

Carbon Sequestration and Soil Carbon Stock under Maize/Legume Cropping System in Alfisols of a Savanna Zone, Nigeria

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 ~~R~~andomized ~~c~~omplete ~~B~~lock ~~D~~esign (RCBD), replicated ~~three~~ 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* (M:D 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 treatment M resulted in 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 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.

Key Words: Soil Carbon Stock; Carbon sequestration in aggregates; Conservation Agriculture; Cereal/Legume cropping; Sustainable soil management

INTRODUCTION

Soil is a vital resource for producing food and fiber needed to support an increasing world population (~~Pappendick & Parr, 1992~~)[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 (CO₂). 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 (~~FAO, 2010~~)[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 (FAO, 2010; Giri *et al.*, 2007). 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 (Eswaran *et al.* 1993; Sombroek *et al.* 1993; Bajtes,

Comment [T1]: Carbon Sequestration and Soil Carbon Stock are often used interchangeably by authors. Thus, carbon sequestration, carbon stock, carbon storage and carbon pool are often used by authors to mean the same thing in many literatures. However, some authors refer to it as carbon pool (particularly used in modeling context where pool means a model compartment representing a C stock, such as that in soil or vegetation). Therefore, using carbon sequestration and soil carbon stock in this context is repetition. The author should choose one out of the two, either carbon sequestration or soil carbon stock. Preferably, the title can be adjusted to read: **Soil organic carbon concentrations and stocks under maize/legume cropping system.**

Comment [T2]: What is treatment M? state the name in full.

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1996; Velayutham *et al.* 2000) that have led to various quantitative estimates of soil organic carbon; including those reported by Bohn (1982), Buringh (1984) and Kimble *et al.* (1990). Reporting of organic carbon status of soils in terms of per cent distribution is one way (Giri *et al.*, 2007); yet, it does not show the stock and reservoir of organic carbon in a particular area. ~~For t~~ This study ~~soil organic carbon will be reported~~ soil organic carbon on unit area basis for a specified depth interval. Over exploitation of soil has resulted in exhaustion of intensive agricultural production systems, steady declining productivity (Reginald *et al.*, 2007) and impoverished soil quality. Therefore, the way in which soil carbon is managed will majorly have impact on plant growth, soil fertility, agricultural sustainability and environmental conservation.

~~Soils of Nigerian~~ The Northern Guinea Savanna Soils of Nigerian are intensively cultivated with maize, sorghum, cowpea, groundnut, cotton and soybeans, and have resulted in inherently poor fertility status (Jones and Wild, 1975; Lombin, 1987; Odunze, 2006), ~~have~~ poor moisture retention capacity, rich in low activity clays and sesquioxides (Odunze *et al.*, 2013) and ~~have~~ very low in organic carbon content (Odunze *et al.*, 2015). 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 (Abu and Abubakar, 2012). In the ~~Nigerian~~ Northern Guinea Savanna zone of Nigerian, soils ~~is~~ are frequently tilled at land preparation; with crop residues ~~are~~ harvested for fencing, fuel wood or livestock feed (Balasubramanian and Nnadi, 1980; Tanimu *et al.*, 2007), and 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 in the area is largely on maximizing crop yield with little or no attention to ~~resulting improve the~~ 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) that 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 and carbon stock potentials for sustainable soil 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

2.0 Materials and Methods:

2.1 Description of the Study Area

—This study was conducted in 2014 and 2015 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. Long-term mean annual rainfall of the study area is 986.5mm and is concentrated between May and October with a peak in August (Odunze, 2011). The mean daily air temperature (maximum and

Comment [T3]: Consider delete as this is a repetition of the above stated objective of the study.

minimum) ranges between 15°C and 38°C (Oluwasemire and Alabi, 2004). Soil type of the study area was classified as Typic Haplustalf according to USDA Soil Taxonomy (Soil Survey Staff, 1999) as cited by Ogunwale *et al.* (2004) and Acrisol in the FAO-UNESCO legend as cited by Valette and Ibanga (1984) and Uyovbisere *et al.* (2000). The soils are low in inherent fertility, organic matter, cation exchange capacity (CEC) and dominated by low activity clays (Jones and Wild, 1975; Odunze, 2003). ~~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, exchangeable and acidity. Also core soil samples were collected using 5cm by 5cm core samplers to determine bulk density of the soils. 50 g soil aggregates were obtained and assessed for aggregate stability using dry sieving methods. Carbon content in aggregate fractions was also determined from aggregates in sieves.~~

Comment [T4]: Check the spelling.

