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Soil Organic Carbon Concentrations and Stocks under Maize/Legume Cropping System in Alfisols of a Savanna Zone, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author OAC designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MYD and AA managed the analyses of the study. Author AA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Carbon sequestration in soil aggregates and Carbon stock (SOC) under Maize-Legume Cropping system in a Northern Guinea Savanna Alfisol, Nigeria trial was conducted in 2014 and 2015 cropping seasons. The experiment was a randomized complete block design (RCBD), replicated three times and treatments used were: Sole Maize (M), *Desmodium* (D) and Soybeans (S); Maize-soybeans intercrop (MS), Maize-*Desmodium* intercrop (MD), Maize Strip cropped with Soybean (MS 2:4) and Maize Strip cropped with *Desmodium* (MD 2:4). Data obtained were evaluated for Organic carbon, carbon stock, Bulk density and mean weight diameter of aggregates in the soil. Results obtained show that Mono-crop (Sole) Maize treatment gave significantly higher BD than other treatments at 8WAP and 16WAP, suggesting that soils under sole maize were degraded for sustainable crop production. Organic carbon sequestered over 2014 to 2015 was least under MD and highest under MD2:4 treatments and mean carbon stock sequestered in the macro and micro aggregates was highest under MD 2:4 (28.35 t Cha^{-1}) and least under MD (8.82 t Cha^{-1}). Soil

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organic carbon (SOC) sequestered in macro aggregates under MS (1.38 gkg^{-1}) were significantly higher than the other treatments. Maize/Desmodium 2:4 treatment was inferred to have best improved soil conditions (quality/health) for sustainable crop production, mitigate climate change and global warming by sequestering carbon better than the other treatments.

Keywords: Soil carbon stock; carbon sequestration in aggregates; conservation agriculture; cereal/legume cropping; sustainable soil management.

1. INTRODUCTION

Soil is a vital resource for producing food and fiber needed to support an increasing world population [1]. However, degradation of soil as a consequence of improper land use management practices pose serious threat to sustainable agriculture, resulting in the need for appropriate soil management strategy. In grassland areas for example, implementing grassland management practices that increase carbon uptake by increasing productivity and/or reducing carbon losses (e.g. through high rates of off-take) can lead to net accumulation of carbon in grassland savanna soils by sequestering atmospheric carbon dioxide (CO_2). The potential to sequester carbon by improving grassland practices or rehabilitating degraded savanna grasslands is substantial because practices that sequester carbon in grasslands often enhance productivity [2]. Practices that sequester carbon in grasslands also tend to enhance resilience in the face of climate variability, and are thus likely to enhance longer-term adaptation to changing climates [2,3]. Therefore, management of soil organic carbon to maintain the soil in good health is a major concern and challenging task in the arid and semi-arid tropical regions, and Nigeria in particular. Strategy for increasing and sustaining crop yields at a high productivity level must include integrated approaches to management of soil carbon that recognizes soil as the foundation and storehouse of most plant nutrients essential for plant growth.

Concerns over global warming have led to several investigations on quality, kind, distribution and behaviour of soil organic carbon [4,5,6,7] that have led to various quantitative estimates of soil organic carbon [8,9,10]. Reporting of organic' carbon status of soils in terms of per cent distribution is one way [3]; yet, it does not show the stock and reservoir of organic carbon in a particular area. For this study soil organic carbon will be reported on unit area basis for a specified depth interval and described as soil carbon stock (SOC). Over exploitation of soil has resulted in exhaustion of intensive agricultural production systems, steady declining productivity [11] and impoverished soil quality. Therefore, the way in which soil carbon is managed will majorly impact on plant growth, soil fertility, agricultural sustainability and environmental conservation.

Soils of Nigerian Northern Guinea Savanna are intensively cultivated with maize, sorghum, cowpea, groundnut, cotton and soybeans, and have resulted in inherently poor fertility status [12,13,14], have poor moisture retention capacity, rich in low activity clays and sesquioxides [15] and have very low organic carbon content [16]. The soils are therefore in a degraded condition to support sustainable agricultural production and require appropriate integrated management practices that will enhance productivity of the soils. Due to the fragile nature of the soil, they degrade rapidly under continuous and intensive cultivation [17]. In the Nigerian Northern Guinea Savanna zone, soil is frequently tilled at land preparation, crop residues are harvested for fencing, fuel wood or livestock feed [18,19], are not returned to restore soil carbon stock and fertility. Continued intensive cultivation, coupled with annual non-return of crop residues to the soil has conferred impoverished soil productivity status and necessitated the study on ‘soil sequestration and carbon stock under maize/legume cropping system in Alfisols of a Savanna zone, Nigeria. Commonly, cereal-based cropping systems in the Northern Guinea grassland Savanna of Nigeria practice legume relays into cereals, strip cropping of cereals with legumes, sole cropping of cereals and legumes. However, the focus for these management practices is largely on maximizing crop yield with little or no attention to resulting soil productivity status that would support subsequent cropping. The present study therefore intends to evaluate carbon sequestration and carbon stock of soils under varying cereal/legume practices with a view to determine most sustainable management practice(s) best enhanced soil productivity in the Northern Guinea Savanna zone Alfisols.

