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# Soil Quality, Carbon Sequestration and Yield of Maize (*Zea mays* L.) under Maize/Legume Cropping System in Alfisols of a Savanna Zone, Nigeria

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## Abstract

The role of maize-legume cropping system on soil quality, carbon sequestration and yield of maize in a Northern Guinea Savanna Alfisol, Nigeria was assessed in 2014 and 2015 rain-fed cropping seasons. The experiment was a Randomized Complete Block Design (RCBD), replicated three times and treatments were Sole (Mono crop) 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, available phosphorus, total nitrogen, soil pH, and CEC, Bulk density, Soil moisture, mean weight diameter and grain yield of Maize. Results show that mean soil acidity (pH water, 6.37; pH $CaCl_2$, 5.78), mean organic carbon (5.23 to 5.69 $g \cdot kg^{-1}$) and mean total nitrogen improved (0.66 $g \cdot kg^{-1}$) in 2015 over values in 2014. Mean weight diameter (MWD) increased from 0.59 in 2014 to 1.05 in 2015; indicating a better aggregation across treatments. Treatment M resulted in significantly higher bulk density (Bd) than other treatments at 8 weeks after planting (WAP) and 16WAP, suggesting that soils under mono-crop maize were impaired for sustainable crop production. Soil organic carbon (SOC) sequestered in macro aggregates under MS (1.38 $g \cdot kg^{-1}$) was significantly higher than the other treatments. Best maize grain yield (GY) was under sole maize (M) and maize strip cropped with *Desmodium* (*MD*2:4) (3.13 $t \cdot ha^{-1}$ and 2.90 $t \cdot ha^{-1}$ in 2015, respectively). Maize strip cropped with *Desmodium* and maize/soybean intercrop enhanced better soil chemical and physical properties than sole maize. Soil quality (SQ) under MD2:4 ranked best (SQ1) for sustainable maize grain production and environmental conservation. Therefore, land use strategies that focus protection of soil organic carbon against further depletion and erosion, contribute nitrogen and/or replenishment of depleted carbon stocks through management techniques that involve legume/cereal cropping systems are advocated for sustainable agricultural production in the Nigerian Savanna zone Alfisols.

**Keywords**

Soil Quality, Carbon Sequestration, Alfisols, Cropping Systems, Sustainable Agriculture

## 1. Introduction

Soil is a vital resource for producing food and fiber needed to support increasing world population [1]. However, degradation of soil as a consequence of improper land use management practices poses serious threat to sustainable agriculture, resulting in the quest for appropriate soil management strategy. Over exploitation of soil has resulted in exhaustion of intensive agricultural production systems, steady declining productivity [2] and impoverished soil quality. Strategy for increasing and sustaining crop yields at a high level must include integrated approach to management of soil quality and fertility, recognizing that soils are the foundation and storehouse of most plant nutrients essential for plant growth [3]. Therefore, the way in which nutrients and quality are managed will majorly impact on plant growth, soil fertility and agricultural sustainability.

Soil quality and fertility are of fundamental importance in sustainable agricultural production and are increasingly becoming central in policy decisions on food security, poverty reduction and environmental management. Protection of soil quality under intensive land use and fast economic development is a major challenge for sustainable resource use in the developing world [4]. Natural Resources Conservation Services [5] noted that the six components of soil quality management are: enhanced organic matter, avoid excessive tillage, manage pest and nutrients efficiently, prevent soil compaction, keep the ground covered and diversify cropping systems. However, 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 [6] [7] [8] have poor moisture retention capacity, rich in low activity clays and sesquioxides [9] and have very low organic carbon content [10]. The soils are therefore in a degraded condition to support sustainable agricultural production and require appropriate integrated management practices that will enhance quality of the soils. Due to the fragile nature of the soil, they degrade rapidly under continuous and intensive cultivation [11].

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 [12] [13], and are not returned to restore soil quality and fertility. Continued intensive cultivation, coupled with annual non-return of crop residues to the soil has conferred impoverished soil quality status and necessitated the study on soil quality, carbon sequestration and grain yield of maize. Commonly, cereal-based cropping systems in the Northern Guinea Savanna of Nigeria practice legume relays into cereals, strip cropping of cereals with legumes, mono-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 quality and fertility status that would support subsequent cropping. The present study therefore aims to evaluate quality, carbon sequestration in soils and grain yield of maize under varying cereal/legume practices with a view to determine management practices most suitable for soil quality improvement and sustainable maize grain yields in the Northern Guinea Savanna zone Alfisols; thus contribute towards agricultural production sustainability and environmental conservation.

This study therefore aims to evaluate Maize/Legumes cropping practices for their effect on soil quality, carbon sequestration potentials for sustainable maize grain yield. Specifically, the study aims to achieve:

1) The assessment of Maize/legume cropping systems for soil quality improvement at end of trial;

2) The evaluation of Maize/Legume cropping systems for organic carbon sequestration in soil aggregate fractions;

3) The evaluation of Maize/Legume cropping systems for maize grain and stover yield.

## 2. Materials and Methods

### 2.1. Description of the Study Area, Weather and Soil Condition

During the 2014 and 2015 rain-fed cropping seasons, this experiment was executed at the experimental farm of Institute for Agricultural Research (IAR) in Ahmadu Bello University (ABU), Samaru, Zaria; located at latitude 11˚11'19.3"N and Longitude 7˚37'02"E, in the Northern Guinea Savanna ecology of Nigeria (**Figure 1**). Long-term mean annual rainfall amount of the study area was given as 986.5 mm, which concentrates between May and October and peaks in August [14]. Mean diurnal air temperature (maximum and minimum) in the agro-ecology evaluated by [15] was said to range between 15˚C and 38˚C. Also, [16] classified soil within the study area as Typic Haplustalf in the USDA Soil Taxonomy system [17] while [18] and [19] classified the soils as Acrisol in the FAO-UNESCO legend. The soils have low inherent fertility, organic matter, cation exchange capacity (CEC) and dominated by low activity clays [16] [20].

