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Tillage, *Desmodium intortum,* Fertilizer Rates for Carbon Stock, Soil Quality and Grain Yield in Northern Guinea Savanna of Nigeria

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Abstract

Northern Guinea Savanna of Nigeria soils are continuously and intensively cultivated, resulting in soil quality degradation, carbon stock depletion, accelerated soil erosion and soil nutrient depletion. Effects of land use change on soil carbon stocks (SOC) are of concern regarding greenhouse gas emissions mitigation and sustainable crop production, because there is a need for food sufficiency while conserving the environment. Also, managing soils under intensive use and restoring degraded soils are top priorities for a sustained agronomic production while conserving soil and water resources. Hence, this study; "Tillage, *Desmodium intortum*, fertilizer rates for carbon stock, soil quality and grain yield in Northern Guinea Savanna" is aimed at devising possible mitigating measures for soil quality degradation, carbon stock depletion and impoverished crop yields using *Zea mays* as test crop. The study was a Randomized Complete Block Design (RCBD) in split-split plot arrangement with four replicates. The four main tillage and *Desmodium intortum* combination treatments were: 1) Maize – without *Desmodium* + Conventional tillage (MC), 2) Maize + *Desmodium* live-mulch incorporated and relayed + Conservation tillage (MDIC), 3) Maize + *Desmodium* in no-tillage system (MDNT), 4) Maize + *Desmodium* in strip tillage (MDST). The main treatment plots were each divided to accommodate four (4) rates of N (60, 80, 100 and 120 kg·ha^{-1}) as sub plots, while the N rate plots were further divided to accommodate three (3) rates of P (6.6, 13.2, and 26.4 kg·ha^{-1}) as sub-subplots. Findings support that Desmodium intercrops with Maize treatments (MDIC, MDNT, and MDST) resulted in increased organic carbon contents in 2013, with MDNT resulting in significantly higher organic carbon content (7.37 g·kg^{-1} in 2012 and 8.37 g·kg^{-1} in 2013) than the other treatments. Also, zero tillage practice (MDNT) sequestered significantly higher carbon stock (18.06 t C ha^{-1}), followed by minimum tillage (MDIC) that sequestered 15.99 t C ha^{-1} than the other treatments. Highest grain yield of 2.61 tha^{-1} under MDIC and MDNT was followed by MDST and least under MC. Total score of soil quality assessment gave least score values of 13 under MDIC and MDNT; thus best soil quality (SQ_1) was ascribed to the minimum tillage with *D. intortum* intercrop and relayed (MDIC) and Zero tillage with *D. intortum* (MDNT) treatments. Maize Strip cropped with *D. intortum* treatment (MDST) was ranked SQ_2.

Keywords

Carbon Stock, Tillage, Soil Quality, Grain Yield, Climate Change Mitigation

1. Introduction

Soils of Northern Guinea Savanna of Nigeria are continuously and intensively cultivated, resulting in soil quality degradation, carbon stock depletion, accelerated soil erosion and soil nutrient depletion while population and food demand is on the increase [1]. Globally, the effects of land use change on soil carbon stocks (SOC) are of concern in the context of international policy agendas on greenhouse gas emissions mitigation [2] and sustainable crop production, because there is a dare need to produce sufficient food for the world's growing population while conserving the environment. The global soil carbon pool however exceeds biomass pools without taking into account that recent soil degradation has led to losses of between 30 percent and 75 percent of their antecedent soil organic carbon; hence, soil carbon increase offers great mitigation potential [3] [4] [5]. Soil organic carbon (SOC) governs soil structural stability and cation exchange capacity directly through its chemical structure and surface properties and indirectly as a source of energy and nutrients for soil biota [6]. Soil organic matter content has a great impact on soil quality and nutrient cycling to significantly influence soil fertility and productivity [5] [7] [8] [9] [10] [11]. Therefore, prudent use and management of organic matter in soils are more important now than ever before to meet the high demands for food and fiber production and satisfy the needs of an increasing world population and industrialization. Managing soils under intensive use and restoring degraded soils are also top priorities for a sustained agronomic and forestry production while conserving soil and water resources. Hence, this study "Tillage with *Desmodium intortum* and fertilizer rates for carbon stock and quality improvement of soils in Northern Guinea Savanna" is aimed at devising possible means of ameliorating identified problems using *Zea mays* as test crop.

