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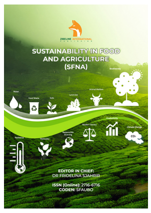

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RESEARCH ARTICLE

SHORT-TERM INFLUENCE OF PLANT AND ANIMAL BASED BIOCHAR ON THE MICRO-AGGREGATION OF TWO TEXTURALLY DIFFERENTIATED SOILS

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ABSTRACT

Towards a climate smart approach of ensuring soil aggregate stability and sustainability, an experiment was carried out at the Department of Crop, Soil and Pest Management Laboratory in the Federal University of Technology, Akure, to determine the influence of three rates of biochar (0g, 50g, and 100g) per kilogram of soil on structural properties of the soil. Biochar rates of two sources (Animal and Plant) were added to two textural soil classes (Clay and Sandy Clay) and replicated three times in a completely randomized design. 100ml of water was added to the soil at five days intervals for a period of twelve weeks in other to stimulate aggregation. Data were collected at 4 weeks after application (WAA), 8 WAA and 12 WAA on Organic carbon content, Soil pH, Dispersion Ratio, Clay Flocculation Index, Aggregated Silt+ Clay and Clay Dispersion Index. It was concluded that 100g of plant-based biochar per kilogram of soil was most suitable for the clay and sandy clay.

KEYWORDS

Tropical soils, soil aggregation, plant-based biochar, animal-based biochar, dispersion.

1. INTRODUCTION

Climate change is a trending threat faced by the whole world (Jonas et al., 2019; Schiermeier, 2019). This has quickened researchers to focus on methods that would mitigate climate change while solving other problems such as soil degradation. Soil degradation is the decline in soil quality caused by several factors which includes but not limited to mismanagement of arable lands. As stated by several researchers, tropical soils have a common problem, degradation, which is evident by poor soil productivity as a result of low pH, low cation exchange capacity (CEC), low inherent fertility, nutrient imbalance, high susceptibility to erosion, low structural stability, susceptibility to surface crusting, soil compaction and erosion and low water retention capacity, among others (Ayodele and Shittu, 2014; Wei et al., 2020; Adekiya et al., 2020; Nweke, 2016; Borrelli et al., 2017; Igwe and Nwokocha, 2005; Akingbola et al., 2016; Adeyemo et al., 2019). All these have detrimental effects on agriculture, thereby threatening food security.

Nigeria has experienced high population growth in the last decade, this has led to an increase in demand for research information in line with ensuring food security, to meet up with the population increase (Farrell, 2018). Therefore, much work is carried out on improving soil productivity (Sharu et al., 2013). To ensure soil productivity, the addition of fertilizers (organic or inorganic) to the soil is crucial, however, the high cost of inorganic fertilizers in Nigeria and its detrimental effect on the ecosystem, has in time shifted focus of researchers to several forms of organic amendment which are readily available especially biodegradable wastes (Nwanne and Ikeh, 2020; Stewart et al., 2020). This is with the aim of ensuring food security, sustaining the soil and mitigating climate change through sequestration of carbon from organic matter. Using the soil to sequester carbon has been recommended as a way to counterbalance the buildup of greenhouse gasses in the atmosphere, but addition of organic matter to soil normally have inadequate stability due to decomposition (Rumpel et al., 2020; Jia et al., 2019). However, organic amendment such as Biochar has resistance to microbial decay, this attribute makes it a good option when considering long term carbon sequestration in soils, thereby making biochar a considerable selection for soil amendment (Budai et al., 2016; Hardy et al., 2019; Adekiya et al., 2020; Tomczyk et al., 2020).

Biochar is a carbon-rich soil amendment which is made by the pyrolysis of biomass (Tomczyk et al., 2020). Several biomasses have been used in making biochar, but much focus is on agricultural waste products. This research focuses on using two forms of waste common in the research study area. These are poultry litter and wood shavings. Biochar additions made from various biomass has been found to improve fertility in tropical soils (Tanzito et al., 2020). Some researcher defined soil fertility as the soil's ability to provide water, air, nutrients, and spaces to the root environment of plants and referred to soil structure as an attribute of soil quality that has a direct effect on crop production, water retention and transmission, root growth and development. In other words, soil fertility is closely linked to soil structure (Currie, 1962; Ogunwole et al., 2015).