This study therefore aims to evaluate Maize/Legumes cropping practices for their effect on soil carbon sequestration in aggregates and soil carbon stock potentials in soils for sustainable productivity of Alfisol in northern Guinea Savanna of Nigeria. Specifically, the study aims to:

1. Evaluate Maize/legume cropping systems for soil carbon stock status at end of two year trial
2. To evaluate Maize/Legume cropping systems for organic carbon sequestration in aggregate fractions

2. MATERIALS AND METHODS

2.1 Description of the Study Area

This study was conducted during 2014 and 2015 rain-fed cropping seasons at the experimental farm of Institute for Agricultural Research (IAR), Samaru, Zaria (latitude 11°11'19.3"N and Longitude 7°37'02"E) in the Northern Guinea Savanna ecology of Nigeria (Fig. 1). Long-term mean annual rainfall of the study area is 986.5mm and is concentrated between May and October with a peak in August [20]. The mean daily air temperature (maximum and minimum) ranges between 15°C and 38°C [21]. Soil type of the study area was classified as Typic Haplustalf according to USDA Soil Taxonomy [22] as cited by [23] and Acrisol in the FAO-UNESCO legend as cited by [24] and [25]. The soils are low in inherent fertility, organic matter, cation exchange capacity (CEC) and dominated by low activity clays [12,26].

2.2 Treatments

The treatments; were (1) Sole Maize (M), (2) Sole Soybeans (S), (3) Sole *Desmodium* (D), (4) Maize/Soybeans Intercrop (MS), (5) Maize/D. *uncinatum* (MD), (6) Maize/ Strip crop Soybeans (MS 2:4), (7) Maize/Strip crop D. *uncinatum* (MD 2:4), laid out on a Randomize Complete Block Design (RCBD) replicated three times. Soybean variety used was IITA-TGX-1951, maize variety was quality protein maize (SAMMAZ 14) and *Desmodium* was; *Desmodium uncinatum.* The