The need to maintain and enhance multi-functionality of soil necessitates its improved and prudent management for meeting the needs of present and future generations. Also, the extent to which soil stewardship and protection is professed determines the sustainability of land use, adequacy of food supply, the quality of air and water resources and the survival of humankind [2]. Hence, decline in SOC under cropping systems can be minimized if relevant information is available on the impact of different nutrient management systems on SOC in the short and long term regimes. For example, the use of nitrogenous fertilizer alone aggravated the problem of soil acidity by lowering the pH from 5.8 to 4.7 after 25 years [12] and this would have adverse effect on the soil quality, crop yields and carbon stock. This study therefore will evaluate tillage practices and relevant minimum data set of the soils under maize-based cropping systems with *Desmodium intortum* intercrop, as well as maize grain yields and carbon stock to determine best-bet soil quality, carbon stock and optimum grain maize yield under the study areas.

Maize production in most smallholder farms in Africa is characterized by intensive cultivation of land (continuously), coupled with low external inputs which results in reduction of soil fertility and productivity as well as its quality [13]. Maize (*Zea mays* L.), which is a major staple cereal produced in this agro-ecology has high yield potentials and occupies about 40% of total area covered by arable crops [14]. An estimated 2 - 3 million hectares of land are currently under maize cultivation in Nigeria [15] Enhanced maize production through effective soil and nutrient management therefore, has strong potentials for improving livelihood of small holder farmers as it could mitigate poverty, improve soil quality, carbon stock, mitigate global warming, climate change and ensure environmental sustainability. Maize (*Zea mays* L.) is a widely consumed cereal crop throughout the world. It is used as a staple food (consumed as a whole grains, couscous, and cooked corn flour). Fermented corn grain is also used for alcohol production, while some companies produce infant's diets from corn. In animal feed, corn is a breeding crop which allows fattening cattle more quickly and thus increases the production of milk from cows [16] in [12]. An important part of corn production is its use for the feeding of poultry [12]. Therefore, emphasis in this study will be on maize-based cropping system in Northern Guinea Savanna of Nigeria.

This study therefore aims to evaluate:

1) The carbon stock distribution pattern and soil quality status of Maize-Desmodium based cropping system;

2) Tillage practices and fertilizer rates of Maize-*Desmodium intortum* intercrops;

3) Maize grain yield of maize-*Desmodium intortum* based cropping systems at the best-bet tillage, fertilizer rates.

2. Materials and Methods

2.1. Description of the Study Area

This study was conducted during the 2012 and 2013 rain-fed cropping seasons at the experimental farm of Institute for Agricultural Research (IAR), Samaru, Zaria, Nigeria. The experimental field is located between latitude 11˚11'19.3"N and longitude 7˚37'02"E, with an altitude of 686 m above sea level in the Northern Guinea Savanna ecology of Nigeria (**Figure 1**). Long-term mean annual rainfall of the study area is 986.5 mm [17], concentrated between May and October with a peak in August. The mean daily air temperature of the area is 24˚C [18]. Soil type of the study area was classified as Typic Haplustalf {USDA Soil Taxonomy [19] [20] and Acrisol in the [21] legend. The soils are low in inherent fertility, organic matter, cation exchange capacity (CEC) and dominated by low activity clays [22] [23] [24].