Furthermore, a group researchers stated that soil aggregation is crucial to ensuring a good soil structure (Lehmann et al., 2020). Soil structure and soil texture are both unique properties of the soil that have a profound effect on the behavior of soils. Little is known about the effect of

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biochar created from poultry litter and wood-shaving on the aggregation of soils that are texturally different, also understanding the need of each texturally differentiated soils is crucial to what biochar type or quantity is most suitable in mitigating degradation and ensuring food security. There is a need to further understand and compare how these soils build the founding blocks of aggregation with biochar addition made from the two known sources of organics, which are plant and animal. The experiment seeks to answer the following research questions: (1) Will the source of biochar determine the efficacy of the biochar in micro-aggregation of the soil? (2) Will biochar, irrespective of the source, have a similar effect on texturally differentiated soils?

2. MATERIALS AND METHODS

2.1 Experimental site

The potted experiment was carried out at the Obakekere Laboratory of the Crop, Soil and Pest Management Department, Federal University of Technology, Akure, Nigeria.

2.2 Sample collection

Animal biomass (poultry litter) was collected from the Department of Animal Production and Health while the plant biomass (wood shavings) was collected from the Department of Forestry and Wood Technology at the Federal University of Technology Akure. Two soil samples were collected from different locations. The first soil sample (Clay soil) was collected from the Teaching and research farm of the Federal University of Technology Akure. The second soil sample (Sandy clay soil) was collected from the Department of Crop Soil and Pest Management at the Federal University of Technology, Akure.

2.3 Sample preparation

Animal and plant biomass obtained were air dried and put through the process of pyrolysis. The process involved heating the biomass in a pyrolizer at a temperature of 400^0c in the absence of oxygen until biomass was completely burnt. The soil samples were air dried to achieve uniformity in moisture content of soils from different location and later sieved with a 2mm sieve.

2.4 Experimental design

The experimental sample was laid out in a completely randomized design consisting of 5 treatments, with three replicates per soil type. The treatment notation and meaning are shown in Table 1.

Table 1: The treatment notation and meaning

Treatment Notation	Meaning
0B	0g of Biochar/ kg of Soil
50AB	50g of Animal Biochar / kg of Soil
100AB	100g of Animal Biochar/ kg of Soil
50PB	50g of Plant Biochar/kg of Soil
100PB	100g of Plant Biochar/kg of Soil

2.5 Experimental procedure

Biochar (0g, 50g and 100g) was weighed and added to 1kg each of the two texturally differentiated soils. 100ml of water was added to the soil (incubation) at 5days interval in other to stimulate aggregation.

2.5.1 Determination of soil properties

2.5.1.1 Soil textural class

The particle size analysis was done using standard hydrometer method described, while the particle fraction was calculated using the formulae and the textural classes described (Gee and Bauder, 1986; Okalebo et al., 2002).

2.5.1.2 Soil pH and Organic carbon content

Soil pH was determined in a 1:2.5 soil to water ratio with a pH meter, while the soil organic matter was determined using Walkey and Black Wet Oxidation method.

2.5.1.3 Measures of micro-aggregation

The dispersion ratio (DR), a measure of the micro-aggregate stability of the soil was computed at 4 weeks after application (WAA), 8WAA and 12WAA using the values of silt and clay seperates in calgon-dispersed and water-dispersed samples following the Bouyoucos hydrometer method of particle size analysis as described (Gee and Bauder, 1986). The computation below is as stated (Adekiya et al., 2020).

$$\text{DR}=\left(\frac{\%\,silt\ in\ water + \%\,Clay\ in\ Water}{\%\,silt\ in\ \ Calgon + \%Clay\ in\ Calgon}\right) X\ 100 \qquad (1)$$

The clay flocculation index (CFI), a measure of how an individual particle of clay aggregate into clot-like masses or precipitate into small lumps was computed as stated using the equation (Atougour et al., 2019):

$$\text{CFI}=\left(\frac{\%\text{ clay in calgon} - \%\text{ clay in water}}{\%\text{ clay in calgon}}\right) X\ 100 \qquad (2)$$

Aggregated silt + clay (ASC), a measure of the interaction or bonding between silt and clay seperates was derived using the equation (Udom and John, 2019):

$$\text{ASC}=(\%\text{ clay in calgon} + \%\text{ silt in calgon}) - (\%\text{ clay in water} + \%\text{ silt in water}) \qquad (3)$$

The clay dispersion Index (CDI) which is used to express soils clay dispersion tendency was derived using (Igwe and Obalum, 2013):

$$\text{CDI}=\left(\frac{\%\text{clay in water}}{\%\text{ clay in calgon}}\right) X\ 100 \qquad (4)$$

2.6 Data Analysis

Microsoft Excel spreadsheet was used to input and prepare all data. Data prepared were subjected to Analysis of Variance (ANOVA) using statistical package for social science (SPSS v.17) while means were compared using Tukey Honestly Significant Difference (HSD) Test at 5% level of probability.