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 thrice. Soybean variety used was IITA-TGX-1951, Maize variety was quality protein maize (SAMMAZ 14) and *Desmodium* was; *Desmodium uncinatum*. Single Maize plant was allowed on ridge peaks at 25cm intra row and 0.75cm inter row distances while soybean and *Desmodium* were both drilled along ridge. Weeding was done manually at 3 and 6 weeks after planting (WAP), as 60 kg N_{ha}⁻¹, 60 kg P₂O₅ha⁻¹ and 60 kg K₂Oha⁻¹ were applied at planting and top dressing was done with 60kgNha⁻¹ at six weeks after planting. Nitrogen source was Urea, phosphorus was sourced from single super phosphate (SSP) and Muriate of potash was the source for potassium. Size of the field was 50m by 35m which is 1750m² (0.175 ha).

Comment [T5]: Report the field preparation before this statement follows.

Comment [T6]: Do you mean 0.75cm or 75 cm?

Comment [T7]: At what spacing were these two crops (soybean and *Desmodium*) drilled?

Comment [T8]: Were these fertilizer elements applied as basal application?

~~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, exchangeable and acidity. Also core soil samples were collected using 5cm by 5cm core samplers to determine bulk density of the soils. 50 g soil aggregates were obtained and assessed for aggregate stability using dry sieving methods. Carbon content in aggregate fractions was also determined from aggregates in sieves.~~

Particle size distribution was determined using the hydrometer method (Gee and Bauder, 1986) and textural classes were obtained from textural triangle using the USDA (1975) approach. Soil bulk density was determined by the Blake and Hartge (1986). Aggregate stability was determined by dry sieving methods of Van Bavel (1950), modified by Kemper and Rosenau (1986). 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. Aggregate size 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 (Kemper and Rosenau, 1986).

$$MWD = \sum_{i=1}^n W_i X_i \dots\dots\dots \text{eqn (1)}$$

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 10000m² and divided by 1000 i.e.,

$$SOC = (\text{Org. C} \times d \times \text{Bd} \times 10000) / 1000 \text{ (t Cha}^{-1}\text{)} \dots\dots\dots (2)$$

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

Mean organic carbon content and SOC at the end of each year for the two years were obtained by dividing sum of the year values and dividing 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.,

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

$$\% \text{ SOC Change} = [(\text{SOC 2014}-\text{SOC 2015})/\text{SOC 2014}] \times 100 \dots \dots \dots (4)$$

This consists of calculating carbon stock as a product of soil organic carbon (gkg^{-1}), bulk density (Mgm^{-3}) and depth (m) and multiplies 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 of 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 Henderson *et al.* (1993). Soil Organic Carbon was measured by wet oxidation method of Walkley and Black (Juo, 1979), and Available Phosphorus was measured by Bray No. 1 method described by Brady and Kurtz (1945) and Jackson (1962). Total Nitrogen was determined by the regular micro-Kjeldahl digestion method (Bremner and Mulvaney, 1982) and exchangeable acidity was determined by shaking soil in 0.01M KCl and filtrate was titrated with 0.1M NaOH (Agbenin, 1995). Exchangeable bases (Ca, Mg, K and Na) were extracted with 1N NH_4OAc (Chapman, 1965). Exchangeable Calcium (Ca) and Magnesium (Mg) were determined by EDTA titration methods (Agbenin, 1995). Potassium (K) and Sodium (Na) was determined using flame photometry (Anderson and Ingram, 1993). Cation Exchange Capacity (CEC) was determined by the 1N Neutral Ammonium acetate (1N NH_4OAc) method described by Rhoades (1982). 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 (SAS, 2011). Differences between means were separated using Duncan's Multiple Range Test at 5% level of probability.