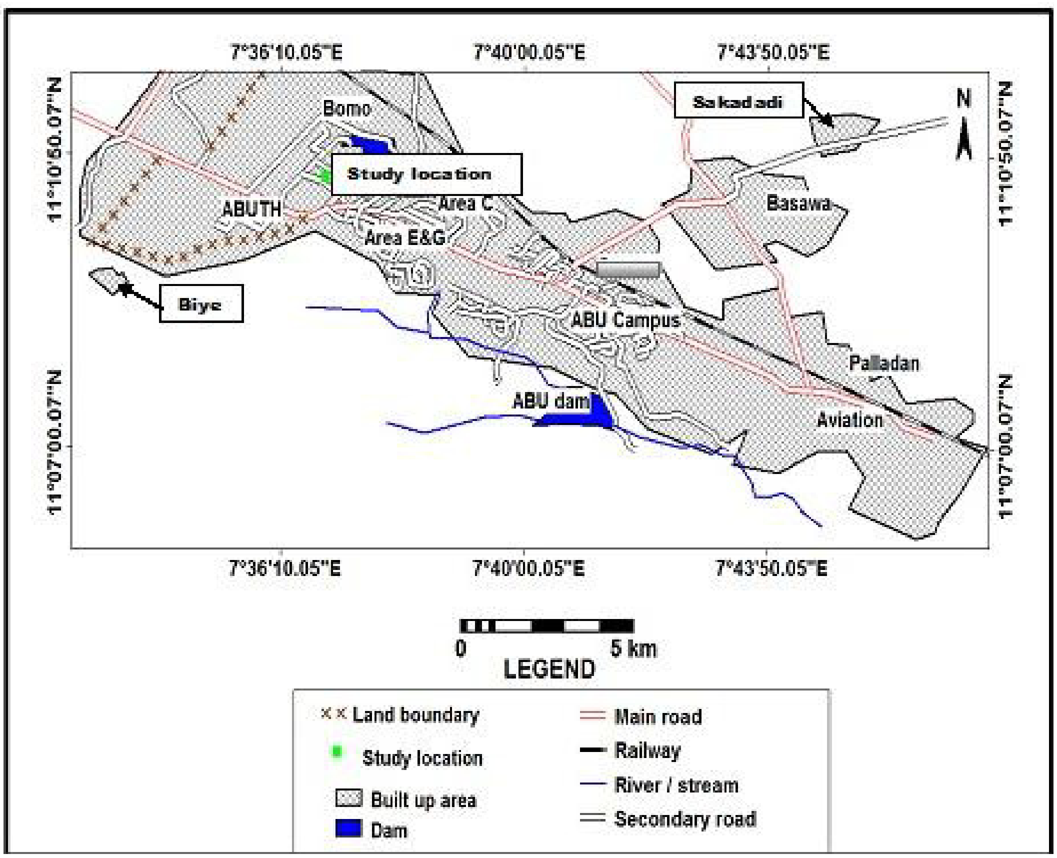

Fig. 1. Location map of study site at IAR, ABU, Zaria, Nigeria

field was ploughed, harrowed and ridged at 75 cm between ridge distances and size of the field was 50m by 35m which is 1750m^2 (0.175 ha). Plot size was 6m by 11m (66m^2). One maize plant was allowed on crest of the ridge at 25cm intra row and 0.75cm inter row distances while soybean and Desmodium were both drilled along ridge at 5 cm intra row and 75 cm inter row spacing. Weeding was done manually at 3 and 6 weeks after planting (WAP), 60 kg Nha^{-1}, 60 kg P_2O_5ha^{-1} and 60 kg K_2Oha^{-1} were basally applied at planting and top dressing was done with 60 kg Nha^{-1} at six weeks after planting with nitrogen sourced from Urea. Phosphorus was sourced from single super phosphate (SSP) and Muriate of potash was the source for potassium.

2.3 Soil Sampling Procedures

A total of 10 soil samples were taken from five points at depths 0-10 cm and 10-20 cm along two diagonals of the study field, homogenized, air-dried, ground and sieved through a 2mm sieve for laboratory analysis. The less than 2 mm fractions were analyzed for soil pH, particle size distribution, organic carbon, total nitrogen, available phosphorus, cation exchange capacity, exchangeable bases and exchangeable acidity to characterize initial properties of the soil. Also core soil samples were collected using 5 cm by 5 cm core samplers to determine bulk density of the soils. 50 g soil aggregates were obtained before trial establishment and in each treatment at harvest and assessed for aggregate stability and distribution using dry sieving methods. Carbon concentration in aggregate fractions was also determined from aggregate sizes in sieves and referred to as carbon sequestered in aggregates. Also, at 8 and 16 weeks after planting (WAP), core soil samples were collected using 5 cm by 5 cm core samplers for the analysis of bulk density to evaluate change in bulk density. Disturbed soil samples were obtained at 0-10 and 10-20 cm depths and core soil samples at 0-5 cm, 5-10 cm, 10-15 cm and 15-20 cm depths in plots/treatment and analyzed for organic carbon concentration and bulk density respectively at harvest to evaluate for soil organic carbon stock (SOC) in the area in each of 2014 and 2015.

2.4 Data Acquisition and Analytical Procedures

Particle size distribution was determined using the hydrometer method [27] and textural classes were obtained from textural triangle using the [28]) approach. Soil bulk density was determined by the [29] method. Aggregate stability was determined by dry sieving methods of [30], modified by [31]. Sieve sizes used were 1mm - 2mm and aggregates in these sieve sizes were recorded and evaluated while the bulk soil samples (50 g) were sieved with 5mm sieve. Aggregates less than 0.25 mm were not evaluated in this study. Aggregate fractions distribution were determined and mean weight diameter (MWD) of the aggregates were calculated as shown in (1) by summing product of mean diameter of aggregates and proportion of soil in each aggregate-size class [31].

$$\text{MWD} = \sum_{n=1}^{n} WiXi \qquad (1)$$

Where

X_i = proportional by weight of sand free aggregate

W_i = mean diameter of proceeding and preceding sieve

Soil organic carbon (SOC) stock was determined as a product of soil carbon of each depth, multiplied by depth, bulk density and 10000m^2 and divided by 1000 i.e.,

$$\text{SOC= (Org. C X d X Bd X10000)/1000 (t C ha}^{-1}\text{)} \qquad (2)$$

Where SOC=Carbon Stock of soil (t C ha^{-1}), Org C= organic carbon concentration (gkg^{-1}), Bd=Bulk density at the depth (Mgm^{-3}), 10,000m^2= 1ha, and 1000kg=1ton