2.2. Treatments and Soil Sampling Procedures

The experiment was a Randomized Complete Block Design (RCBD) in split-split plot arrangement with four replicates. The four main tillage and *Desmodium intortum* combination treatments were: 1) Maize − without *Desmodium* + Conventional tillage (MC), 2) Maize + *Desmodium* live-mulch incorporated and

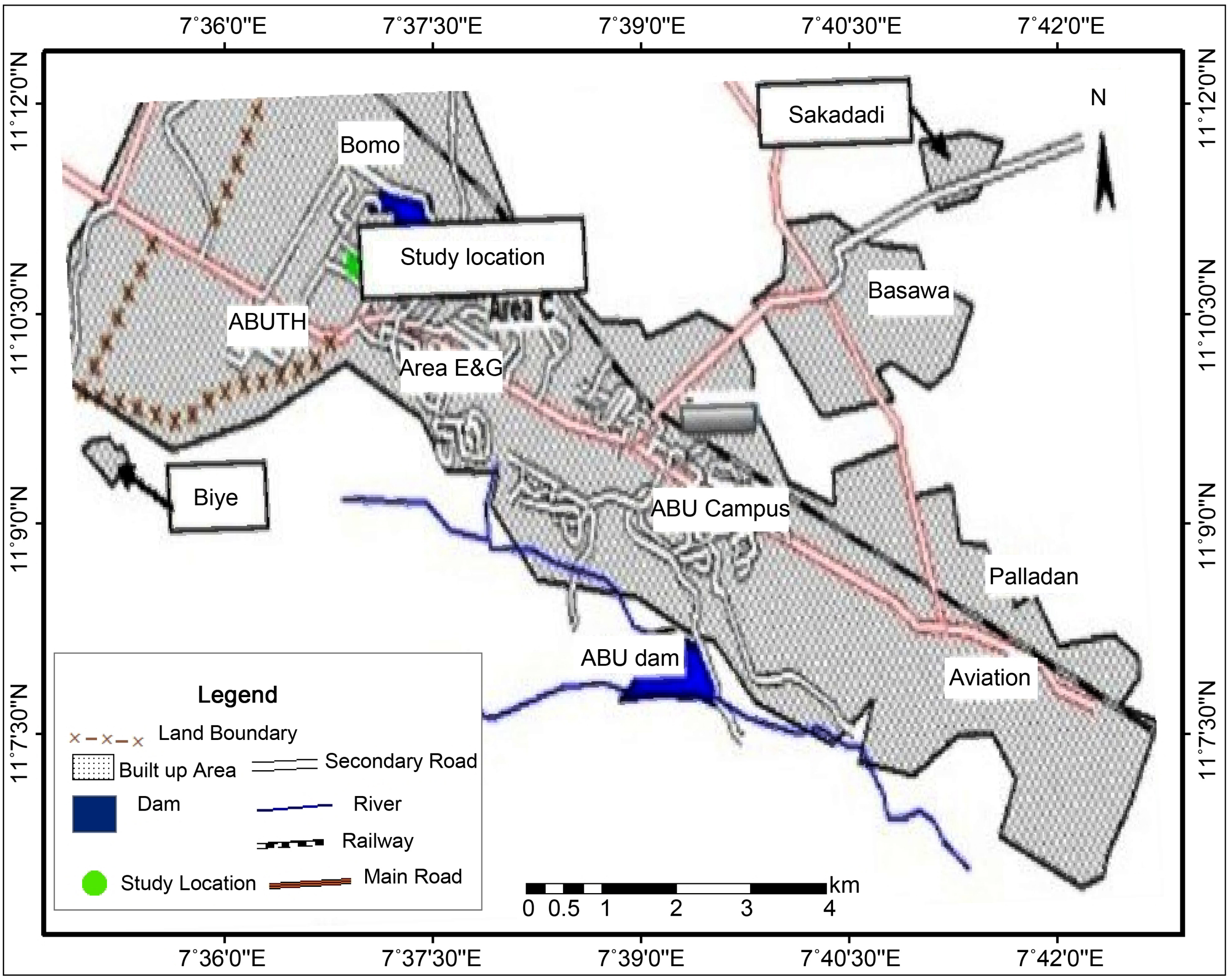

Figure 1. Map of Samaru, Zaria showing the study location.