Comment [T9]: Better written as organic carbon concentration (expressed in % or g kg^{-1}) and soil organic carbon stock (expressed in Mg/ha or t Cha^{-1}).

Comment [T10]: This statement is confusing and not clear. Ordinarily, the mean soil organic carbon (SOC) concentration and stock in the 20 cm depth should be obtained by summing SOC concentrations and stocks in the 0–10 and 10–20 cm depth intervals and dividing by two.

Comment [T11]: Move to the appropriate place based on my earlier comment.

3.0 RESULTS and DISCUSSION

3.1 ~~PreInitial Soil Condition:~~ Characteristics of Studied Soil

Soil Physical and chemical properties

Comment [T12]: Consider delete

— 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} in 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 (0-10cm) 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 degradation for sustainable agricultural productivity than the subsurface depths.

Comment [T13]: Considering your statement above (that the soil is dominated by sand, could you say that the soil been prone to wind erosion was as a result of coarseness nature of the soil? If not, reverse that statement.

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 (Horst, 1989). Organic carbon values were higher at the surface (0-10 cm) layer (2.11gkg^{-1}) and lower at subsurface soil (10-20 cm) layer (1.99gkg^{-1}). Total Nitrogen of soils at surface layer was 0.50gkg^{-1} and lower at the sub-surface with a mean value of 0.40gkg^{-1} . Available phosphorus of the surface soils (0-10 cm) was 4.91mg kg^{-1} and 4.99mg kg^{-1} at the sub-surface soils (10-20 cm). Exchangeable calcium had a value of 2.20cmol kg^{-1} at the surface layers (0-10 cm) and 2.30cmol kg^{-1} at the sub-surface soils. Exchangeable Mg was higher at the sub-surface and lower at the surface soils with values of 0.62cmol kg^{-1} and 0.59cmol kg^{-1} respectively. Exchangeable K values were slightly low in both surface; 0.31cmol kg^{-1} and 0.36cmol kg^{-1} in the surface and sub-surface depths (Table 1). These values confirm Jones and Wild (1975), Lombin (1987), Odunze (2006); Odunze *et al.* (2013) that soils of northern Guinea Savanna have inherent poor fertility status. Exchangeable Na values were generally low; value at surface was 0.10cmol kg^{-1} and 0.27cmol kg^{-1} at sub-surface layer. Exchangeable Acidity ($\text{H}^+ + \text{Al}^{3+}$) values at both surface and subsurface layer were less than 1.0cmol kg^{-1} ; suggesting that the soils had no acidic problems. Cation Exchange Capacity (CEC) of the soils was 7.75cmolkg^{-1} at the surface (0-10 cm) and 7.50cmolkg^{-1} at sub-surface layer (10-20 cm). Low CEC values of the experimental area ($< 10\text{cmolkg}^{-1}$) suggests dominance of low activity clays and sesquioxides (Odunze *et al.*, 2014), 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~~-cm depths to conform poor soil quality status of soils of the Nigerian Savanna Alfisol (Odunze *et al.*, 2014, 2015).

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 ($\text{cm}^3\text{cm}^{-3}$)	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
$\text{H}^+ + \text{Al}^{3+}$ (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 Physical Properties Following Experimentation

3.2 Effect of cropping systems on soil bulk density (Bd) and Percent Change over two years:

Table 2 presents ~~result the effect of cropping systems/treatments of on~~ bulk density (Bd) for ~~treatments in~~ 2014 and 2015 years, ~~showing with the~~ highest Bd ~~resulted under obtained in~~ sole maize (M) plots with value of 1.61Mgm^{-3} at 8 and 1.48Mgm^{-3} at 16 WAP 2014. Least bulk density value ~~resulted under was obtained in plots cropped with~~ sole *Desmodium* (D); (1.48Mgm^{-3} at 8WAP and 1.39Mgm^{-3} at 16WAP). 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 (Lal and Shukla, 2005). ~~Studies have shown that~~ 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 (Arshad *et al.*, 1996; Arshad & Coen, 1992). Hence, soils under sole maize treatment (M) having high bulk density values, could impair moisture retention, water flow, root development, nutrient cycling (Ike, 1987; Lal and Shukla, 2005) 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.