Mean organic carbon concentration and SOC at the end of each year for the two years were obtained by dividing sum of the two year values by 2, while change in organic carbon and SOC were calculated from the difference between 2014 and 2015 organic carbon and SOC end of year values, divided by the 2014 value, and multiplied by 100, presented as percent change. i.e,

$$\text{\% Org. C Change= [(org 2014-org.2015)/org 2014] X 100} \qquad (3)$$

$$\text{\% SOC Change= [(SOC 2014-SOC 2015)/SOC2014] X 100} \qquad (4)$$

This consists of calculating carbon stock as a product of soil organic carbon (gkg^{-1}), bulk density (Mgm^{-3}) and depth (m) and multiplied by one hectare (1ha). Soil organic carbon sequestration was obtained from soil aggregates in each sieve size i.e., soil fraction contained in each of the sieve sizes. The soils used were obtained at depth 0-10 cm and 10-20cm depth. Soil pH was determined electrometrically at a ratio of 1:2.5 Soils to Water and $CaCl_2$ as described by [32]. Soil Organic Carbon was measured by wet oxidation method of Walkley and Black [33], and Available Phosphorus was measured by Bray No. 1 method described by [34] and [35]. Total Nitrogen was determined by the regular micro-Kjeldahl digestion method [36] and exchangeable acidity was determined by shaking soil in 0.01M KCl and filtrate was titrated with 0.1M NaOH [37]. Exchangeable bases (Ca, Mg, K and Na) were extracted with 1N NH_4OA_C [38]. Exchangeable Calcium (Ca) and Magnesium (Mg) were determined by EDTA titration methods [37]. Potassium (K) and Sodium (Na) was determined using flame photometry [39]. Cation Exchange Capacity (CEC) was determined by the1N Neutral Ammonium acetate (1N NH_4OA_C) method described by [40] method. After harvest in each of 2014 and 2015, soil samples were obtained from each plot and analyzed for organic carbon, organic carbon in aggregates and carbon stock. Also, core samples were obtained from plots and analyzed for bulk density, using the 5 cm by 5 cm core rings. Data obtained was subjected to Analysis of variance (ANOVA) using General Linear Model (GLM) procedure of SAS 9.3 Software [41]. Differences between means were separated using Duncan's Multiple Range Test at 5% level of probability.

3. RESULTS AND DISCUSSION

3.1 Initial Characteristics of Studied Soil

Bulk density (BD) of surface soils prior to experimentation range between 1.43 Mgm^{-3} to 1.57 Mgm^{-3} and is moderate in range to support sustainable agriculture (Table 1). Sand Fractions dominate the soil separates with values as high as 490 gkg^{-1} at the surface layers (0-10 cm) and 450 gkg^{-1} at the sub surface depths (10-20 cm). Silt value was 430 gkg^{-1} at the surface layers (0-10 cm), 460 gkg^{-1} in the sub surface layers (10-20 cm) and Clay value was 80 gkg^{-1} at the surface layers (0-10 cm) and 90 gkg^{-1} in the subsurface layers (10-20 cm). The Textural class according to USDA classification for surface and subsurface horizons was loam. Mean weight diameter (MWD) at the surface soil (0-10 cm) was 0.48 and was lower than that of subsurface (0.52) soil (10-20 cm) and suggests that surface soils could be more prone to erosion by wind and highly degraded for sustainable agricultural productivity.

Table 1. Initial physical and chemical properties of the experimental field

Soil property	Depth	
	0-10 cm	**10-20 cm**
Bulk density (Mgm^{-3})	1.43	1.57
Mean weight diameter	0.48	0.52
Soil moisture content (cm^3cm^{-3})	0.28	0.37
pH (H_2O)	5.8	6.80
pH ($CaCl_2$)	4.89	5.20
Avail. P(mg kg^{-1})	4.91	4.99
Organic C (gkg^{-1})	2.11	1.99
Total N (gkg^{-1})	0.50	0.40
CEC ($cmolkg^{-1}$)	7.75	7.50
Exch. Bases ($cmolkg^{-1}$)		
Calcium	2.20	2.30
Magnesium	0.59	0.62
Potassium	0.31	0.36
Sodium	0.10	0.27
$H^+ + Al^{3+}$($cmolkg^{-1}$)	0.05	0.05
Particle size distribution (gkg^{-1})		
Sand	490	490
Silt	430	460
Clay	80	90
Textural class	Loam	Loam
SOC (t C ha^{-1})	3.02	3.12