relayed + Conservation tillage (MDIC), 3) Maize + *Desmodium* in no-tillage system (MDNT), 4) Maize + *Desmodium* in strip tillage (MDST). The main treatment plots were each divided to accommodate four (4) rates of N (60, 80, 100 and 120 kg·ha^{-1}) as sub plots, while the N rate plots were further divided to accommodate three (3) rates of P (6.6, 13.2, and 26.4 kg·ha^{-1}) as sub-sub plots. Maize and *Desmodium intortum* were the planting materials used while urea was the source of nitrogen fertilizer and single super phosphate was the source of phosphorous in this study. Maize (SAMMAZ-14; Quality Protein Maize) seed was obtained from the Institute for Agricultural Research, Ahmadu Bello University (IAR/ABU), Samaru, Zaria, Nigeria while *Desmodium intortum* seed was sourced from the International Center for Insect Physiology and Ecology (ICIPE) Kenya. *Desmodium intortum* is a forage legume capable to suppress *Striga hermonthica*, contributes high biomass and N to soil, conserve the soil against erosion and moisture depletion and is easy to propagate (by stem cutting and seed) [25] [26] [27] [28]. In 2012 and 2013 and in MC plots, conventional tillage (plowing, harrowing and ridging) was employed. For MDIC plots, manual plowing (with hoe) was done to incorporate *Desmodium* plants while replanting of *Desmodium intortum* was done along one side ridge slopes. In the MDNT plots, no tillage was done, while in MDST plots strip tillage of previous year ridges (1/2 ridges) was done using hoe. In MDNT plots, pulverization of soil was made in planting holes and two seeds of maize was planted using local hoe. Maize seeds were planted on ridge peaks at 25 cm intra-row and 75 cm inter-row spacing and thinned to one plant per stand two weeks after planting (2 WAP). *Desmodium intortum* seeds were drilled in bands along ridge slopes in MDIC, MDNT and MDST plots.

In 2012 and 2013 after harvest, a total of 48 soil samples were taken from 0 - 15 cm from the replicates. Samples collected were air-dried, crushed and sieved with a 2 mm sieve for each treatment. The less than 2 mm fractions were analyzed for their chemical properties. Result of analysis was used to judge changes in soil quality and carbon stock following second year treatment effect. Soil pH determination followed the [29] method while organic carbon was determined by wet oxidation method of Walkley and Black [30] method. Soil organic carbon stock (SOC) was measured with the impression:

$$\text{SOC} = \left(\text{C} \times \text{D} \times \text{BD} \times 10000\right) \big/ 1000 \left(\text{t C ha}^{-1}\right) \qquad (1)$$

where C = organic carbon concentration (g·kg^{-1}), Bd = bulk density (Mg m^{-3}), depth = d (cm) and SOC = carbon stock of soil (t C ha^{-1}), 10,000 m^2 = 1 ha, and 1000 kg = 1 ton [7] [10] [31].

Also, total nitrogen was determined by the regular micro Kjeidahl digestion [32] method and available phosphorus was determined by the [33]; [34] extraction method. Exchangeable bases (Ca, Mg, K, & Na) were extracted with 1N NH_40Ac [35]. Exchangeable Calcium (Ca) and magnesium (Mg) were determined by EDTA titration methods [36] [37], while potassium (K) and sodium (Na) were determined using flame photometry [38]. Cation exchange capacity

(CEC) was determined by the 1N neutral Ammonium acetate (1N NH_40Ac) method [39].

for this study, soil bulk densities were estimated as follows [40]:

$$BD = \frac{100}{\frac{\%OM}{0.244} + \frac{100 - \%OM}{1.64}} \tag{2}$$

where %OM = percentage organic matter content. Conversion factor of matter to organic carbon was taken as 1.724 [30].

Soil Quality:

Basic soil indicators selected for a minimum data set in this study were relevant soil data [41] [42] [43] [44] obtained in this study. This includes: 1) Data on organic carbon, total nitrogen, available phosphorus, cation exchange capacity, bulk density, carbon stock and pH of the soils at crop harvest. 2) Data on maize grain yield for the study period. Soil quality was assessed by using the [45] equation; *i.e.*,

$$SQ = f\left(SP, P, E, H, ER, BD, FQ, MI\right), \tag{3}$$

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 5 was used in the assessment of parameters in the model; where 1 is best and 5 is worst condition. Indicator ratings was divided into three groups; namely, more is better was applied to N, P, CEC, SOC and organic carbon, while less is better applied to bulk density and optimum is better was applied to pH. Also, 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 [11]. Therefore, $SQ = f\left(SP, P\right)$ was used to assess quality of soils in this study at the end of rain-fed cropping seasons.