Figure 1 however shows that bulk density improved under sole 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% to imply that bulk density best improved under MS 2:4, followed by MS over the 2014 to 2015 cropping seasons.

Comment [T14]: Was the bulk density of the soil determined at intervals during the crops growth stage? If yes, what was the reason behind this practice? Note also that it was not reported as such in the materials and methods section, that soil sampling was done at intervals during the crops growth stage and the reason behind the practice.

Comment [T15]: See comment above.

Comment [T16]: Not clear. Recast the two sentences to give better meaning.

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

Treatment	2014			2015			Percent Change
	8 WAP	16WAP	Mean	8WAP	16WAP	Mean	
	Mgm^{-3}						%
M	1.61a	1.48a	1.55	1.57	1.46	1.52	1.94
		1.39b	1.49			1.53	-2.69
S	1.59ab			1.56	1.49		
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

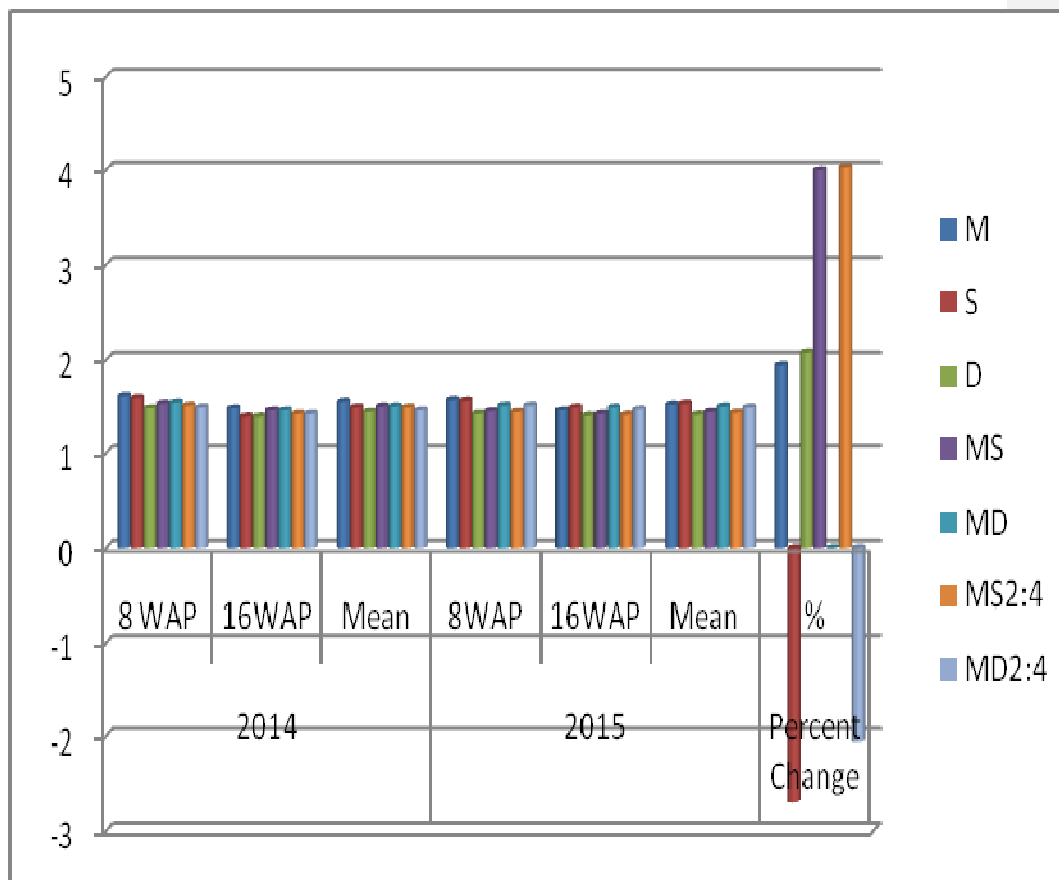


Fig. 1: Effect of cropping systems on Soil Bulk density (Mgm^{-3}) and Percent Change over two years; 2014-2015