### 2.2. Soil Sampling, Treatments and Analytical Procedures

#### 2.2.1. Soil Sampling Procedures

A total of 10 soil samples were taken from five points at depths of 0 - 10 cm and 10 - 20 cm along the diagonals of the field, homogenized, air-dried, ground and sieved through a 2 mm sieve for laboratory analysis. The less than 2 mm fractions were analyzed for soil pH, particle size distribution, organic carbon, total

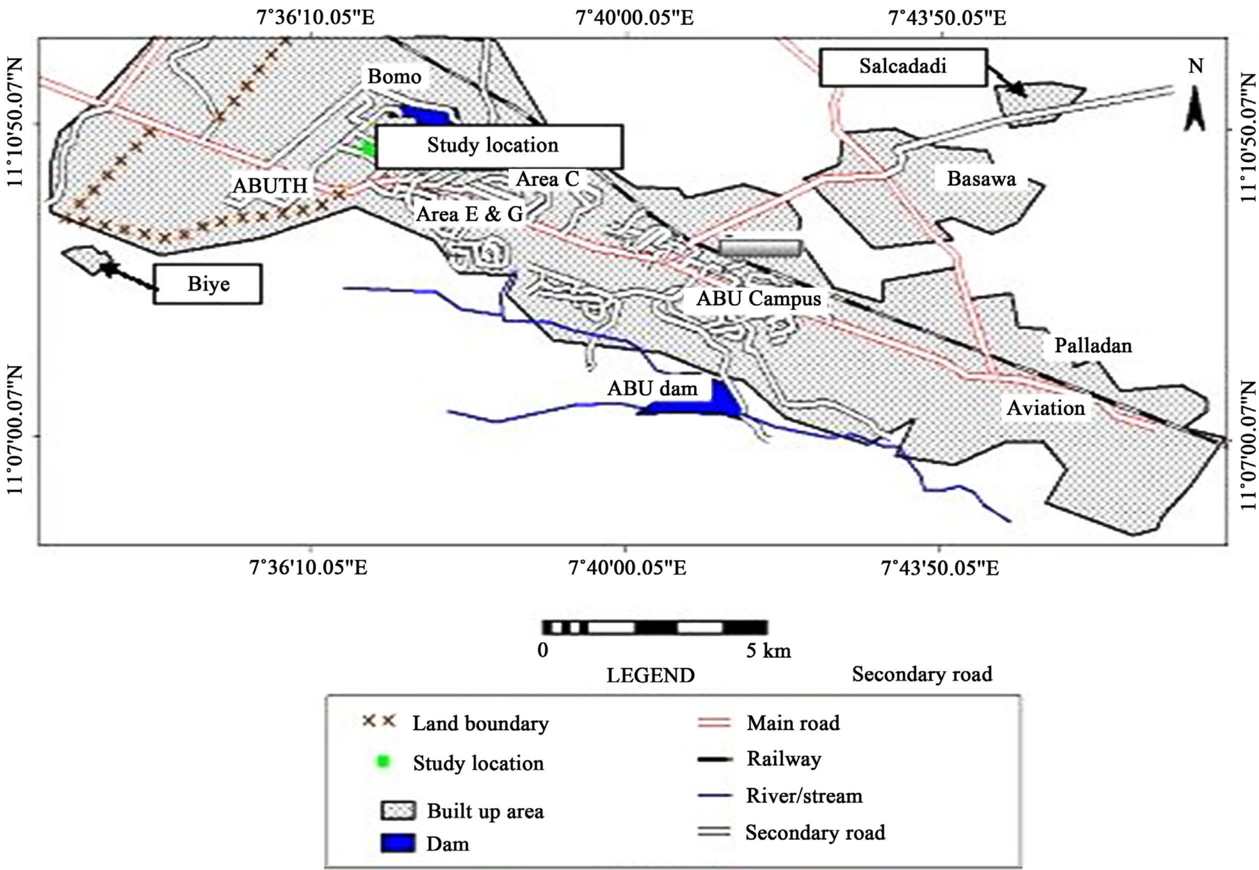


**Figure 1.** Location map of study area in Zaria, Northern Guinea Savanna.

nitrogen, available phosphorus, cation exchange capacity, exchangeable bases and exchangeable acidity to characterize initial properties of the soil. Also core samples were collected using 5 cm by 5 cm core samplers to determine bulk density and moisture content. Soil aggregates were obtained and assessed for aggregates stability using dry sieving methods at harvest and carbon content concentration in aggregate fractions were determined from aggregates retained in sieve sizes. Also, at 8 and 16 weeks after planting (WAP), undisturbed core soil samples were obtained from each treatment at 0 - 5, 5 – 10, 10 - 15 and 15 - 20 cm depths and analyzed for bulk density. From each treatment also, soil samples were obtained at 0 - 10 and 10 - 20 cm and analyzed for pH, available phosphorus, total nitrogen, exchangeable cations, cation exchange capacity and organic carbon concentration at harvest.

#### 2.2.2. Treatments

The treatments were laid out on the field on Randomize Complete Block Design (RCBD). Soybean variety used was IITA-TGX-1951, Maize variety was quality protein maize (SAMMAZ 14) and *Desmodium* was *Desmodium uncinatum.* One maize plant was allowed on ridge crest at 25 cm intra row and 0.75 cm inter row distances while soybean and Desmodium were both drilled along ridge slopes at 5 cm intra-row and 75 cm inter row spacing. Weeding was done manually at 3 and 6 weeks after planting (WAP). The 60 kg N $ha^{-1}$, 60 kg $P_2O_5$ $ha^{-1}$ and 60 kg $K_2O$ $ha^{-1}$ were basally applied at planting and top dressing was done with 60 kg N $ha^{-1}$ at six weeks after planting; using urea fertilizer as nitrogen source. Phosphorus was sourced from single super fertilizer, while potassium was sourced from muriate of potash. Main treatments of the experiment were: 1) Sole (monocropped) 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). Size of the field was 50 m by 35 m which is 1750 $m^2$ (0.175 ha) and plot size was 6 by 11 $m^2$ (66 $m^2$). Maize cobs were air-dried, ears threshed, grains cleaned and weight of grain recorded on the basis of grain yield per treatment and converted to grain yield in tons per hectare. Also, stover yield of maize was assessed from air-dried maize stover in net plots of two ridges in each treatment replicate, weighed and calculated in ton per hectare ($t \cdot ha^{-1}$).