Soil pH in water was 5.80 at surface soils and 6.80 in the sub-surface depth, while pH in $CaCl_2$ at the soil surface was pH 4.89 and 5.20 in the sub-surface soils. The soils are therefore slightly acid and within the range for optimal nutrient uptake by plant roots [42]. Organic carbon values were higher at the surface (0-10 cm) layer (2.11 gkg^{-1}) and lower at subsurface soil (10-20 cm) layer (1.99 gkg^{-1}). Total Nitrogen of soils at surface layer was 0.50 gkg^{-1} and lower at the sub-surface with a mean value of 0.40 gkg^{-1}. Available phosphorus of the surface soils (0-10 cm) was 4.91 mg kg^{-1} and 4.99 mg kg^{-1} at the sub-surface soils (10-20 cm). Exchangeable calcium had a value of 2.20 cmol kg^{-1}at the surface layers (0-10 cm) and 2.30 cmol kg^{-1} at the sub-surface soils. Exchangeable Mg was higher at the sub-surface and lower at the surface soils with values of 0.62 cmol kg^{-1} and 0.59 cmol kg^{-1}respectively. Exchangeable K values were slightly low in both surface; 0.31 cmol kg^{-1} and 0.36 cmol kg^{-1} in the surface and sub-surface depths (Table 1). These values confirm [12, 13, 14, 15] that soils of Northern Guinea Savanna have inherent poor fertility status. Exchangeable Na values were generally low; value at surface was 0.10 cmol kg^{-1} and 0.27 cmol kg^{-1} at sub-surface layer. Exchangeable Acidity (H^+ + Al^{3+}) values at both surface and subsurface layer were less than 1.0 cmol kg^{-1}; suggesting that the soils had no acid problems. Cation Exchange Capacity (CEC) of the soils was 7.75 $cmolkg^{-1}$at the surface (0-10 cm) and 7.50 $cmolkg^{-1}$ at sub-surface layer (10-20 cm). Low CEC values of the experimental area (< 10 $cmolkg^{-1}$) suggests dominance of low activity clays and sesquioxides [43], as well as low soil organic carbon content (Table 1). Initial carbon stock shows low values of 3.02 and 3.12 t Cha^{-1} at the 0-10 and 10-20 com depths to conform poor soil quality status of soils of the Nigerian Savanna Alfisol [43], 16].

3.2 Effect of Cropping Systems on Soil Bulk Density (Bd) and Percent Change Over Two Years

Result of bulk density (Bd) for treatments in 2014 and 2015 years showing highest Bd resulted under sole maize (M) with value of 1.61 Mgm^{-3} at 8 and 1.48 Mgm^{-3} at 16 WAP 2014 is presented in Table 2. Lowest bulk density value was obtained in plots cropped with sole *Desmodium* (D); 1.48 Mgm^{-3} at 8 WAP and 1.39 Mgm^{-3} at 16 WAP. Perhaps, sole maize treatment caused more compaction on the soils relative to the other treatments, while sole *Desmodium uncinatum* best improved soil bulk density for roots growth and ramification [44]). Soil properties and processes such as moisture retention, water flow, root development, nutrient cycling and the sustainability of micro and macro organisms are negatively influenced by high bulk density values [45, 46]. Hence, soils under sole maize treatment (M) having high bulk density values, could impair moisture retention, water flow, root development, nutrient cycling [47, 44] and sustainability of micro and macro organisms activity to bestow a degraded status to the soils. At 8 and 16 WAP, there was no significant difference among the treatment in 2015 on bulk density conditions, though values decreased (improved) below 2014 records; perhaps due to improved management practice adopted in 2015.

Fig. 2 however shows that bulk density value reduced under mono-crop (M) maize by 1.94%, Sole Desmodium by -2.08%, Maize/Soybean by -4.0% and Maize/Soybean 2:4 by -4.03%. Bulk density increased (compaction) under Sole Soybean by 2.69% and Maize/Desmodium 2:4 by -2.06% in 2015 cropping season, to imply that bulk density best improved under MS 2:4, followed by MS over the cropping seasons.

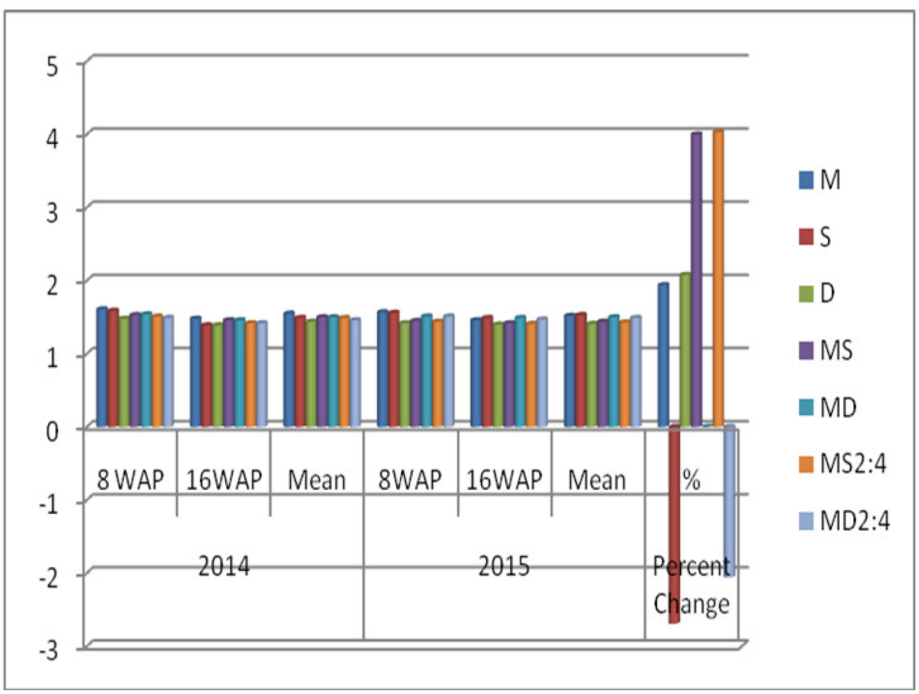

Fig. 2. Effect of cropping systems on soil bulk density (Mgm^{-3}) and percent change over two years; 2014-2015