3.3 Effect of cropping systems on mean weight diameter of soil aggregates and percent change over 2014 and 2015

Table 2 shows that 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 obtained in sole maize plots and though was not significantly different from treatment under D, MS 2:4 and MD 2:4 in 2014. 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 (Lowery *et al.*, 1996). Therefore, the greater mean weight diameter under Maize/Soybeans and Sole Soybean cropping pattern 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). Figure 2 however reveals that change in mean weight diameter over between 2014 and 2015 was highest under Maize/Desmodium intercrop, followed by Sole Desmodium, while the least value was observed in?. Therefore, Maize/Desmodium, followed by Sole Desmodium cropping

Comment [T17]: Incomplete sentence.

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*

Comment [T18]: Why did you choose to use standard error mean as against LSD value?

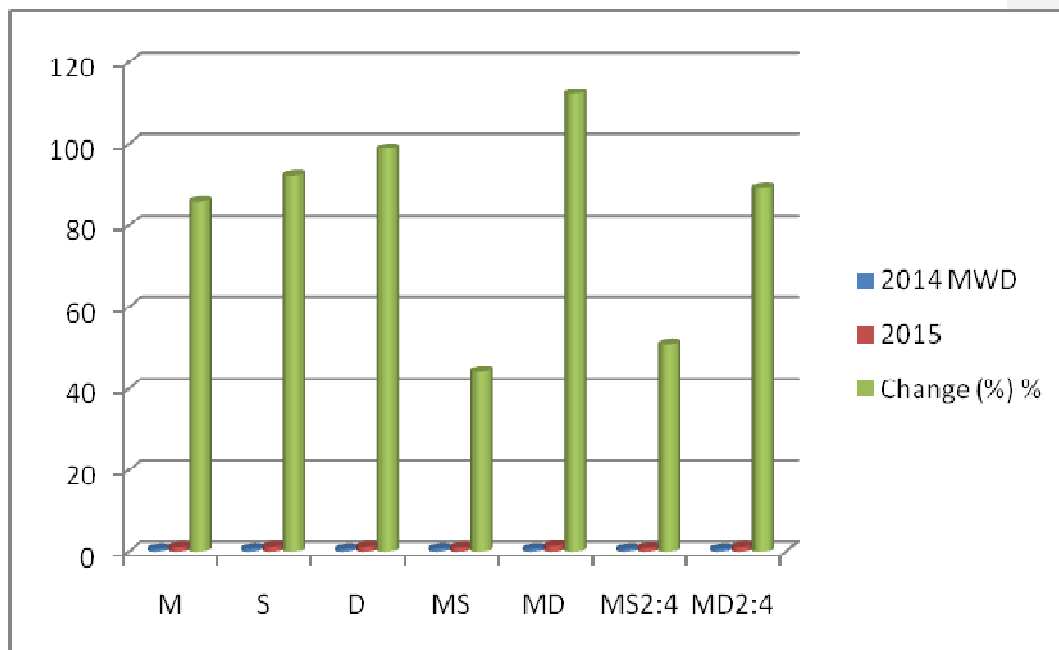


Fig 2: Effect of Cropping Systems on Mean Weight Diameter (MWD) and Percent Change (%) over 2014-2015