#### 2.2.3. Data Acquisition and Analytical Procedures

Soil Quality indicators selected for a minimum data set in this study were relevant soil data [1] [21] [22] obtained in this study for Nigerian Northern Guinea Savanna zone Alfisols. They are (1) data on total nitrogen, organic carbon, available phosphorus, pH, mean weight diameter of aggregates, carbon sequestered in aggregate fractions, bulk density of soils after crop harvest and data on maize grain yield for study period. Soil Quality was assessed using [23] equation; *i.e.*

$$SQ = f\left(SP, P, E, H, ER, BD, FQ, MI\right) \quad (1)$$

where SQ = soil quality, SP = soil properties, P = potential productivity, E = environmental factors, H = Health (Human/Animals), ER = erodibility, BD = Biodiversity, FQ = food quality and MI = Management input. A score scale of 1 to 7 was used in the assessment of parameters in the model; where 1 is the best and 7 is worst condition. However, E, H, ER, FQ and MI were each scored 1.0 because the research field used for the experiment had been on a long-term research use (1922 to date) and is being optimally managed to satisfy optimal environmental conditions for sustainability, health factors for human and livestock optimal food quality obtained, biodiversity and input management [9]. Therefore, SQ = f(SP,P) was used to assess quality of Alfisols in the Nigeria Guinea Savanna Zone at the end of 2015 rain-fed cropping season. Particle size distribution was determined using the hydrometer method [24] and textural classes were obtained from the textural triangle using the [25] approach. Soil bulk density was determined by the [26] method. Aggregate stability was determined by dry sieving methods of [27], modified by [28]. Sieve sizes used were 1 mm - 2 mm and aggregates in these sieve sizes were recorded and evaluated while the bulk samples were sieved with 5 mm sieve. Aggregate size fractions distribution were determined and mean weight diameter (MWD) of the aggregates were calculated by summing the product of mean diameter of aggregates and proportion of soil in each aggregate-size class [28], as given in Equation (2), to define stability of the soil aggregates.

$$\text{MWD} = \sum_{n=1}^{n} W_i X_i \tag{2}$$

where $X_i$ = proportional by weight of sand free aggregate

$W_i$ = mean diameter of proceeding and preceding sieve

Soil organic carbon (SOC) was determined by using values of soil carbon obtained from each sieve size *i.e.* soil contained in each of the sieve sizes. The soil used was obtained at depth 0 - 10 cm and 10 - 20 cm depth. Soil pH was determined electrometrically in a ratio of 1:2.5 Soil to Water and $CaCl_2$ as described by [29]. Soil organic carbon was measured by wet oxidation method of Walkley and Black [30], and Available Phosphorus was measured by Bray No. 1 method described by [31] and [32]. Total nitrogen was determined by the regular micro-Kjeldahl digestion method [33] and exchangeable acidity was determined by shaking the soil in 0.01 M KCl and titrate the filtrate with 0.1M NaOH [34]. Exchangeable bases (Ca, Mg, K and Na) were extracted with 1N $NH_4OA_C$ [35]. Exchangeable Calcium (Ca) and Magnesium (Mg) were determined by EDTA titration methods [34]. Potassium (K) and Sodium (Na) was determined using flame photometry [36]. Cation Exchange Capacity (CEC) was determined by the1N Neutral Ammonium acetate (1N $NH_4OA_C$) method described by [37]. Data obtained was subjected to Analysis of variance (ANOVA) using General Linear Model (GLM) procedure of SAS 9.3 Software [38]. 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

#### 3.1.1. Ph Physical Parameters

**Table 1** presented data on bulk density (BD) of the soils before use for experimentation, to show that it ranged between 1.43 $Mg \cdot m^{-3}$ to 1.57 $Mg \cdot m^{-3}$ at surface and subsurface layers respectively, and was moderate in range [27] to support sustainable crop production. Also, sand fractions dominate the soil fractions with high values (490 $g \cdot kg^{-1}$) at the surface layers (0 - 10 cm) and 450 $g \cdot kg^{-1}$ at the sub surface depths (10 - 20 cm). Silt value was 430 $g \cdot kg^{-1}$ at the surface layers (0 - 10 cm), 460 $g \cdot kg^{-1}$ in the sub surface layers (10 - 20 cm); suggesting increase of silt content with depth, while clay value was low (80 $g \cdot kg^{-1}$) in the surface layers (0 - 10 cm) and increased (90 $g \cdot kg^{-1}$) in the subsurface layers (10 - 20 cm). Textural class [25] for surface and subsurface horizons was loam (**Table 1**). Mean weight diameter (MWD) was 0.48 at the surface layer (0 - 10 cm) and was lower than that of subsurface (0.52) layer (10 - 20 cm), to suggest that surface soils would be susceptible to erosion by wind and degraded for sustainable crop productivity. Soil moisture contents (SMC) at the surface soil was 0.28 $cm^3$ $cm^{-3}$ and 0.37 $cm^3 \cdot cm^{-3}$ in the subsurface layer (**Table 1**); perhaps because the surface soils are more sandy and loose water easily to percolation and evaporation [10], prone to moisture stress by dehydration and therefore require that soil and water

**Table 1.** Initial physicochemical properties of the experimental field.

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

conservation measures be put in place to sustain available moisture for sustainable crop production on the soils.

#### 3.1.2. Chemical Parameters

Reaction (pH) of soil in water was 5.80 at surface and 6.80 at sub-surface depths. In $CaCl_2$ solution, pH at the soil surface was 4.89 and 5.20 in the sub-surface soils (**Table 1**). The soils were therefore slightly acid and optimal for nutrient uptake by plant roots [39]. Organic carbon values were higher at the surface (0 - 10 cm) layer (2.11 $g \cdot kg^{-1}$) than subsurface soil (10 - 20 cm) layers (1.99 $g \cdot kg^{-1}$), though generally very low. Total Nitrogen of was 0.50 $g \cdot kg^{-1}$ at surface layer and lower at the sub-surface with a mean value of 0.40 $g \cdot kg^{-1}$. Available phosphorus of surface soils (0 - 10 cm) was 4.91 mg $kg^{-1}$ and 4.99 $mg \cdot kg^{-1}$ at the sub-surface soils (10 - 20 cm). Exchangeable calcium was 2.20 $cmol \cdot kg^{-1}$ at the surface layers (0 - 10 cm) and 2.30 $cmol \cdot kg^{-1}$ at the sub-surface depths. The exchangeable Mg was higher at sub-surface and lower in surface soils with values of 0.62 $cmol \cdot kg^{-1}$ and 0.59 $cmol \cdot kg^{-1}$ respectively. Exchangeable $K^+$ values were low in both at surface and sub-surface depths; 0.31 cmol·kg$^{-1}$ and 0.36 cmol·kg$^{-1}$ respectively (**Table 1**), to confirm [6] [7] [8] [9], 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 ($H^+$ + $Al^{3+}$) at both surface and subsurface layer were less than 1.0 cmol·kg$^{-1}$ and confers acid problems free status to the soils. Cation Exchange Capacity (CEC) of surface soils (0 - 10 cm) was 7.75 cmol·kg$^{-1}$ and 7.50 cmol·kg$^{-1}$ at sub-surface layer (10 - 20 cm). Low CEC values of the experimental area (<10 cmol·kg$^{-1}$) suggests dominance of low activity clays and sesquioxides [40], as well as low soil organic matter content (**Table 1**), thus predisposing the environment to global warming and climate change effects.