The maize was harvested at physiological maturity and the ears were dehusked, dried and threshed. Maize grain yield at harvest was air-dried for two weeks and weight recorded in tonnes per hectare. Data obtained was subjected to Analysis of variance (ANOVA SAS 9.3 Software [46]. Differences between means were separated using Duncan's Multiple Range Test at 5% level of probability.

3. Results and Discussion

Soils of the study area were dominated with silt fractions (465 $g \cdot kg^{-1}$) followed by sand separates (370 $g \cdot kg^{-1}$) and clay (**Table 1**) to be classified as loam in texture. Bulk density of the soils was in the moderate to high value (1.58 $Mg\ m^{-3}$), while the reactions were acid (pH 5.20). Available phosphorus (5.46 $mg \cdot kg^{-3}$), total nitrogen (0.39 $g \cdot kg^{-1}$), organic carbon (5.73 $g \cdot kg^{-1}$) and cation exchange capacity (5.00 $cmol \cdot kg^{-1}$) of the soils were in the low range of values to suggest

Table 1. Physical and chemical properties of experimental field in 2012 before planting of Maize.

Parameters (0 - 15 cm)	Units	Values
Particle size: Sand	g·kg^{-1}	370
Silt	g·kg^{-1}	465
Clay	g·kg^{-1}	165
Texture	g·kg^{-1}	Loam
Bulk density	Mg m^{-3}	1.58
pH (H_2O)		5.20
Avail. P	Mg kg^{-1}	5.46
Total N	g·kg^{-1}	0.39
Org. C	g·kg^{-1}	5.73
CEC (1N NH_40A_C)	C mol·kg^{-1}	5.00
Exch. Bases	C mol·kg^{-1}	
Ca	C mol·kg^{-1}	0.89
Mg	C mol·kg^{-1}	0.60
K	C mol·kg^{-1}	0.17
Na	C mol·kg^{-1}	0.18

that the soils are degraded and impoverished in quality and fertility status [10] [24] [47].

Following experimentation in 2012 and 2013, organic carbon content (**Table 2**) under conventional tillage with sole maize decreased from 5.95 g·kg^{-1} to 5.65 g·kg^{-1} (5.1%) to suggest that conventional tillage with sole maize (MC) portends degradation of soil, facilitation of global warming and climate change [31] [47]. However, the Desmodium intercrops with Maize treatments (MDIC, MDNT, and MDST) resulted in increased organic carbon contents in 2013, with MDNT (Zero tillage planted with *Desmodium intortum* and Maize) resulting in significantly ($P < 0.05$) higher organic carbon content (7.37 g·kg^{-1} in 2012 and 8.37 g·kg^{-1} in 2013) than the other treatments (**Table 2**). This would suggest that Desmodium intercrop with maize under minimum and zero tillage practices would sequester more organic carbon in soils, improve soil quality and fertility, as well as combat global warming and climate change. Inorganic nitrogen fertilizer rates' use for maize production in this study (**Table 2**) show that whereas 80 kg N ha^{-1} increased organic carbon in soil from 2012 value (6.71 g·kg^{-1}) to 2013 value (6.73 g·kg^{-1}), 100 kg N ha^{-1} sequestered sustainably higher organic carbon in 2012 (6.6 g·kg^{-1}) to 2013 (7.62 g·kg^{-1}), to suggest that under this technology, 100 kg N ha^{-1} could be preferred for use in maize cultivation over other rates. The 26.4 kg P ha^{-1} phosphorus fertilizer rate sequestered significantly ($P < 0.05$) higher organic carbon (6.54 g·kg^{-1}) in 2012 that increased to 6.91 g·kg^{-1} in 2013, despite that 13.2 kg P ha^{-1} sequestered significantly higher Phosphorus in 2012 (6.78 mg·kg^{-1}) but increased to 6.86 mg·kg^{-1} in 2013 that was significantly lower than value sequestered by 26.4 kg P ha^{-1} in 2013 (**Table 2**). Therefore, the

Table 2. Effect of Tillage, N and P fertilizer rates on Organic carbon, Bulk Density and Carbon stock at 0 - 15 cm depth.