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

Table 4 shows that in 2014, Sole 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; except MD 2:4, that sequestered significantly higher (9.51 g kg^{-1}) soil organic carbon and (27.01 t Cha^{-1}) soil carbon stock to the soil. In 2015 however, Sole maize treatment resulted in reduced organic carbon and SOC, while MD 2:4 treatment sequestered significantly higher organic carbon (10.10 g kg^{-1}) and SOC (29.69 t Cha^{-1}) than the other treatments (Table 4). Figure 3 therefore reveals that treatment MD 2:4 sequestered significantly higher mean soil organic carbon (9.81 g kg^{-1}) and SOC (28.35 t Cha^{-1}) over the two years of study. Maize /*Desmodium* intercrop (MD) resulted in least OC content, with value of 2.72 g kg^{-1} in 2014 and 3.25 g kg^{-1} in 2015. Treatment MD 2:4 had higher OC content in 2015 and the least was under MD intercrop. Figure 3 therefore reveals that mean organic carbon over 2014 to 2015 was least under MD and highest under MD2:4 treatments. Also, mean carbon stock sequestered 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 season reveal that 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 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 (Anikwe, 2010; Peters and Szilagyi, 2006) because; for example, the legume-based treatments all sequestered positive carbon stock in soil (Fig 3), as

Comment [T19]: Bulk density was presented in Table 2 above, why is the repetition here? If there will be need for this, it should be presented as a correlation or regression analysis which must be in graphic form. Therefore, modify the content of Table 4.

against sole maize (M) that sequestered negative carbon stock. Increasing soil organic matter (SOM) is widely recognized as a means to increase agricultural production (James *et al.*, 1999). It would therefore be inferred that Sole Maize resulted in negative change in carbon sequestration (stock), to suggest that continuous sole maize 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.

Table 4: Effect of Maize/Legume Cropping System on Bulk Density, Organic Carbon and Carbon Stock: 2014-2015

Trt	2014			2015			Mean		Change	
	BD	Org. C	SOC	BD	Org. C	SOC	Org. C	SOC	Org. C	SOC
	Mgm ⁻³	gkg ⁻¹	t.Cha ⁻¹	Mgm ⁻³	gkg ⁻¹	t.Cha ⁻¹	gkg ⁻¹	t.Cha ⁻¹	%	
M	1.48a	6.06b	17.94	1.46	5.65c	16.50	5.86	17.22	-6.77	-8.03
S	1.39b	3.96de	11.01	1.49	5.15bc	15.35	6.54	13.18	30.05	39.42
D	1.39b	4.27d	11.87	1.40	4.35c	12.18	4.31	12.03	1.87	2.61
MS	1.46ab	5.85c	17.08	1.42	6.85b	19.45	6.35	18.27	17.09	13.88
MD	1.46ab	2.72e	7.94	1.49	3.25c	9.69	2.99	8.82	19.49	22.04
MS2:4	1.42ab	4.25d	12.07	1.41	4.50c	12.69	4.38	12.38	5.88	5.14
MD2:4	1.42ab	9.51a	27.01	1.47	10.10a	29.69	9.81	28.35	6.20	9.92
Mean	1.43	5.23	14.96	1.44	5.69	16.39	5.46	15.68	8.80	9.56
SE±	0.03	0.46		0.20	0.67					

Means with same letter are not significantly different at (P<0.05) using DNMR; Trts = Treatments; OC= Organic carbon; SOC= Carbon Stock in Soils; BD= Bulk density

