, 2 and 3. There were differences in soil temperature among treatments and at different sampling dates. At the beginning of the experiment the temperature were almost equal in all treatments at about 34^{o}C. The elevated temperatures lasted approximately 6 days and descended with sharp fluctuations to lower values (< 26 ºC) in the subsequent weeks, showing a typical biodegradation curve. The temperature stabilized between 30-48 days of incubation (Fig.2) and coincides with the period of lower organic carbon level (Table 2). After 60 days of incubation, soil temperature declined gradually and stabilized in all treatments with minor fluctuations.Generally, temperature was higher under soil treated with PM and CD, and that may have accelerated mineralization of their organic carbon. Least soil temperature was observed in SS, followed by BA and RF. The low temperature of the soil treated with RF may have contributed to its high OC content. This agrees with the sfindings of Yong *et al.* (2016) which noted that increase in temperature has a negative impact on soil OC content, soil aggregation and stability since humic acid and humin molecules become less aliphatic and more decomposed with the increase in temperature.

Conclusion

Results of these investigations revealed significant positive differential effects of organic residues on soil pH, organic carbon and stability of aggregates. Reduction in soil acidity was highest in soil treated with CD but similar to that of PM. Soil organic carbon significantly (p=0.05) increased with application of the organic residues. The results showed that RF was more effective in increasing the soil organic carbon contents. The amount of OC increased with the increasing time of incubation in all the amended soils. Mean weight diameter differed significantly and came in the order of RF > CD >SS >PM > BA > Control The soil temperature stabilized between 30-48 days of incubation and coincided with the period of lower organic carbon level. These findings indicate that these organic residues can used to manipulate soil organic carbon and to promote soil aggregate stability.

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