Tillage	Organic carbon		Combined	Organic matter		Combined	Bulk Density		Mean
	2012	2013		2012	2013		2012	2013	
	$g \cdot kg^{-1}$			%			$Mg\ m^{-3}$		
MC	5.95c	5.65c	5.80c	1.04c	0.97c	1.0c	1.55	1.55	1.55
MDIC	6.68b	7.15b	6.92b	1.15b	1.23b	1.19b	1.54	1.53	1.54
MDNT	7.37a	8.37a	7.87a	1.27a	1.44a	1.36a	1.53	1.52	1.53
MDST	5.98c	6.22c	6.06c	1.03c	1.07c	1.05c	1.55	1.55	1.55
S.E±	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
N Level (kg N ha^{-1})									
60	6.42ab	6.44b	6.43c	1.11ab	1.11b	1.11c	1.54	1.54	1.54
80	6.71a	6.73ab	6.72b	1.16a	1.16b	1.16b	1.54	1.54	1.54
100	6.60a	7.62a	7.11a	1.14a	1.31a	1.23a	1.54	1.53	1.54
120	6.24b	6.60b	6.42c	1.08b	1.14b	1.11c	1.55	1.54	1.55
S.E±	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
P Levels (kg P $ha^{-1)}$									
6.6	6.15c	6.78c	6.47c	1.06c	1.17	1.12b	1.55	1.54	1.54
13.2	6.78a	6.86b	6.82a	1.17a	1.18	1.18a	1.54	1.54	1.54
26.4	6.54b	6.91a	6.73b	1.13b	1.19	1.16a	1.54	1.54	1.54
S.E±	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Interaction									
T × N	**	NS	*	**	NS	**	NS	NS	NS
T × P	**	NS	NS	**	NS	**	NS	NS	NS
N × P	**	NS	*	**	NS	**	NS	NS	NS
T × N × P	**	**	*	**	NS	**	NS	NS	NS

Means with the same letter are not statistically different at 5% level of significance, * = significant.

intercrop of Maize with *Desmodium intortum* under minimum tillage (MDIC and MDST) and zero tillage practices using 100 kg N ha^{-1} and 26.4 kg P ha^{-1} interacted to impact improved soil quality, fertility and crop production, controlled global warming and climate change.

Significantly improved soil organic matter content under the minimum tillage (MDIC & MDST) and zero tillage (MDNT) treatments when compared with conventional tillage with maize sole cropping (MC) would account for the reduced bulk density values under the minimum tillage practices (Table 2) though not significantly different. This suggests that sequestered carbon in soil under the minimum and zero tillage practices would also cause a reduction in soil bulk density as an attribute of improved soil health/quality.

Calculated soil carbon stock from mean organic carbon and bulk density of the soil at depth 0 - 15 cm (Table 3) reveals that zero tillage practice (MDNT) sequestered significantly ($P < 0.05$) higher carbon stock (18.06 t C ha^{-1}), followed by minimum tillage (MDIC) that sequestered 15.99 t C ha^{-1} than the other

Table 3. Effect of Tillage, N and P fertilizer rates on Bulk Density, Organic Carbon and Carbon Stock over the 0 - 15 cm depth: 2012-2013.

Tillage	Mean Organic Carbon	Mean Bulk Density	SOC
	g·kg^{-1}	Mg m^{-3}	t Cha^{-1}
MC	5.80c	1.55	13.49d
MDIC	6.92b	1.54	15.99b
MDNT	7.87a	1.53	18.06a
MDST	6.06c	1.55	14.09c
	N Levels		
60	6.43c	1.54	14.85c
80	6.72b	1.54	15.52b
100	7.11a	1.54	16.42a
120	6.42c	1.55	14.93c
	P Levels		
6.6	6.47c	1.54	14.95b
13.2	6.82a	1.54	15.75a
26.4	6.73b	1.54	15.55a

Means with the same letter are not statistically different at 5% level of significance, * = significant.

treatments. Also, 100 kg N ha^{-1} and 26 kg P ha^{-1} sequestered significantly higher carbon stock in soils than the other treatments to suggest this minimum tillage and/or zero tillage practices for farmer adoption and environmental sustainability.