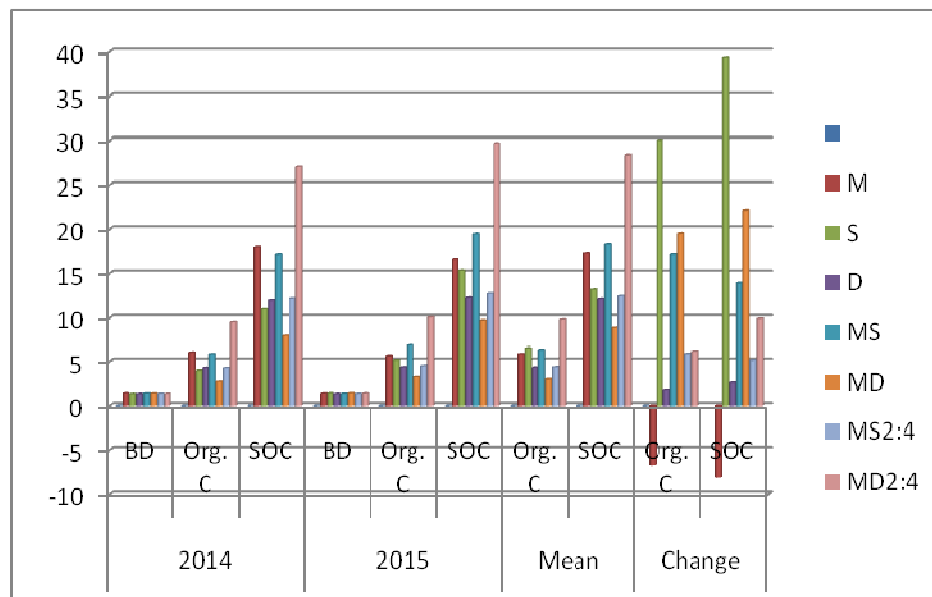


Fig. 3: Effect of Maize/Legume Cropping Systems on Bulk Density, Organic carbon (OC), Carbon stock (SOC) of soils within 2014 and 2015 and means across years

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

Table 5 shows effect of Maize/Legume cropping systems on organic carbon (OC) content in large (a) or macro aggregates (2.36-2.00mm) and small (b) or micro aggregate (2.00mm-0.25mm) during the 2014 and 2015 and percent change within the two years at Samaru. Resulting aggregates show that adoption of maize-soybean sequestered the highest OC content in large (macro) aggregate in each of the two years (2014 and 2015) as well as the change of carbon sequestered in the large and small aggregate fractions. This was followed by MD2:4 treatments that sequestered significantly higher soil organic carbon amount in macro aggregates than the other treatments across the periods of observation study. This suggests that the best strategies focus on in the protection of soil organic carbon against further depletion and erosion, or the replenishment strategy of depleted soil carbon stocks is through certain management-cropping techniques (Anikwe, 2010) which will involve legume/Cereal cropping systems such as Maize/Soybean and Maize/Desmodium 2:4 systems. The least amount of organic carbon sequestered in large macro aggregate 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 more readily be available for micro organisms to access. The Sole soybean and Maize/Soybean 2:4 treatments sequestered most carbon in the micro aggregate fraction (Fig. 4), while MD 2:4 treatments resulted in net negative carbon sequestration in micro aggregate fractions.

Comment [T20]: What happened to aggregate size of <0.25 mm?

Comment [T21]: Reframe this section of the sentence to give a meaning to the sentence.

Table 5: 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

Treatment	2014		2015		% Change	% 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: **MAg** and **MiAg**= 2.36-2mm and 2-0.25mm 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*.

