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RESIDUAL EFFECTS OF ORGANIC AND MINERAL FERTILIZER APPLICATION ON CARBON SEQUESTRATION AND AGGREGATE STABILITY IN SAVANNA SOIL

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Abstract

Residual effects of organic and mineral fertilizer application on carbon sequestration and aggregate stability in a savanna soil were investigated, with aim of establishing the relationship between aggregate stability and carbon sequestration as related to management practices. The study was carried out in the DNPK trial farm at Samaru, Northern Guinea Savanna of Nigeria, with four main treatments; cow dung (D), nitrogen (N), phosphorus (P) and potassium (K) at 3 levels and 81 treatment combinations arranged into nine plots of 220m^3 each, with a discard of 0.91m. Surface soil samples were collected from seven plots. The disturbed samples were air-dried, sieved and analyzed for particle and aggregate size distributions, total and non-hydrolysable organic carbon and total nitrogen. Soil carbon sequestration rate, clay dispersible index (CDI), and mean weight diameter (MWD) were also calculated. Data obtained were transformed to account for spatial variability, thereafter subjected to ANOVA using DMRT to compare the treatment means, and simple linear regression to detect functional relationship among variables. The results obtained showed that management practices have significant effects on soil carbon, dry and wet aggregates, MWD and particle size distribution with a high concentration of OC in large macro aggregate fraction (>2mm). Dry and wet MWD strongly correlated with organic carbon concentration (R^2 = 0.939 and 0.797 respectively, $P<0.05$), showing that OC is central to the formation, stabilization and maintenance of soil aggregates in DNPK trial farm. SCSR showed no significant changes with management practices indicating that all management practice have the same rate of carbon sequestration.

Keywords: Residue, carbon sequestration, aggregate stability and savanna

Introduction

Intensified continuous cultivation due to increasing population pressure in West Africa savanna has replaced the traditional methods (shifting cultivation and bush fallow) of maintaining and improving soil quality. This condition has led to the depletion of most savanna soils. To this end, incorporation of organic and inorganic fertilizer becomes an essential component of the soil productivity and fertility management practices in the region. Also, this management practice replenishes soil organic matter and nutrient for sustained soil productivity (Tian *et al.,* 2001), which in turn has beneficial effects on soil structural stability (Feller and Beare, 1997) and soil organic carbon. Soil management influences the dynamics of carbon in soils affecting the quantity and quality of soil organic matter, soil aggregation and microbial populations (Six *et al.,* 2002). Thus, importance has been placed on the use of agricultural soils for the mitigation of atmospheric CO_2 through sequestration of soil carbon (Lal, 2002; 2003). Denef and Six (2005), reported that maintenance of soil carbon is an effective mechanism to combat land degradation and increase future food production. Also, Post *et al.,* (2004), IPCC, (2007) and Smith *et al.,* (2008) noted that soil carbon sequestration is a viable short-term option to mitigate increased CO_2 to curb global warming. Soil organic carbon which is a soil quality indicator influences aggregation in soils. Hence, studies (Cambardella and Elliot, 1993; Six *et al.,* 1999; 2000) on mass distribution of soil organic carbon among aggregate classes suggest that increase in soil aggregation through the adoption of best management practices usually leads to high soil organic carbon sequestration. The long term, cow dung, nitrogen, phosphorus and potassium (DNPK) trial farm initiated in Samaru in 1950 was aimed at assessing nutrient balances resulting from the increased use of organic and inorganic fertilizers on some poorly buffered soils under intensive agricultural land use (Ogunwole and Ogunleye, 2004). Studies exist on the flow of carbon, nitrogen and phosphorus, benefits of the trial to Samaru soils (Yaro *et al.,* 2003; Yusuf, 2007), fertility (Agbenin and Goladi, 1997), surface soil aggregation and trace metal enrichment (Ogunwole and Ogunleye, 2004) and effects on physicochemical properties of the soil (Lawal *et al.,* 2012). Little information is available on the effects of long-term manure addition along with mineral fertilizer on carbon sequestration and soil aggregation. Hence, the objective of this study is to investigate the relationship between aggregate stability and carbon sequestration, while relating these to management practices.