### 3.2. Effect of Cropping Systems on Soil Bulk Density (Bd)

**Figure 2** presents result of bulk density (Bd) for treatments in 2014 and 2015 years, showing highest Bd resulted under sole (mono-crop) maize (M) with value of 1.61 Mg·m$^{-3}$ at 8 and 1.48 Mg·m$^{-3}$ at 16 WAP 2014. Lowest bulk density value resulted under sole *Desmodium* (D); 1.48 Mg·m$^{-3}$ at 8 WAP and 1.39 Mg·m$^{-3}$ at 16 WAP. Perhaps, mono-crop 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. 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 [41] [42]. Hence, soils under sole maize treatment (M) having high bulk density values, would impair moisture retention, water flow, root development, nutrient cycling and sustainability of micro and macro organisms activity to impact degraded status to the soils. This high bulk density may have resulted from crusting of the soils under sole maize [43]. At 8 and 16 WAP, there was no significant difference among the treatment in 2015 on bulk density conditions, though values decreased below 2014 records; perhaps due to improved management practice adopted in 2015.

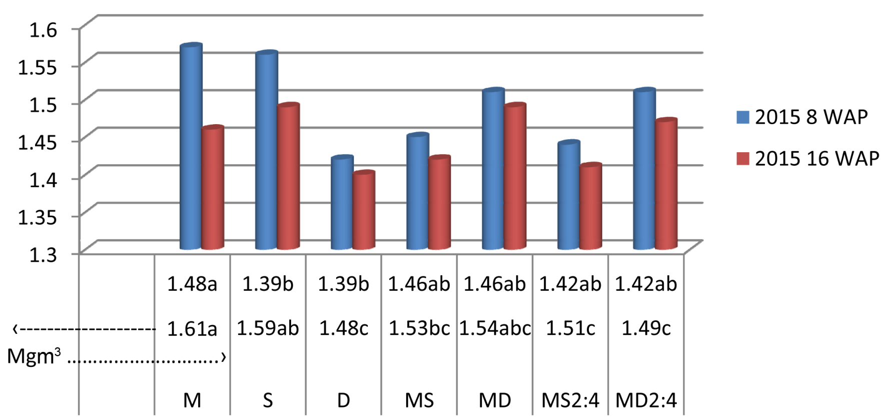


**Figure 2.** Effect of cropping systems on bulk density of soils: 2014-2015. Means with same letter are not significantly different at ($P < 0.05$) using DNMRT.

### 3.3. Effect of Cropping Systems on Soil Aggregates

Maize/Soybean intercrop (MS) resulted in significantly ($P < 0.05$) greater mean weight diameter (MWD) than the other cropping systems (**Table 2**), followed by Maize/Desmodium intercrop (0.6467) and Sole soybean (0.615). The lowest MWD resulted under sole maize; which 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 when trying to maintain a balance of air and water in the soil system and the development of plant roots. Therefore, the greater mean weight diameter under Maize/Soybeans and Sole soybean suggest balanced air, water and plant roots development soil conditions for sustainable crop production. There was no significant difference in MWD under the treatments in 2015, though MWD generally increased across all the treatments in 2015, with Maize/*Desmodium* giving higher MWD (1.282).

### 3.4. Effect of Cropping System on Soil pH during and over 2014 and 2015 Cropping Season

**Table 3** presents data on pH changes within years and means over years on soil acid conditions resulting from Maize/Legume cropping systems' trials to shows that MD 2:4 significantly ($P < 0.05$) increased soil pH in water and $CaCl_2$, followed by treatment MS 2:4 and lowest pH (high acidity) was recorded under sole maize. Treatments S, D, MS, MD, MS 2:4 and MD2:4 had significantly different pH value in water while S, D, MS, MD and MS 2:4 had similar pH in $CaCl_2$. The pH in water and $CaCl_2$ were both lowest under sole maize; perhaps suggesting impoverished soil pH conditions for sustainable crop production. The pH in water and $CaCl_2$ were slightly higher in 2015 than in 2014, except for treatment M, where pH in $CaCl_2$ reduced; *i.e.* more acidic. In Sole *Desmodium*, pH increased slightly from 6.10 to 6.13 (pH water) and 5.82 to 5.85 (pH $CaCl_2$). A pH range of 6.0 to 6.8 is ideal for most crops because it coincides with optimum

**Table 2.** Effect of cropping system on mean weight diameter of aggregates: 2014/2015.

| Treatments | 2014 | 2015 |
|---|---|---|
| | 16 WAP | 16 WAP |
| Sole Maize | 0.5417b | 1.0067 |
| Sole Soybean | 0.6150ab | 1.1083 |
| Sole *Desmodium uncinatum* | 0.5633b | 1.1200 |
| Maize/Soybean intercrop | 0.6467a | 0.9317 |
| Maize/*Desmodium* intercrop | 0.6040ab | 1.2820 |
| Maize/Soybean strip crop 2:4 | 0.5683b | 0.8567 |
| Maize/*Desmodium* strip crop 2:4 | 0.5700b | 1.0786 |
| Mean | 0.5944 | 1.0548 |
| SE± | 0.02 | 0.0001 |

Means with same letter are not significantly different at ($P < 0.05$) using DMRT.