Table 2. Effect of cropping systems on soil bulk density (Mgm^{-3}) and percent change over two years; 2014-2015

Treatments	2014			2015			% Change
	8WAP	16WAP	Mean	8WAP	16WAP	Mean	
	Mgm^{-3}						
M	1.61a	1.48a	1.55	1.57	1.46	1.52	1.94
S	1.59ab	1.39b	1.49	1.56	1.49	1.53	-2.69
D	1.48c	1.39b	1.44	1.42	1.40	1.41	2.08
MS	1.53bc	1.46b	1.50	1.45	1.42	1.44	4.00
MD	1.54abc	1.46b	1.50	1.51	1.49	1.50	0.00
MS2:4	1.51c	1.42b	1.49	1.44	1.41	1.43	4.03
MD2:4	1.49c	1.42b	1.46	1.51	1.47	1.49	-2.06
Mean	1.54	1.43	1.49	1.46	1.44	1.45	2.69
SE±	0.03	0.03		0.19	0.20		

Means with the same letter are not significantly different at 5% level of Probability using DMRT; M=sole maize, S=Sole soybean D=Sole Desmodium, MS= Maize/Soybean intercrop, MD=Maize/Desmodium intercrop, MS2:4=Maize/strip crop soybean and MD 2:4=Maize/Strip crop Desmodium, WAP=Weeks After Planting; Depth considered=0-20 cm

3.3 Effect of Cropping Systems on Mean Weight Diameter of Soil Aggregates and Percent Change Over 2014 and 2015

Maize/Soybean intercrop (MS) resulted in significantly ($P < 0.05$) greater mean weight diameter (MWD) than the other cropping systems, followed by Maize/Desmodium intercrop (0.6467) and Sole soybean (0.615). The least MWD resulted under sole maize and was not significantly different from treatment under D, MS 2:4 and MD 2:4 in 2014 (Table 3). However, aggregate stability or the distribution of stable aggregates is important to maintain a balance of air and water in the soil system and the development of plant roots. Hence, well-aggregated soils in good physical condition maintain the balance of air and water required to promote many other soil properties [48]. Therefore, the greater mean weight diameter under Maize/Soybeans and Sole Soybean suggest balanced air and water and plant roots development soil conditions for sustainable crop production. There was no significant difference in MWD under the treatment in 2015, though MWD generally increased across all the treatments in 2015, with Maize/*Desmodium* giving higher MWD (1.282). Table 3 also reveals that change in mean weight diameter over 2014 and 2015 was highest under Maize/Desmodium intercrop, followed by Sole Desmodium. Therefore, Maize/Desmodium, followed by Sole Desmodium cropping systems could cause improved soil aggregation in Northern Guinea Savanna Alfisols for sustainable crop production.

Table 3. Effect of cropping systems on mean weight diameter MWD) and percent change (%) over 2014-2015

Treatment	2014	2015	Change (%)
	MWD		%
M	0.5417b	1.0067	85.84
S	0.6150ab	1.1083	92.36
D	0.5633b	1.1200	98.83
MS	0.6467a	0.9317	44.07
MD	0.6040ab	1.2820	112.25
MS2:4	0.5683b	0.8567	50.75
MD2:4	0.5700b	1.0786	89.23
Mean	0.5944	1.0548	77.46
SE±	0.02	0.0001	

Means with the same letter are not significantly different at 5% level of probability using DMRT; Depth considered=0-20 cm, NB: M=sole maize, S=Sole soybean D=Sole Desmodium, MS=Maize/Soybean intercrop, MD=Maize/Desmodium intercrop, MS2:4=Maize/strip crop soybean and MD 2:4=Maize/strip crop Desmodium

3.4 Effect of Maize/Legume Cropping Systems on Bulk Density, Organic carbon (OC), Carbon stock (SOC) of soils within 2014 and 2015 and means across years