Table 4 reveals sole maize with conventional tillage (MC) resulted in significant acidification of the soil (pH 5.20) in 2012 more than the other treatments. However in 2013, MC treatment resulted in better acid condition for nutrient uptake (pH 5.60) than other treatments though not significantly. The 100 kg N ha^{-1} fertilizer rate best modified soil reaction (pH 5.39) than other treatments in 2012, but in 2013, 80 kg N ha^{-1} significantly ($P < 0.05$) modified soil reaction better than the other treatments (**Table 4**). Phosphorus fertilizer rates appear not to have affected soil pH in 2012 and 2013 under this study (**Table 4**).

Total nitrogen in soils after harvest in 2012 and 2013 was least under MC treatment, while MDNT contributed significantly ($P < 0.05$) higher nitrogen values in both years (**Table 4**). Total nitrogen in soil was significantly higher under 80 and 100 kg N ha^{-1} rates in 2012 than other treatments, but in 2013, N-rates did not result in any statistical difference. The 26.4 kg P ha^{-1} rate interacted to cause significant nitrogen deposit (0.60 g·kg^{-1}) in soil than the other rates in 2012, but 6.6 kg P ha^{-1} contributed significant nitrogen deposit in soil (0.66 g·kg·ha^{-1}) than the other rates in 2013. Perhaps, nitrogen fertilizer applied under MC was not adequately exploited by plants, thus leaving higher nitrogen not utilized in the soil than other tillage treatments.

Available phosphorus in soil after harvest in 2012 and 2013 was significantly ($P > 0.05$) higher under MDIC (**Table 4**). Perhaps, this could partly be attributed

Table 4. Effect of Tillage, N and P fertilizer rates on pH, Total N, Avail P, and CEC on Soil in 2012 and 2013.

Tillage	Soil pH (H_2O)		Total N (g·kg^{-1})		Avail P (mg·kg$^{-1)}$		CEC (cmol·kg^{-1})	
	2012	2013	2012	2013	2012	2013	2012	2013
MC	5.20c	5.60a	0.51c	0.52c	5.63c	3.84c	0.69	0.59c
MDIC	5.41a	5.44a	0.61b	0.61b	6.50a	7.84a	0.79	1.86a
MDNT	5.30b	5.53a	0.72a	0.81a	6.14b	7.43a	0.78	2.02a
MDST	5.32b	5.50a	0.50c	0.55c	5.72c	5.37b	0.72	1.06b
SE±	0.02	0.06	0.02	0.002	0.1	0.3	0.05	0.15
N level (kg N ha^{-1})								
60	5.30b	5.43b	0.57b	0.61	5.40c	5.17c	0.63b	1.10b
80	5.32b	5.66a	0.65a	0.62	5.99b	6.59b	0.73a	1.50ab
100	5.39a	5.58ab	0.62a	0.63	7.08a	7.79a	0.86a	1.72a
120	5.23c	5.47b	0.51c	0.63	5.53c	4.94c	0.75ab	1.20b
SE±	0.02	0.06	0.02	0.002	0.1	0.3	0.05	0.15
P level (kg P ha^{-1})								
6.6	5.28a	5.52a	0.56c	0.66a	5.71b	5.85b	0.70b	1.42
13.2	5.31a	5.53a	0.59b	0.61ab	5.58a	6.67a	0.84a	1.33
26.4	5.33a	5.56a	0.60a	0.59b	5.70b	5.84b	0.69b	1.39
SE±	0.02	0.05	0.01	0.002	0.09	0.26	0.04	0.13
Interaction								
T × N	**	NS	**	**	**	**	*	*
T × P	**	NS	*	**	NS	**	**	NS
N × P	**	NS	**	**	NS	**	**	NS
T × N × P	**	NS	**	**	NS	**	**	NS