**Table 3.** Effect of maize/legume cropping systems on soil ph within and over years: 2014/2015.

| Treatments | 2014 | | 2015 | | Mean across years | |
|---|---|---|---|---|---|---|
| | pH | | | | Water | $CaCl_2$ |
| | Water | $CaCl_2$ | Water | $CaCl_2$ | | |
| M | 5.99f | 5.29c | 6.00e | 4.90b | 5.99e | 5.21d |
| S | 6.32cd | 5.72b | 6.35cd | 5.85a | 6.33d | 5.79c |
| D | 6.10fe | 5.82b | 6.13e | 5.85a | 6.43c | 5.84c |
| MS | 6.47bc | 5.91b | 6.50bc | 5.90a | 6.51bc | 6.01b |
| MD | 6.27de | 5.72b | 6.30d | 5.75a | 6.30d | 5.74c |
| MS 2:4 | 6.54b | 5.95b | 6.55b | 5.95a | 6.55b | 6.07b |
| MD 2:4 | 6.94a | 6.28a | 6.75a | 6.15a | 7.00a | 6.21a |
| Mean | 6.38 | 5.81 | 6.37 | 5.78 | 6.44 | 4.35 |
| SE± | 0.06 | 0.11 | 0.06 | 0.15 | 0.03 | 0.04 |

Means with same letter are not significantly different at ($P < 0.05$) using DNMRT.

solubility of the most important plant nutrients [44] [45]. Also, means across the two years show that pH in water under sole maize had lower value than all the other treatments and highest pH in water resulted under treatment MD 2:4. Treatment MD 2:4 had higher pH in $CaCl_2$ and water, suggesting improved soil acid conditions for sustainable crop production (**Table 3**).

### 3.5. Effect of Maize/Legume Cropping Systems on Soil Organic Carbon (OC), Total Nitrogen (TN) and Available Phosphorus (Avail. P) within and over 2014 and 2015 Cropping Seasons

**Table 4** reveals that Maize/strip *Desmodium* (MD 2:4) resulted in 9.51 g·kg$^{-1}$ OC concentration that was statistically ($P < 0.05$) higher than treatments under M, S, D, MS, MD and MS2:4 in 2014. Maize /*Desmodium* intercrop (MD) resulted in lowest OC concentration with value of 2.72 g·kg$^{-1}$. There was no significant difference among MS 2:4 (4.25 g·kg$^{-1}$) and D (4.27 g·kg$^{-1}$). In 2015, soil OC slightly increased across treatments; except for mono-crop maize (M) which decreased slightly. Treatment MD 2:4 had higher OC concentration in 2015 and the lowest was under MD intercrop. This confirms that the keys to successful soil carbon sequestration are increased plant growth and productivity, increased net primary production and decreased decomposition [3] [46] because MD 2:4 sequestered carbon from maize and Desmodium biomass, as against sole maize (M) that sequestered carbon from maize biomass only. More so, **Table 4** shows that means across the two years indicate significantly higher OC concentration in MD2:4 than the other cropping systems. Soil under MD 2:4 consistently sequestered higher OC concentration than other cropping systems when evaluated for two years and means across the two years, had higher total nitrogen (TN) with value of 1.32 g·kg$^{-1}$, followed by MS (0.93 g·kg$^{-1}$) and the lowest was under

**Table 4.** Effect of maize/legume cropping systems on Organic Carbon (OC), Total Nitrogen (TN), Available Phosphorus (Av. P) within 2014 and 2015 and means across years.

| Trts | 2014 | | | 2015 | | | Mean of years | | |
|---|---|---|---|---|---|---|---|---|---|
| | OC | TN | AV.P | OC | TN | AV. P | OC | TN | AV. P |
| | $g \cdot kg^{-1}$ | | $mg \cdot kg^{-1}$ | $g \cdot kg^{-1}$ | | $mg \cdot kg^{-1}$ | $g \cdot kg^{-1}$ | | $mg \cdot kg^{-1}$ |
| M | 6.06b | 0.39d | 11.30bc | 5.65c | 0.51c | 10.30b | 5.10c | 0.50d | 13.80c |
| S | 3.96de | 0.69c | 17.32a | 5.15bc | 0.61c | 15.05a | 4.87d | 0.67c | 18.68a |
| D | 4.27d | 0.45d | 6.24e | 4.35c | 0.63c | 6.20c | 4.63e | 0.50d | 9.26g |
| MS | 5.85c | 0.93b | 9.83cd | 6.85b | 0.98b | 10.83b | 6.60b | 0.96b | 13.32d |
| MD | 2.72e | 0.39d | 13.14b | 3.25c | 0.54c | 13.10a | 3.57g | \0.46e | 16.24b |
| MS 2:4 | 4.25d | 0.47d | 10.81bcd | 4.50c | 0.56c | 6.81c | 4.13f | 0.51d | 11.81e |
| MD 2:4 | 9.51a | 1.32a | 7.69de | 10.10a | 1.48a | 7.58c | 7.57a | 1.40a | 10.68f |
| Mean | 5.23 | 0.66 | 10.90 | 5.69 | 0.76 | 9.99 | 5.21 | 0.71 | 13.40 |
| SE± | 0.46 | 0.05 | 1.05 | 0.67 | 0.09 | 0.078 | 0.07 | 0.01 | 0.16 |

Means with same letter are not significantly different at ($P < 0.05$) using DNMRT; Trts = Treatments; OC = Organic carbon; TN = Total Nitrogen; AV. P = Available Phosphorus.

M in 2014 (**Table 4**). This would give credence to the assertion that organic matter improves soil quality by improving other properties such as nutrient and water storage, buffering capacity and microbial activity/diversity [42]. In 2015, soil TN increased across all treatments while treatment MD 2:4 resulted in higher TN (1.48 $g \cdot kg^{-1}$) content and the least was under mono-crop (sole) maize. The soil TN under maize intercrop with legumes (Soybean and *Desmodium*) was higher than that of mono-crop maize; perhaps because active soil organic nitrogen or the mineralizable nitrogen from organic matter of these treatments, is the biologically dynamic and labile organic nitrogen that can be mineralized within a one year [47] [48] to cause increase of TN over mono-crop maize treatment. Treatment MD had lowest mean TN across the two years. Perhaps, treatment MD 2:4 sequestered more organic matter into soil than the other treatments for soil organic matter to be a sink and source for plant nutrients, function in maintaining soil fertility, influencing aggregation and improving water retention [49] [50] for sustainable crop production.

Available phosphorus in 2014 was higher than those in 2015 among the treatments. Treatment S had significantly higher available phosphorus than other treatments and the least resulted under sole *Desmodium* in 2014. In 2015, treatment S resulted in higher available P and the least were under treatment D. Perhaps in 2014 soybean residues deposited some phosphorus, following residue and below ground biomass decompositions that improved soil available phosphorus in 2015. Therefore, sole soybean favored soil available phosphorus over the two years study; though, there was a decrease in available P in 2015 when compared to that in 2014.