Materials and Methods

Site description

The experiments were conducted at the DNPK trial farm located at Samaru (11°1´N, 07°38´E, altitude 686m), Northern Guinea Savanna of Nigeria. The area has a mean annual rainfall of 1050mm, mean annual temperature of 24-26°C (Oluwasemire, 1999) and the soil is classified as Typic Haplustalf (Ogunwole *et al*., 2001). Four main treatments namely; cow dung (D), nitrogen (N), phosphorus (P) and potassium (K) at three levels, and at all possible treatment combinations were applied. This gives a total of eighty-one (81) treatment combinations randomly arranged into 9 plots and each plot size was 220m^2 with a discard of 0.91m around each plot. Sources of mineral fertilizer have been ammonium sulphate (1950-1968), calcium ammonium nitrate (1969-1991) and urea (1991-date) for N, single superphosphate and muriate of potash for P and K respectively. Organic manure has been sourced from cow dung at the rate of 5000 Kg/ha. After harvesting the crop, all crop residues are removed and burnt in a trench, this is done as a management practice. Before sampling in 2006, the trial site has been under fallow for ten years (Ogunwole and Ogunleye, 2004).

Sampling and Laboratory analysis

Surface soil samples were collected from seven selected plots in three replicates. The plots sampled for analysis are described in Table I. A stratified random sampling procedure which divided the plots into three homogenous subplots of 72m^2 each was adopted. Disturbed soil samples collected were air-dried, passed through 2mm sieve and used for laboratory analysis. The hygrometer method of Gee and Bauder (1986) was used to determine particle size distribution, while organic carbon was determined using the Walkley-Black wet oxidation method (Nelson and Sommers, 1982). Acid hydrolysis was employed to determine the non-hydrolysable carbon (Tan *et al*., 2004; Paul *et al*., 2001). Soil carbon sequestration rate (SCSR) was calculated using the method of Conant *et al.* (2003) i.e.

$$\mathrm{SCSR} = \frac{\mathrm{TOC}\ (\mathrm{T_1}-\mathrm{T_0})}{\mathrm{T_d}} \ldots\ldots\ldots\ldots (1)$$

Where;
TOC = total OC of the treatments, T_1 = treatment plot, and T_o = control plot.
Clay dispersible index (CDI) was calculated as the ratio of the weight of clay fraction obtained from particle size analysis with water (clay in water dispersed samples), and the weight of clay fraction obtained from particle size analysis with Calgon (clay in Calgon dispersed samples).

$$\mathrm{CDI} = \frac{\text{Clay in water dispersed samples}}{\text{Clay in Calgon dispersed samples}} \ldots.. (2)$$

Table I: Description of the seven selected plots of the DNPK trial farm

S/No	Plot Number	Treatment	Rates Kg ha^{-1}
1	3 (N)	N alone	N = 48-135
2	4 (DNPK)	D+N+P+K	D = 5000, N =48-135, P =18-54, K = 29-58
3	14 (Control)	Zero amendment	Nil
4	32 (P)	P alone	P =18-54
5	56 (D)	D alone	D = 5000
6	78 (NPK)	N+P+K	N =48-135, P =18-54, K = 29-58
7	Continuous Cropping		

A 200g of air-dried soil was dry sieved through four nests of sieves (2000µm, 500µm, 250 µm and 53µm) on a mechanical shaker for 60 seconds. The amount of aggregate in each sieve size range was determined as a fraction of the initial air-dried sample weight. MWD was calculated using the van Bavel (1949) method and is used as an index of soil structural stability to erosion (Unger, 1997);

$$\mathrm{MWD} = \sum \mathrm{X_i}\ \mathrm{W_i} \ \ldots\ldots.. (3)$$

Where;
X_i =mean diameter of each aggregate fraction, W_i =total proportion of the sample weight occurring in the size fraction.