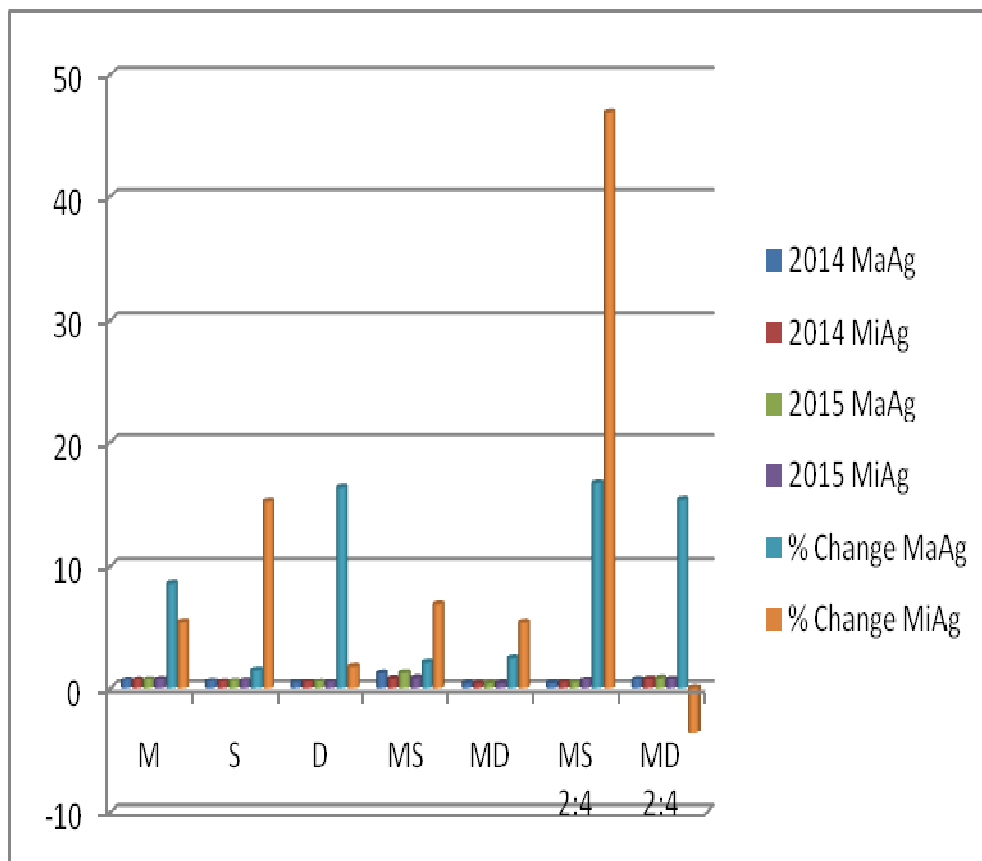


Fig. 4: Effect of Maize/Legume cropping systems on Organic Carbon (gkg^{-1}) sequestration in large and small macro aggregates and Percent change (%) over 2014 and 2015 seasons

4.0 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 ($P < 0.05$) higher organic carbon sequestered in large (macro) aggregate 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 large macro aggregate ~~resulted under~~ was found in Maize/Desmodium intercrop. Change in mean weight diameter of aggregates over the 2014 and 2015 was highest ~~under~~ in Maize/Desmodium intercrop, followed by Sole Desmodium. ~~to~~ This suggests that these cropping systems could cause improved soil aggregates development in Savanna Alfisols for sustainable crop production. Sole Maize ~~resulted in~~ significantly ($P < 0.05$) gave higher bulk density and sequestered ($P < 0.05$) higher organic carbon and carbon stock (SOC) than the other legume-

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based ~~treatments~~ cropping pattern in 2014; except MD 2:4, that contributed significantly higher (9.51gkg^{-1}) organic carbon and (27.01 t Cha^{-1}) carbon stock to the soil. In 2015, MD 2:4 treatment sequestered significantly higher soil organic carbon (10.10gkg^{-1}) and SOC (29.69 t Cha^{-1}) than the other treatments. Over 2014 and 2015 cropping season, Sole maize depreciated in soil organic carbon by $+6.77\%$, 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 values under in sole maize plots 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), sequestered highest soil organic carbon and carbon stock, sequestered high organic carbon in soil macro and micro aggregates and resulted in highest organic carbon and carbon stock change over the study period more than the rest other treatments. These suggested 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 carbon better than the other treatments.

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Comment [T22]: Not clear.

Comment [T23]: This was wrongly stated. Sequestering soil organic carbon is different from soil organic carbon concentration inputs. Reconcile the statement.

Comment [T24]: Not clear.

Comment [T25]: See my earlier comments

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Comment [T26]: Confusion, reconcile these three terms or key words to avoid confusing readers. Note that sequestration is a term that has to do with reducing atmospheric carbon IV oxide through increased soil carbon stock. Carbon sequestration and carbon stock mean the same as earlier stated in my correction on the topic.

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