### 3.6. Effect of Cropping Systems on Exchangeable Cation and Cation Exchange Capacity (CEC)

Data on soil Exchangeable Cation (Ca, Mg, K and Na) and Cation Exchange Capacity (CEC) is presented in Table 5 and shows that treatment MD 2:4 had higher calcium value followed by treatment MS and the lowest was under treatment MD in 2014. In 2015, Calcium ($Ca^{2+}$) values improved across treatments and MD2:4 resulted in higher $Ca^{2+}$ content that was not significantly different from treatment MS. Also, treatment MS resulted in higher Magnesium ($Mg^{2+}$) content that was not significantly different from treatment MD 2:4 and the lowest resulted under maize/*Desmodium* intercrop which was statistically similar with treatment D in 2014.Treatment MS resulted in higher $Mg^{2+}$ content and treatment MD resulted in the lowest $Mg^{2+}$ content in 2015. Results also show that treatment MD2:4 had higher Potassium ($K^+$) value than all other treatments followed by MS 2:4 and the lowest resulted under sole soybean which was significantly the same with all other treatments (M, D, MS; MD, MS 2:4).

In 2015, treatment MD2:4 resulted in higher $K^+$ content that was significantly ($P < 0.05$) different from the other treatments and the least $K^+$ was under sole soybean and was statistically similar with the other treatments (Table 5). Also, M and MD 2:4 resulted in higher sodium ($Na^{2+}$) content and were statistically different from other treatments. The lowest sodium ($Na^{2+}$) content was observed in treatment MS, D, S and MS 2:4 in 2014. Treatment under MD 2:4 resulted in higher $Na^{2+}$ content and was significantly ($P < 0.05$) different from other treatments; except sole maize (M) in 2014 and 2015. MS treatment resulted in the lowest $Na^{2+}$ content in 2015, though not significantly different from values under sole soybean (S) and sole Desmodium (Table 5).

**Table 5.** Maize/legume cropping systems effect on exchangeable cations and cation exchange capacity of soil: 2014 and 2015.

| Trts | 2014 | | | | | 2015 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ca | Mg | K | Na | CEC | Ca | Mg | K | Na | CEC |
| | Cmol·kg$^{-1}$ | | | | | | | | | |
| M | 1.50cd | 0.52b | 0.14b | 0.11a | 5.09b | 2.10b | 0.57b | 0.19b | 0.09a | 4.63b |
| S | 1.70c | 0.47b | 0.12b | 0.04b | 5.03b | 1.80c | 0.51bc | 0.14b | 0.03b | 4.52bc |
| D | 1.20de | 0.32c | 0.12b | 0.04b | 4.42c | 1.30d | 0.37d | 0.17b | 0.03b | 4.03bc |
| MS | 2.55b | 0.87a | 0.15b | 0.03b | 6.76a | 3.10a | 0.93a | 0.16b | 0.02b | 6.05a |
| MD | 1.00e | 0.30c | 0.14b | 0.07ab | 4.98bc | 1.10d | 0.33d | 0.15b | 0.07ab | 4.38bc |
| MS 2:4 | 1.60c | 0.84b | 0.17b | 0.03b | 4.42c | 1.70d | 0.49c | 0.18b | 0.06ab | 4.00c |
| MD 2:4 | 3.15a | 0.84a | 0.24a | 0.012a | 6.98a | 3.20a | 0.87a | 0.26a | 0.11a | 6.44a |
| Mean | 1.81 | 0.59 | 0.15 | 0.05 | 5.38 | 2.04 | 0.58 | 0.18 | 0.06 | 4.86 |
| SE± | 0.13 | 0.03 | 0.02 | 0.02 | 0.19 | 0.09 | 0.02 | 0.02 | 0.02 | 0.19 |

Means with same letter are not significantly different at ($P < 0.05$) using DNMRT.

Cation Exchange Capacity (CEC) under MD 2:4 resulted in significantly ($P <$ 0.05) higher value than other treatments, except for MS both in 2014 and 2015. Treatments D and MS 2:4 had statistically similar ($P > 0.05$) CEC value, and gave the lowest CEC content in 2014. In 2015, CEC across all the treatments reduced, but MD 2:4 resulted in higher CEC value, while treatment MS 2:4 resulted in the lowest CEC value in soil (Table 5). The significantly ($P < 0.05$) high cations and CEC values under MD 2:4 is attributed to the fact that increases in soil organic matter, cation exchange capacity (CEC) and nutrients availability may occur in no-till systems with legumes and with large additions of organic residues [51], that may have occurred in this treatment.

### 3.7. Effect of Maize/Legume Cropping Systems on Organic Carbon Sequestration in Macro and Micro Aggregates during the 2014 and 2015 Cropping Season and Means across Years at Samaru, Northern Nigeria

Table 6 shows effect of Maize/Legume cropping systems on organic carbon (OC) concentration in macro (a) aggregates (2.36 - 2.00 mm) and micro (b) aggregate (2.00 mm - 0.25 mm) during the 2014and 2015 rain-fed cropping season and means across the two years at Samaru. Resulting aggregates show that adoption of maize-soybean sequestered highest OC concentration in macro aggregate in each of the two years (2014 and 2015) and when the years were combined. This was followed by MD2:4 treatments that had significantly higher organic carbon concentration in macro aggregates than the other treatments across the periods of observation. Of note is that greater organic matter concentrations and higher mineralization rates are often associated with macro-aggregate fractions [52], while organic matter associated with micro-aggregates may be more protected physically and the more recalcitrant, biochemically [53] [54]. Also, land

**Table 6.** Maize/legume cropping systems effect on organic carbon sequestration in macro and micro aggregate fractions.