Samples (200g) were moist overnight by capillary action on a moist tension plate at 60cm suction. The moistened soil was placed on various sieve sizes (2000µm, 500µm, 250 µm and 53µm) and oscillated in water at 12 oscillations per 40 seconds. The resultant water-stable aggregates on each sieve were oven dried at 50°C for 24 hours before the temperature was raised to 105°C until the samples were dried. After oven drying, the mass of each sieve fraction was determined, while the mass of the < 53µm (silt + clay) was obtained by difference. Aggregated silt and clay (ASC) used as an index of micro aggregate stability is defined as the difference between silt and clay in Calgon and water dispersed samples of the whole soil (Mbagwu and Bazzoffi, 1998). Stability of the soil was inferred according to Franzluebbers (2006) from the MWD of the aggregates, which is the ratio of MWD of wet aggregates to the MWD of the dry aggregates.

Analysis

Soil parameters measured were transformed before subjected to statistical analysis to compensate for spatial variability. Values of aggregate stability were arc sin-transformed, while those of carbon and nitrogen were logarithm- transformed before data analysis. Data were subjected to analysis of variance (ANOVA), while Duncan's Multiple Range Test was used to compare treatment means where F-values were significant. simple linear regression analyses were carried out to detect functional relationship among key soil variables. All analyses were done using a statistical software package (SAS Institute, 1998).

Results and Discussion

Dry aggregate and particle size distribution

There were management induced changes in dry aggregate size distribution among the treatment (Table 2). The N treatment recorded highest proportion of dry aggregate in the large macro aggregate (>2mm). The D, control and NPK recorded a similar proportion of large macro aggregate, while P and CC recorded the lowest proportion. Under the medium (2-0.5mm) and small macro aggregate (0.5-0.25mm), plots that received P treatment with or without other amendments and CC treatment were statistically similar. The lowest values of medium and small were realized in plots that received N, D and D in combination with mineral fertilizer. The various treatments also had significant effect on the micro aggregate (> 0.053). P, NPK and CC had higher fractions of micro aggregate than N, DNPK and control, while D had the least fraction. Particle size distribution in this study was affected by management practices. CC had highest values of clay and silt percentages, while control and NPK recorded least clay and silt percentages respectively (Table 2). Soils under different management practices differed markedly in dry and wet aggregate, MWD, soil organic carbon, total nitrogen pool particle size distribution, sizes and aggregate soil organic carbon concentration within the soil. The result of the large macroaggregates suggests that N, D and the control enhanced large macroaggregates (>2mm) and will control erosion than other treatments. The 0.25mm-0.053mm recorded highest values under the P amended plots with or without other treatments. This agrees with Hades and Quinton (1990) observation, that N and zero fertilizer addition affect the size of larger soil structural units at air dryness. However, P fertilizer causes aggregation of soil structural units into smaller aggregates. CC which is manual tillage practice that might have involved disruptive force in incorporation and mixing of crop residues favoured the formation of micro aggregates, silt and clay fractions. This is because macro aggregates are highly susceptible to disruptive force thereby making them more dependent on cultural practices.

Wet aggregate size distribution and CDI

There were no significant differences in wet large macro aggregate (>2mm) among the treatments, but DNPK treatment recorded highest values. However, small macro aggregate, large and small micro aggregate fraction recorded significant management influence. NPK, D, P and control amended soils had significant higher small macro aggregate values than N. But P, D and control are statistically similar to DNPK and CC. Both large and small micro aggregate recorded statistically par values among DNPK, P, control, N, D and CC treatments, while NPK recorded the least values. As expected, there was no management influence on aggregate silt and clay (ASC) fraction (Table 3). Highest values of clay dispersion index (CDI) was observed in N plot, which was statistically similar to control, P, D, DNPK and CC, but higher than NPK (Table 3). The result of CDI and ASC implies that N, D and CC amended soils will enhance wet micro aggregate stability than other management practices, probably because of the binding effect of nitrogen and manure with soils particles to form micro-aggregate since CDI and ASC are wet aggregate stability indices (Table 3). Higher concentration of organic carbon was observed in >2mm under P amended soil. This could be as a result of increase of organic matter via phosphorus fertilizer application because phosphorus in soil increases plant root biomass, thereby increasing organic matter and aggregate formation (Russell and Williams, 1982; Murata *et al.,* 1995).