Fig. 3 shows that in 2014, Sole Maize resulted in significantly ($P<0.05$) higher bulk density, soil organic carbon and carbon stock (SOC) than the other legume-based treatments; except MD 2:4, that contributed significantly higher ($9.51 gkg^{-1}$) soil organic carbon and ($27.01\ t\ Cha^{-1}$) carbon stock to the soil. In 2015 however, Sole maize treatment resulted in reduced organic carbon and SOC, while MD 2:4 treatment resulted in significantly higher organic carbon (10.10gkg^{-1}) and SOC (29.69 t Cha^{-1}) than the other treatments. Fig. 3 therefore reveals that treatment MD 2:4 recorded significantly higher mean soil organic carbon (9.81gkg^{-1}) and SOC (28.35 t Cha^{-1}) over the two years of study. Maize /*Desmodium* intercrop (MD) resulted in lowest OC content, with value of 2.72gkg^{-1} in 2014 and 3.25gkg^{-1} in 2015. Treatment MD 2:4 had higher OC content in 2015 and the lowest was under MD intercrop. Also, mean organic carbon concentration over 2014 to 2015 was least under MD and highest under MD2:4 treatments. Also, mean carbon stock recorded was highest under MD 2:4 (28.35 t Cha^{-1}) and least under MD (8.82 t Cha^{-1}). Assessing the soil for percent change over 2014 and 2015 cropping seasons reveal that soil under mono-cropped (Sole) maize depreciated in soil organic carbon (6.77 %), suggesting degradation of the soils for sustainable crop production by over 6.0% of the 2014 value; a condition that could exacerbate global warming, atmospheric carbon dioxide enrichment and climate change occurrence in the study area. Also, carbon stock under mono-cropped maize (M) for the period of study depicted negative value (-8.03%) to confirm that the keys to successful soil carbon sequestration are increased plant growth and productivity, increased net primary production and decreased decomposition [49], 50] because; for example, the legume-based treatments all resulted in positive carbon stock in soil (Fig. 3), as against sole maize (M) that gave negative carbon stock. Increasing soil organic matter (SOM) is widely recognized as a means to increase agricultural production [51]. It would therefore be inferred that mono-cropping (M) maize resulted in negative change in carbon sequestration (stock), to suggest that continuous maize mono cropping would cause adverse organic carbon depletion and impoverished carbon stock for enhanced global warming, climate change and degraded soil quality for sustainable crop production.

3.5 Effect of Maize/Legume cropping systems on Organic Carbon sequestration in macro and micro aggregates and Percent Change over 2014 and 2015 seasons

Effect of Maize/Legume cropping systems on organic carbon (OC) content in (a) macro aggregates fractions (2.36-2.00mm) and (b) micro aggregates (2.00 mm-0.25 mm) during the 2014 and 2015 and percent change for the two years at Samaru are contained in Table 4. Results on the aggregate sizes show that adoption of maize-soybean sequestered the highest OC concentration in macro aggregates in each of the two years (2014 and 2015) as well as the change of carbon sequestered in the macro and micro aggregate fractions. This was followed

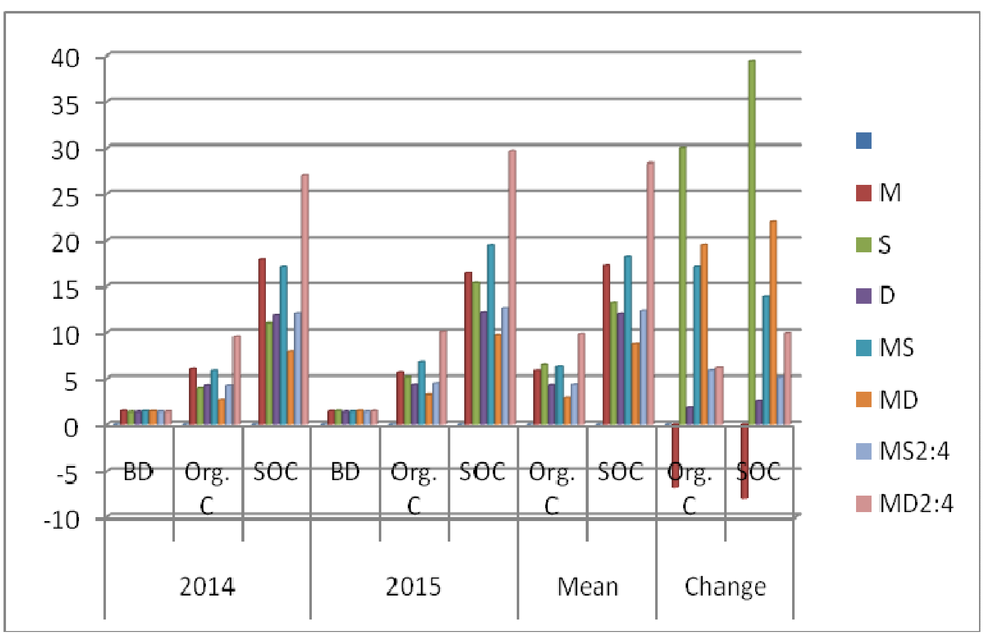

Fig. 3. Effect of maize/legume cropping systems on bulk density, organic carbon (OC), carbon stock (SOC) of soils within 2014 and 2015 and means across years