3. RESULTS

3.1 Initial micro-aggregation status of the two texturally differentiated soils

Table 2: Initial micro-aggregation status of the two texturally differentiated soils

Properties	Soil 1	Soil 2
Sand %	25.28	45.28
Silt %	24	12
Clay %	50.72	42.72
Textural class	**Clay**	**Sandy clay**
Organic Carbon (O.C)	1.11	0.7
Organic matter (O.M)	0.086	1.21
Dispersion ratio (DR) %	39.36	51.21
Clay Flocculation Index (CFI) %	69.60	43.77
Clay Dispersion Index (CDI) %	30.40	56.23
Aggregated Silt+Clay (ASC) %	45.31	26.70
Soil pH	5.34	6.67

Mean values are presented in this table

Micro-aggregation status of the soils used in this study are described in Table 2. The soils were analyzed and concluded to be clay and sandy clay in texture. The values recorded for the dispersion ratio (DR) and clay dispersion index (CDI) were lower in the clay compared with the sandy clay. The clay flocculation index (CFI) and aggregated silt + clay (ASC) was higher in the clay compared with the sandy clay. The clay had 1.11% organic carbon content while the sandy clay had 0.7%. The pH values recorded for both soils were acidic, although sandy clay was less acidic that clay.

3.2 Dispersion ratio in a clay as affected by animal-based and plant- based biochar rates

According to Figure 1., the highest dispersion ratio (DR) of mean value 38.92% was recorded for clay soil without biochar amendment. At 4 weeks after application (WAA) clay soil with treatment 50AB had a decrease of 8.84%, 50PB had a decrease of 15.78%, 100AB had a decrease of 11.67% while 100PB had a decrease of 20.43% when compared with soil with treatment 0B (control). This trend was noticed throughout the weeks. Considering Figure 2. Which shows the DR in the sandy clay, same trend noticed in Figure 1 also obtains here. However, the DR in clay was lower than the DR in sandy clay.

3.3 Other micro-aggregation metrics in clay and sandy clay as affected by plant-based and animal-based biochar

In Table 3., there was no significant difference (P>0.05) among clay flocculation index (CFI) and clay dispersion index (CDI) recorded mean values in clay at 4WAA and 8WAA. However, at 12WAA a significant difference (P>0.05) was recorded among animal-based biochar (100AB and 50AB), plant-based biochar (100PB and 50PB) and no biochar (0B) which is the control, but there was no significant difference (P>0.05) between treatment of same source for both CFI and CDI. The CFI and CDI values recorded for sand showed significant difference (P>0.05) across weeks. Where the highest value for CFI was recorded for 100PB across weeks and 0B the lowest. The highest value for CDI in sand was recorded for 0B while 100PB had the lowest.

Table 3: Soil micro-aggregation metrics in clay and sandy clay affected by plant-based and animal-based biochar

Treatments	CFI (%)	CDI (%)	ASC (%)	CFI (%)	CDI (%)	ASC (%)
	Clay			Sandy Clay		
	4WAA					
0B	68.30a	31.70a	45.64e	43.82d	56.18a	26.69e
50AB	65.48a	34.52a	48.21d	50.84c	49.16b	27.45d
50PB	67.48a	32.52a	50.22b	61.77a	38.23d	28.68b
100AB	66.45a	33.55a	49.03c	55.52b	44.48c	28.00c
100PB	66.86a	31.14a	51.58a	64.89a	35.11d	29.28a
	8WAA					
0B	70.64a	29.36a	46.91d	44.13c	55.87a	26.77d
50AB	72.59a	27.41a	51.90c	51.17b	48.83b	28.08c
50PB	73.64a	26.36a	53.43b	62.89a	37.11c	29.76b
100AB	72.80a	27.20a	52.34c	55.88b	44.12b	28.66c
100PB	73.39a	26.61a	54.97a	66.82a	33.18c	30.60a
	12WAA					
0B	73.50b	26.50a	48.48e	43.74c	56.26a	28.84d
50AB	75.33ab	24.67ab	53.41d	51.57b	48.43b	28.58c
50PB	77.72a	22.32b	55.65b	63.29a	36.71c	30.35ab
100AB	77.12ab	22.88ab	54.65c	56.27b	43.73b	30.03b
100PB	77.78a	22.22b	57.32a	67.31a	32.69c	30.87a