Aggregate stability, whole soil N and C and OC sequestration

Stability of MWD, macro (>0.25mm) and micro (<0.25mm) were affected by management practices. Plots that received CC and P treatments had highest values of stability across the three treatments (Table 4). Significant differences were observed in whole soil N and C, with CC treatment having higher values than the other treatments. No significant differences were recorded in OC sequestration values among the treatments (Table 4). An average of 25g/kg/yr was recorded across the treatments. Excessive application of nitrogenous fertilizer (which stimulates microbial activity) and high rate of mineralization of organic matter (as a result of high temperature in the savannah), release organic nutrients including carbon. These could probably be the reason for the observed low concentration of organic carbon in the N and DNPK plots (Table 4). The continuous cropping plot recorded highest value of organic carbon in >0.25mm and <0.053mm fraction, and this could probably be due to resistant in decomposition of residue turnover and tillage effect that might have accumulated the organic carbon over time than the rest of management practices.The high concentration of OC in large macro aggregate fraction (>2mm) could be attributed to the accumulation of soil organic matter via the long term application of organic manure and residue addition from the long fallow period (almost a decade). The combination of organic matter and residue accumulation might have led to the observed high concentration of OC in the DNPK amended soil. The control plot with zero amendment on the other hand might have recorded highest value probably due to the fact that control has a larger sink for organic carbon relative to others that have been under natural fallow.

Manure application alone or with inorganic fertilizer has been reported to increase carbon concentration and may impact macro aggregate formation (Batjes, 1999; Hao *et al.,* 2003).

Stability of MWD, macro- and micro- aggregate also increased in CC and P treatments. This could be probably due to increase in microbial-derived binding agents that bind and enhance aggregates as a result of soil organic matter increase via the application of P fertilizer and fresh residue turnover in a continuous cropping plot since it is cultivated under manual tillage operation. Mrabet (2002) reported an increase in aggregate stability and MWD as a result of the increase in organic carbon concentration, while Russel and Williams (1982) and Murata *et al*. (1995) reported that phosphorus fertilizer application in soils, increase soil organic matter, which in turn improves aggregate stability. Indirect addition of Ca in P fertilizer may have contributed to improved stability in soils amended with P fertilizer.

OC in wet aggregate and wet sieved dry aggregate

OC in both macro and micro water-stable aggregate was influenced by management practices. OC values in large macro aggregate fraction in P plot are higher and statistically similar to NPK, D, DNPK and CC but different from values of the control and N treatment. CC had highest values under small macro aggregate (>0.25mm) fraction, and similar statistically with P treatment, with or without other amendments, but higher than N and D treatments. When management effect on OC water-stable large micro aggregate was evaluated, OC was higher in NPK soil, which was similar to CC, control, N, P and D, but higher than DNPK. While the small micro aggregate recorded statistically similar values in CC, N, P and D (in decreasing order), but CC and N have higher values than control and DNPK (Table 5). Various fraction of wet sieved dry OC fraction (expect > 0.25mm) were affected by management practices. In large macro aggregate (>2mm), control and DNPK plots recorded highest values, while N plot recorded the least values. The highest value observed in CC treatment under micro aggregate fraction were similar to values obtained in mineral fertilizer plots (P, N and NPK), while control recorded the least values (Table V). Non-hydrolysable known as biochemically protected OC was also influenced by management practices. CC, N and DNPK are similar to D, NPK and control but higher than P.Dry and wet MWD were strongly correlated with SOC concentration, $R^2 = 0.939$ and 0.797 respectively, $P<0.05$ (Table 6), suggesting that SOC is central to the formation, stabilization and maintenance of soil aggregates in DNPK trial farm. In this study, there was a significant increase in the concentration of SOC under CC treatment, similar to Oades (1984) and Six *et al* (2000a, 2000b). The SOM pool is stabilized through association with silt and clay particle within macro and micro aggregates. As would be expected, the trend in N distinction parallels OC distinction (Table 5) probably reflecting the definite stoichiometric relationship between C and N in soil (McGill and Cole, 1981). Lower amount of total N in N and NPK plots might be due to rapid crop uptake because of higher solubility and availability than in D or DNPK plots (Agbenin and Felix-Henningsen, 1999), and also due to the difference in quality of the litter input (Ussin *et al.,* 2006). As there is a release of mineralized N from residue turnover decomposition and fertilizer being applied during annual cropping of CC plot.