Table 4. Effect of Maize/Legume cropping systems on organic carbon (gkg^{-1}) sequestration in large and small macro aggregates and percent change (%) over 2014 and 2015 seasons

Treatments	2014		2015		% Change	
	MaAg	MiAg	MaAg	MiAg	MaAg	MiAg
M	0.70c	0.73c	0.76c	0.77c	8.57	5.48
S	0.63d	0.59d	0.64d	0.68e	1.59	15.25
D	0.49e	0.53e	0.57e	0.54f	16.33	1.89
MS	1.35a	0.87a	1.38a	0.93a	2.22	6.90
MD	0.39g	0.37g	0.40g	0.39g	2.56	5.45
MS 2:4	0.42f	0.49f	0.49f	0.72d	16.67	46.94
MD 2:4	0.78b	0.83b	0.90b	0.80b	15.39	-3.62
Mean	0.68	0.63	0.73	0.69	7.35	9.52
SE±	0.004	0.001	0.006	0.006		

Means with the same letter are not significantly different at 5 % level of probability using Duncan Multiple Range.= Significant. NB: MAag and MiAg= 2.36-2 mm and 2-0.25 mm respectively. Trt=Treatment, M=sole maize, S=Sole soybean D=Sole Desmodium, MS= Maize/Soybean intercrop, MD=Maize/Desmodium intercrop, MS2:4=Maize/strip crop soybean and MD 2:4=Maize/strip crop Desmodium*

by MD2:4 treatments that sequestered significantly higher organic carbon concentration in macro aggregates than the other treatments across the periods of observation. This suggests that the best strategies focus on the protection of soil organic carbon against further depletion and erosion, or the replenishment of depleted carbon stocks through certain management techniques [49] will involve legume/ Cereal cropping systems such as Maize/Soybean and Maize/Desmodium 2:4 systems. The least amount of organic carbon sequestered in macro aggregates was under MD intercrop. Also, M, D, MS 2:4 and MD 2:4 treatments sequestered more carbon in the macro aggregate fractions, suggesting that aggregates developed in these treatments would be more readily available for micro organisms to access. The Sole soybean and Maize/Soybean 2:4 treatments sequestered most carbon concentration in the micro aggregate fractions, while MD 2:4 treatments resulted in net negative carbon sequestration in micro aggregate fractions.

4. CONCLUSION

Findings from the study show that sole maize treatment caused more compaction of the soils relative to other treatments, while sole *Desmodium uncinatum* best improved soil bulk density. Maize/Soybean intercrop treatments resulted in significantly ($P<0.05$) highest organic carbon sequestered in macro aggregates in each of the two years (2014 and 2015) and was followed by Maize/Desmodium 2:4 treatments that were significantly higher than the rest other treatments with organic carbon sequestered in macro aggregates across the periods of observation. The least amount of organic carbon sequestered in macro aggregates resulted under Maize/Desmodium intercrop. Change in mean weight diameter of aggregates over the 2014 and 2015 was highest under Maize/Desmodium intercrop, followed by Sole Desmodium to suggest that these legume-based cropping systems could cause improved soil aggregates development in Savanna Alfisols for sustainable crop production. Sole (mono-crop) Maize resulted in significantly ($P<0.05$) higher bulk density and sequestered ($P<0.05$) higher organic carbon and carbon stock (SOC) than the other legume-based treatments in 2014; except MD 2:4, that contributed significantly higher (9.51 gkg^{-1}) organic carbon concentration and (27.01 t C ha^{-1}) carbon stock to the soil. However in 2015, MD 2:4 treatment resulted in significantly higher organic carbon concentration (10.10 gkg^{-1}) and SOC (29.69 t C ha^{-1}) than the other treatments. Over 2014 and 2015 cropping season, Sole (mono-crop) maize depreciated in soil organic carbon (6.77 %), suggesting degradation of the soils for sustainable crop production by over 6.0 % of the 2014 value to exacerbate global warming, atmospheric carbon dioxide enrichment and climate change in the study area. Also, carbon stock under sole maize for the period of study depicted negative value (-8.03 %) to confirm that the keys to successful soil carbon sequestration are increased plant growth and productivity, increased net primary production and decreased decomposition.

It is therefore inferred that Maize Strip Cropped with *Desmodium* (MD 2:4) had high Mean Weight Diameter (MWD 1.282), resulted in highest soil organic carbon concentration and carbon stock, sequestered high organic carbon in soil macro and micro aggregates and resulted in highest organic carbon concentration and soil carbon stock change over the study period more than the rest other treatments. These suggest therefore that MD2:4 treatments would best improve the soil conditions (quality/health) for sustainable crop production, mitigate climate change and global warming by sequestering soil organic carbon better than the other treatments.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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