Means followed by the same letters in a column are not significantly (P<0.05) different according to Duncan's Multiple Range Test.
WAA- Weeks after application

As shown in Table 3., the treatment 100PB had the highest significant (P>0.05) value for aggregates silt + clay (ASC) in clay and sandy clay.

3.4 Soil pH and organic carbon content in clay and sandy clay affected by plant-based and animal-based biochar

Table 4., shows that at 4WAA, the highest mean Ph value was recorded for 100PB, while the lowest was recorded for the control (0B) in both sandy clay and clay. There was a clear significant difference (P>0.05) among biochar quantities (100PB, 100AB> 50PB, 50AB> 0B). The organic carbon (OC) content of the soils without biochar amendment was significantly lower than other treatments. 100PB had the highest mean value in both sandy clay and clay, followed by 50PB and then 100AB. However, 50PB was not significantly different (P>0.05) from 100AB.

Table 4: Soil pH and organic carbon (OC) content in clay and sandy clay affected by plant-based and animal-based biochar

Treatment	pH		OC (%)	
	Clay	Sandy Clay	Clay	Sandy Clay
	4WAA			
0B	5.33c	6.64c	1.09d	0.38d
50AB	5.42b	6.73b	1.47c	0.85c
50PB	5.45b	6.76b	1.87b	1.26b
100AB	5.59a	6.90a	1.77b	1.15b
100PB	5.62a	6.93a	2.11a	1.49a
	8WAA			
0B	5.32c	6.52a	0.98d	0.34d
50AB	5.40b	6.71b	1.46c	0.82c
50PB	5.44b	6.75b	1.87b	1.23b
100AB	5.58a	6.91a	1.75b	1.11b
100PB	5.62a	6.94a	2.10a	1.46a
	12WAA			
0B	5.27c	6.60c	0.97d	0.32d
50AB	5.37b	6.70b	1.46c	0.80c
50PB	5.42b	6.74b	1.86b	1.21b
100AB	5.56a	6.89a	1.74b	1.09b
100PB	5.59a	6.93a	2.10a	1.44a

Means followed by the same letters in a column are not significantly (P<0.05) different according to Duncan's Multiple Range Test.
WAA- Weeks after application

4. DISCUSSION

4.1 Dispersion ratio in a clay as affected by animal-based and plant- based biochar rates

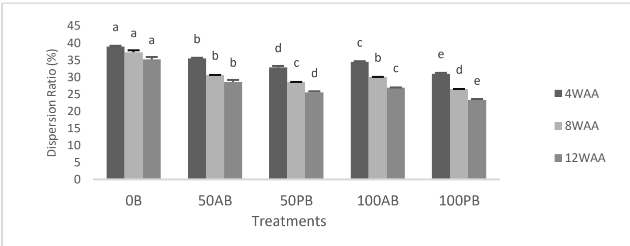

Figure 1: Dispersion ratio in a clay as affected by animal-based and plant- based biochar rates (0g/Kg, 50g/kg and 100g/kg of soil). Error bars correspond to the standard deviation and compared to the control (0B) (P<0.05)

The structural stability of the soil determined through aggregate formation at microlevel was measured using the DR, Figure 1 and Figure 2 shows the influence of each biochar type on the soil's (clay and sandy clay) ability to disperse or become less stable. The higher the value of DR, the more dispersed and less stable the soil is. Although all treatment reduced the soils dispersibility, there was significant difference (P>0.05) among treatments. The highest effect was recorded for the plant-based biochar (100PB) while the lowest was for soil without biochar amendment (0B). From the recorded mean values, the plant-based biochar stimulated aggregation more in both clay and sandy clay compared to the animal-based biochar. The aggregation stimulation trend among treatments in descending order according to Figure 1. And Fig 2. is 100PB> 50PB> 100AB> 50AB> 0B. The reduction in dispersibility of the soils across weeks without biochar amendment was probably as a result of the continuous wetting and drying cycle which has been found to stimulate aggregation in soils (Hu et al., 2018).