Soil management practices have no significant effect on soil sequestration rate. This implies that all management practice have the same rate of carbon sequestration and could be probably because all treatments had been under fallow and grass vegetation for almost a decade after long term application of mineral and organic fertilizers. These grass vegetation trap atmosphere carbons during photosynthesis dies and add organic residue, thus increasing carbon sequestered. CC was slightly higher because of its younger age (Lickacz and Penny, 2001) and higher soil aggregation (Ussin *et al.,* 2006), hence store carbon. Soil aggregation plays dominant role in SOC sequestration by physical protecting SOM through incorporation into soil aggregates (Golchin *et al*., 1994).

Conclusion:

Long-term application of organic and mineral fertilizer had significant effects on soil aggregate stability. Phosphorus amended plots with or without other treatments had a great influence on soil carbon and aggregate formation. The relationship between organic carbon and aggregate stability suggested that OC is central to the formation, stabilization and maintenance of soil aggregates of the study area. All management practices had the same effects on soil carbon sequestration rate pointing to the fact that the study area was under fallow and grass vegetation for about a decade, encouraging atmospheric trapping of carbon during photosynthesis thus increasing carbon sequestration.

Table 2: Dry aggregate fractions, mean weight diameter and particle size distribution as affected by management practices in DNPK trial farm

Treatments	Macro aggregates			Micro aggregate	MWD dry (mm)	Particle Size Distribution		
	>2mm	2-0.5mm	0.5-0.25mm	>0.053mm		Clay	Silt	Sand
Control	0.31ab	0.14bcd	0.09bc	0.16abc	1.40a	14.53c	28.33b	57.13bc
P	0.19c	0.16ab	0.12a	0.20a	0.98bc	15.53bc	24.33b	60.53ab
N	0.36a	0.10e	0.07c	0.16abc	0.12cd	14.98bc	30.67b	58.00bc
NPK	0.27ab	0.17a	0.11ab	0.20a	0.18bcd	15.87bc	22.00c	63.13a
D	0.32ab	0.13cd	0.09bc	0.14bc	1.31b	15.20bc	29.33b	55.47c
DNPK	0.24bc	0.12ed	0.08c	0.16abc	0.12cd	16.20ab	27.50b	56.13c
CC	0.18c	0.15abc	0.12a	0.18ab	0.91bc	17.53a	36.33a	46.13d
SE	0.03	0.01	0.01	0.02	0.03	0.51	1.03	1.24

Table 3: Wet aggregate fractions, aggregated silt and clay, mean weight diameter and clay dispersible index as affected by management practices in DNPK trial farm