| Trts | 2014 | | 2015 | | Mean over Years | |
|---|---|---|---|---|---|---|
| | Macro | Micro | Macro | Micro | Macro | Micro |
| | $g \cdot kg^{-1}$ | | | | | |
| M | 0.70c | 0.73c | 0.76c | 0.77c | 0.73c | 0.75c |
| S | 0.63d | 0.59d | 0.64d | 0.68e | 0.64d | 0.64d |
| D | 0.49e | 0.53e | 0.57e | 0.54f | 0.53e | 0.53f |
| MS | 1.35a | 0.87a | 1.38a | 0.93a | 1.36a | 0.89a |
| MD | 0.39g | 0.37g | 0.40g | 0.39g | 0.39g | 0.38g |
| MS 2:4 | 0.42f | 0.49f | 0.49f | 0.72d | 0.46f | 0.60e |
| MD 2:4 | 0.78b | 0.83b | 0.90b | 0.80b | 0.84b | 0.82b |
| Mean | 0.68 | 0.63 | 0.73 | 0.69 | 0.71 | 0.66 |
| SE± | 0.004 | 0.001 | 0.006 | 0.006 | 0.004 | 0.003 |

Means with same letter are not significantly different at ($P < 0.05$) using DNMRT.

uses and land cover changes have significant impacts on soil physical structure that often result in changes in soil organic matter storage and turnover [53] [54] [55]. Therefore, it could be inferred that the best land use strategies are those that focus on protection of soil organic carbon against further depletion and erosion, or the replenishment of depleted carbon stocks through management techniques that involve legume/Cereal cropping systems, such as Maize/Soybean and Maize/Desmodium 2:4 systems. The lowest amount of OC concentration sequestered in macro aggregate was under MD intercrop.

### 3.8. Soil Development, Maize Yield and Soil Quality Following Maize/Legume Cropping Systems for 2014-2015

Soils developed under Maize Strip Cropped with *Desmodium* (MD 2:4) had optimal soil pH condition, highest soil organic carbon, total nitrogen and cation exchange capacity over the other treatments (Table 7). Also, MD2:4 treatments were second to Maize/Soybean intercrop in sequestering organic carbon in macro and micro soil aggregate fractions. These suggest that MD2:4 treatment developed soils of high quality (SQ1) for sustainable crop production. This could give credence to the assertion that best land use strategies are those that focus on protection of soil organic carbon against further depletion and erosion, or the replenishment of depleted carbon stocks through management techniques that involve legume/Cereal cropping systems, such as Maize/Soybean and Maize/Desmodium 2:4 systems [46] [51] [54]. Perhaps, because *Desmodium uncinatum* is a perennial legume crop, its roots were able to grow deep into the soil in search of moisture and ramified the root zones better than soybean, contributed high below and above ground biomass for better soil quality development than the other treatments. Maize/Soybean intercrops treatment sequestered highest amounts of organic carbon in the macro and micro aggregate soil fractions developed, but was not as good as MD2:4 in contributing total nitrogen, organic

**Table 7.** Soil development, quality and maize yield evaluation following maize/legume cropping system at end of 2015.

| Trt | Bd 16wap | MWD | Soil pH | | OC | TN | AV. P | CEC | MY | AMaC | AMiC | Total/Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $Mg \cdot m^{-3}$ | mm | $H_2O$ | $CaCl_2$ | $g \cdot kg^{-1}$ | | $mg \cdot kg^{-1}$ | $cmol \cdot kg^{-1}$ | $t \cdot ha^{-1}$ | $g \cdot kg^{-1}$ | | |
| M | 1.46 (4) | 1.007 (5) | 6.00 (7) | 4.90 (6) | 5.65 (3) | 0.50 (5) | 13.80 (3) | 4.63 (3) | 3.13 (1) | 0.76 (3) | 0.77 (3) | 43/5 |
| S | 1.49 (6) | 1.108 (3) | 6.35 (4) | 5.85 (4) | 5.15 (4) | 0.67 (3) | 18.68 (1) | 4.52 (4) | nil | 0.64 (4) | 0.68 (5) | 42/4 |
| *D* | 1.40 (1) | 1.120 (2) | 6.13 (6) | 5.85 (4) | 4.35 (6) | 0.50 (5) | 9.26 (7) | 4.03 (6) | nil | 0.57 (5) | 0.54 (6) | 41/3 |
| MS | 1.42 (3) | 0.932 (6) | 6.50 (3) | 5.90 (3) | 6.85 (2) | 0.96 (2) | 13.32 (4) | 6.05 (2) | 0.867 (4) | 1.38 (1) | 0.93 (1) | 31/2 |
| MD | 1.49 (6) | 1.282 (1) | 6.30 (5) | 5.75 (5) | 3.25 (7) | 0.46 (6) | 16.24 (2) | 4.38 (5) | 2.900 (2) | 0.40 (7) | 0.39 (7) | 53/6 |
| MS 2:4 | 1.41 (2) | 0.857 (7) | 6.55 (2) | 5.95 (2) | 4.50 (5) | 0.51 (4) | 11.81 (5) | 4.00 (7) | 1.633 (3) | 0.49 (6) | 0.72 (4) | 54/7 |
| MD 2:4 | 1.47 (5) | 1.079 (4) | 6.75 (1) | 6.15 (1) | 10.10 (1) | 1.40 (1) | 10.68 (6) | 6.44 (1) | 1.633 (3) | 0.90 (2) | 0.80 (2) | 27/1 |

NB: Bd = Bulk density; MWD = Mean weight diameter; OC = Organic Carbon; TN = Total nitrogen; AV.P = Available Phosphorus; CEC = Cation Exchange Capacity; MY = Maize Yield; AMaC = Carbon sequestered in Macro aggregates; AMiC = Carbon sequestered in Micro aggregates; Values in red are scores on 1 - 7 range; Values in green are the soil quality (SQ) ranks.

carbon or reducing soil acidity. Soil quality developed under MS was therefore rated SQ2. However, Maize/Soybean intercrop is not practiced by farmers in this agro-ecological zone, perhaps because soil developed under this treatment is of a lower quality (SQ2)) and the practice depressed yield of maize grains. Table 7 also shows that Maize strip cropped soybean (MS2:4) resulted in poorer soil quality condition (SQ7); in particular because, it resulted in low mean weight diameter of soil aggregates, low cation exchange capacity, available phosphorus and sequestered low amounts of carbon in soil macro-aggregates. This suggests that this practice of strip cropping soybean in maize fields may not be a sustainable practice, though yield of soybean and maize grains could provide cushioning effects against crop failure.