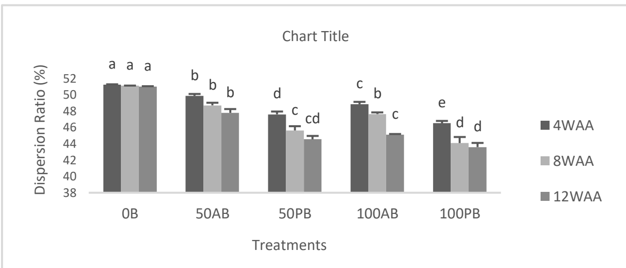

Figure 2: Dispersion ratio in a sandy clay as affected by animal-based and plant- based biochar rates (0g/Kg, 50g/kg and 100g/kg of soil). Error bars correspond to the standard deviation and compared to the control (0B) (P<0.05)

4.2 Other micro-aggregation metrics in clay and sandy clay as affected by plant-based and animal-based biochar

With reference to Table 3, the ASC shows the percentage of silt and clay that have become aggregated through the treatments. There is significant difference (P<0.05) among treatments where 100PB had the highest recorded value followed by 50PB. The plant-based biochar had more significant effect on the soils compared to the animal-based biochar of the same quantity. This finding could be attributed to the fact that trees stores carbon being that the source of the plant-based biochar used for the experiment is wood shavings gotten from matured trees harvested for its timber while the source of the animal-based biochar is poultry droppings (Whitehead, 2011; Mackey, 2014).

There was no significant difference (P>0.05) for clay in the values recorded for CFI in 4 WAA and 8 WAA until 12 WAA, however, the trend shows a higher mean value recorded for 100PB. This shows that biochar stimulated flocculation among clay particles was most significant 12 weeks after application and the plant-based biochar having the most effect for clay. However, for sandy clay notable significant difference was noticed at 4WAA, 8WAA and 12WAA, meaning biochar was able stimulate flocculation in the sandy clay earlier than in the clay. This was probably because of the lower clay content in the sandy clay compared to the clay, which makes the lower clay content available to a more adequate quantity biochar.

4.3 Soil pH and organic carbon content in clay and sandy clay affected by plant-based and animal-based biochar

Biochar has been found by many researchers to reduce soil acidity this was evident in the research as shown in Table 4 (Chintala et al., 2014; Obia et al., 2015; Cornelissen et al., 2018; Mensah and Frimpong, 2018). There was reduction in acidity (increase in pH) at 4WAA compared to the acidity level in the soils before the experiment. This reduction only occurred in soils with biochar amendment (50AB, 50PB, 100AB and 100PB) but not the control (0B). Also, the effect of biochar on soil acidity was only related to quantity of the biochar and not the biochar source. From the mean values in Table 4., 100PB had the most effect on reducing acidity followed by 100AB. However, there was minimal increase in soil acidity level at 8WAA and 12 WAA. This was probably due to the source of water (rainfall) used in wetting the soil (100ml of rainwater at 5days interval) to stimulate aggregation. It has been concluded by several researchers that rainwater is acidic (Okpoebo et al., 2014; Khayan et al., 2019).

The soil organic carbon content increased significantly (P>0.05) with addition of biochar as stated in Table 3; this was expected as biochar is a carbon-rich amendment. However, after application subsequent decrease in organic carbon content was noticed through mean values at 8WAA and 12WAA. Since biochar is a stable form of carbon and takes a longer time for mineralization depending on the source, the decrease must have been due to mineralization of inherent organic carbon of the soil (Singh et al., 2012). Higher reduction of organic carbon content was noticed in sandy clay compared to clay soils. This was probably because clay + silt content of soils has been found to have direct relationship with organic matter stabilization (Jolivet et al., 2003). Furthermore, it has been concluded that soil aggregation increases soil carbon stability (Qin et al., 2017). This is justified by the mean values recorded, the clay had lesser dispersion ratio (higher aggregate stability) compared to sandy clay.

5. Conclusion

From the results of this research it can be concluded that plant-based biochar made from wood shavings biomass is more effective in stimulating aggregation of soil separates compared to animal-based biochar from poultry droppings.

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