Treatments	Macro aggregates		Micro aggregates		ASC	MWD wet	CDI
	>2mm	>0.25mm	>0.053mm	<0.053mm			
Control	0.07	0.37abc	0.46a	0.19a	7.38	1.39abc	0.21ab
P	0.05	0.41ab	0.47a	0.19a	10.52	1.36bcd	0.18ab
N	0.09	0.32c	0.45ab	0.19a	9.20	1.34cd	0.22a
NPK	0.07	0.43a	0.42b	0.15b	11.70	1.41ab	0.07b
D	0.05	0.39ab	0.46a	0.18ab	13.63	1.37abcd	0.12ab
DNPK	0.17	0.36bc	0.47a	0.19a	6.89	1.32d	0.12ab
CC	0.07	0.36bc	0.44ab	0.17ab	12.14	1.44a	0.11ab
SE	0.08	0.02	0.01	0.01	0.38	0.01	0.07

Table 4: Organic carbon in various wet sieved aggregate fractions, wet sieved dry aggregate fraction and non-hydrolysable carbon as affected by management practices in DNPK trial farm

Treatments	OC in various wet aggregate fractions				OC in various wet sieved dry aggregate			NHC
	>2mm	>0.25mm	>0.053mm	<0.053mm	>2mm	>0.25mm	>0.053mm	
Control	0.74b	0.66bc	0.65ab	0.65b	0.13a	0.75	0.56b	0.28ab
P	1.11a	0.88ab	0.61ab	0.71ab	0.11b	0.62	0.69ab	0.21b
N	0.70b	0.48c	0.64ab	0.79a	0.12ab	0.74	0.78ab	0.37a
NPK	0.78ab	0.83ab	0.83a	0.64ab	0.12ab	0.70	0.77ab	0.30ab
D	0.79ab	0.50c	0.62ab	0.68ab	0.12ab	0.90	0.67b	0.30ab
DNPK	0.91ab	0.83ab	0.55b	0.56b	0.13a	0.58	0.66b	0.36a
CC	0.93ab	1.04a	0.73ab	0.81a	0.12ab	0.88	0.97a	0.43a
SE	0.06	0.06	0.04	0.04	0.27	0.05	0.05	0.04

Table 5: Stability of mean weight diameter, macro and micro aggregate, total nitrogen and soil organic carbon as affected by management practices in DNPK trial farm

Treatments	Stability of			OC sequestration rate (g/kg/yr)	Total nitrogen (gKg^{-1})	Total carbon (gKg^{-1})
	MWD	<0.25mm	>0.25mm			
Control	1.28bc	2.75b	1.61bc	25.03	0.08b	0.46b
P	1.35ab	3.22a	1.79a	25.00	0.09b	0.41b
N	1.25c	2.78b	1.54c	25.00	0.08b	0.56b
NPK	1.34b	2.73b	1.71ab	25.00	0.08b	0.42b
D	1.29bc	3.04ab	1.67ab	25.01	0.09b	0.54b
DNPK	1.27bc	3.13ab	1.71ab	25.02	0.09b	0.62b
CC	1.42a	3.28a	1.77a	25.03	0.12a	0.95a
SE	0.01	0.04	0.02	0.02	0.01	0.04

Table 6: Relationship between mean weight diameter, aggregate stability, non-hydrolysable carbon, soil organic carbon and wet sieved dry aggregate carbon

Variables				
Dependent	Independent	Equation	R^2	P level
MWD dry	Soil organic carbon	$Y = 1.872 - 1.941\ X$	0.939	0.05
MWD wet	Soil organic carbon	$Y = 1.763 - 1.309\ X$	0.662	0.05
MWD wet	Wet aggregate OC	$Y = 0.320 + 2.757\ X$	0.797	0.05
MWD wet	Non-hydrolysable carbon	$Y = 1.511 - 0.993\ X$	0.087	0.05
Macro aggregate stability	Non-hydrolysable carbon	$Y = 2.736 - 6.686\ X$	0.458	0.05
Micro aggregate stability	Soil organic carbon	$Y = 2.343 - 2.220\ X$	0.401	0.05
MWD stability	Non-hydrolysable carbon	$Y = 2.029 - 4.802\ X$	0.585	0.05
MWD stability	Wet sieved dry aggregate OC	$Y = -10.6 + 209.0X$	0.511	0.05

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