Mono-crop (Sole) maize treatment (M) encouraged the development of soils with relatively high bulk density (1.46 $Mg \cdot m^{-3}$), poor aggregate mean weight diameter (1.007), high soil acidity and low total nitrogen (0.05 $g \cdot kg^{-1}$); suggesting soils with impoverished quality (SQ5) conditions, though maize yield was high, perhaps due to high organic carbon and improved management practice. Sole soybean and sole *Desmodium* grain yields were not assessed and may have contributed to downgrade soil quality ranking of soils developed under these treatments (SQ4 & SQ3 respectively). However, sole *Desmodium* resulted in the lowest (best) bulk density value (1.40 $Mg \cdot m^{-3}$) and was good in mean weight diameter development (1.12), while Sole Soybean treatment contributed highest available phosphorus (18.68 $mg \cdot kg^{-1}$) than the other treatments.

### 3.9. Maize Grain and Stover Yields under Maize/Legume Cropping System: 2014 and 2015

In 2014 and 2015 cropping seasons, maize intercropped with *Desmodium uncinatum* (MD) significantly ($P < 0.05$) out-yielded the other treatments in terms of maize grain with 2.23 $t \cdot ha^{-1}$ in 2014 and increased to 2.90 $t \cdot ha^{-1}$ in 2015, giving 30.05% grain yield improvement (Table 8). Following this was mono-crop (sole) maize (M) land use that yielded 2.13 $t \cdot ha^{-1}$ in 2014 and 3.13 $t \cdot ha^{-1}$ in 2015; an increase of 46.95%. This yield level was significantly higher than MS, MS 2:4 and MD 2:4 in 2014 and MS, MD, MS 2:4 and MD 2:4 in 2015, and is attributed to

**Table 8.** Maize yield ($t \cdot ha^{-1}$) under maize/legume cropping system in 2014 and 2015.

| Treatment | 2014 | | 2015 | | % change over 2014 & 2015 | |
|---|---|---|---|---|---|---|
| | Grain | Stover | Grain | Stover | Grain | Stover |
| M | 2.13ab | 3.77ab | 3.13a | 4.53ab | 46.95 | 46.68 |
| MS | 0.49c | 1.95c | 0.87b | 2.63b | 77.55 | 34.87 |
| MD | 2.23a | 4.68a | 2.90a | 4.90a | 30.05 | 4.70 |
| MS 2:4 | 0.96bc | 3.28abc | 1.63ab | 4.63ab | 69.79 | 41.16 |
| MD 2:4 | 1.27ac | 2.95c | 1.63ab | 3.63ab | 28.35 | 23.05 |

Means with the same letter are not significantly different at 5% level of probability using Duncan's multiple range test.

the high organic carbon (**Table 4**) content of soils under M. However, continued optimal grain yield under mono-crop maize system may not be sustained because agriculture is a soil-based industry that extracts nutrients from the soil. Effective and efficient approaches to slowing nutrients removal and return nutrients to the soil will be required in order to maintain and increase crop productivity and sustain agriculture for a long term [56]. Mono-crop maize (M) treatment largely extracts nutrients from the soil. **Table 8** also shows that MS, MD, MS 2:4 and MD 2:4 treatments caused maize grain yield increases, with MS and MS 2:4 treatments having higher percent grain yield increases than sole maize. These grain yield increases are attributed to effects of the legumes to contribute nitrogen and carbon stock to the soils for maize crop use.

In 2014 and 2015 also, MD produced significantly ($P < 0.05$) higher stover yield than the other treatments (**Table 8**) and was followed by M in 2014 and MS 2:4 in 2015. Though percent stover change in M suggests high amount of stover that could improve soil conditions if incorporated, the practice in sub humid zone grassland savanna of Nigeria is that crop residues are harvested, fed to livestock, used for fencing or as fuel wood [12] and are not returned to the soil. Therefore land use strategies that focus protection of soil organic carbon against further depletion and erosion, contribute nitrogen and/or the replenishment of depleted carbon stocks through management techniques that involve legume/Cereal cropping systems are advocated for sustainable agricultural production in the Nigerian Savanna zone Alfisols.

## 4. Conclusions

Findings from the study show that bulk density (BD) of surface soils prior to experimentation was in the range of between 1.43 $Mg \cdot m^{-3}$ to 1.57 $Mg \cdot m^{-3}$ and was rated moderate in range for sustainable agriculture. Also, soils of the study area have inherent poor fertility status and quality. Following trial treatments on the soil however, mono-crop maize treatment (M) caused high grain yields that decreased over the two year trial, caused more soil compaction and acidity relative to other treatments; suggesting that mono-crop maize treatment could degrade soil reaction, even within two years, would increase soil compaction and cause progressive decrease in crop yield and therefore not a sustainable cropping system option for Nigerian Savanna zone Alfisols. Sole *Desmodium uncinatum* best improved soil bulk density, but MS treatments resulted in significantly ($P < 0.05$) higher OC concentration sequestered in macro aggregate in each of the two years (2014 and 2015) and when the years were combined; though MS treatment may not be encouraged because it did not support sustainable maize grain yield. However, MD2:4 treatments gave significantly higher organic carbon concentration in macro aggregate across the periods of observation than the rest other treatments. The lowest amount of OC concentration sequestered in macro aggregate resulted under MD intercrop, though it gave high maize grain and stover yields that increased with years.

It is therefore concluded that Maize strip cropped with *Desmodium* (MD2:4) treatment had high Mean Weight Diameter (MWD 1.282), best soil pH condition, highest soil organic carbon concentration, total nitrogen and cation exchange capacity and sequestered high organic carbon in soil macro and micro aggregates more than the rest other treatments, as well as recorded high maize grain yield (2.9 $t \cdot ha^{-1}$); though not significantly different from the highest (3.133 $t \cdot ha^{-1}$), but exceeded 2.0 $t \cdot ha^{-1}$ farmer yield level in Zaria area. The MD 2:4 treatment developed soils of high quality (SQ1) for sustainable maize crop production, mitigate global warming and climate change and is therefore advocated for farmers' adoption in the Savanna zone Alfisols. Also, appropriate measures to conserve soil and water against flood and/or erosion on arable land are advocated to ensure sustainable agricultural productivity and environmental conservation in this agro-ecology. Therefore land use strategies that focus soil organic carbon/carbon stock enrichment and protection of soil organic carbon against further depletion, soil erosion and contribute nitrogen into the soil through management techniques that involve legume/Cereal cropping systems are advocated for sustainable agricultural production in the Nigerian Savanna zone Alfisols. Such strategies include Maize:Soybean 2:4 (MS 2:4), and Maize:Desmodium 2:4 (MS 2:4) strip cropping and Maize/Desmodium intercrop systems.

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