Means with the same letter are not statistically different at 5% level of significance, * = significant at 5%, ** = significant at 1%, NS = not significant, T = tillage, MC = maize-without *Desmodium* in conventional tillage, MDIC = maize + *Desmodium* incorporated and relayed in conservation tillage, MDNT = maize + *Desmodium* in no-tillage, MDST = maize + *Desmodium* in strip tillage.

to Phosphorus deposited from decomposed roots of maize and Desmodium, Desmodium biomass incorporated at land preparation and Phosphorus fertilizer applications not utilized by plants. The low available phosphorus under MC in 2012 and 2013 could be partly attributed to plant uptake and soil erosion. Soil erosion is pronounced under maize mono cropping [48] [49]. Available phosphorus under MDNT increased from its value in 2013 (6.14 mg·kg^{-1} in 2012 and 7.43 mg·kg^{-1} in 2013), perhaps due to decomposed Desmodium biomass of 2012. Also, 100 kg N ha^{-1} fertilizer rate resulted in 7.79 g·kg^{-1} nitrogen deposit in 2012 and 7.79 g·kg^{-1} nitrogen in 2013 to perform significantly better than the other rates, but was followed by 80 kg N ha^{-1} rate (Table 4).

Similarly, 13.2 kg P ha^{-1} rate significantly contributed higher phosphorus to the soil in 2012 and 2013, than the other rates (Table 4).

Cation exchange capacity of the soil was very low generally and not significantly different in 2012. However, in 2013, MDNT treatment (zero tillage) resulted in significantly higher CEC (2.02 C mol kg^{-1}) than other treatments (Table

4), but was followed by MDIC. Similarly, 100 kg N ha^{-1} rate caused significantly higher CEC values in 2012 and 2013 than other N rates (Table 4). Also, in 2012, 13.2 kg P ha^{-1} resulted in significantly ($P < 0.05$) higher CEC value than other P rates, but the rates were not significantly different in 2013 (Table 4).

Table 5 reveals that in 2012 maize grain yield was not significantly different between tillage treatments, though MDIC resulted in a higher yield (2.18 tha^{-1}) than other treatments. In 2013 however, minimum tillage treatments (MDIC & MDST) and the zero tillage treatments resulted in significantly ($P < 0.05$) higher grain yields than the sole maize (MC) under conventional tillage. Mean grain yields under the minimum tillage with Desmodium intercrops (MDIC) yielded 2.61 tha^{-1}, MDNT yielded 2.57 tha^{-1} and MDST yielded 2.20 tha^{-1} to be preferred for sustainable maize grain production, mitigation of global warming, climate change and environmental conservation over the 2.05 tha^{-1} yield of mono crop maize under conventional tillage (MC).

Nitrogen rates data reveals that 100 kg N ha^{-1} applications caused significantly higher grain yield (2.67 tha^{-1}) in 2012 than the other N-rates and not significantly different yields in 2013. Also, 13.2 kg P ha^{-1} resulted in significantly higher maize grain yields in 2012 (2.15 tha^{-1}) and 3.03 tha^{-1} in 2013 than other

Table 5. Effect of tillage, N and P rates on Maize grain yield in 2012 and 2013.

Tillage	Grain yield (tha^{-1})		
	2012	2013	Mean
MC	1.89a	2.21b	2.05
MDIC	2.18a	3.04a	2.61
MDNT	2.13a	3.00a	2.57
MDST	1.90a	2.50a	2.20
S.E±	0.15	0.04	
N Level (kg N ha^{-1})			
60	1.92a	2.04c	1.98
80	2.06a	2.72b	2.39
100	2.08a	3.25a	2.67
120	1.90a	2.58c	2.24
S.E±	0.15	0.04	
P Level (kg P ha^{-1})			
6.6	1.80a	2.40b	2.10
13.2	2.15a	3.03a	2.59
26.4	2.02a	2.69b	2.36
S.E±	0.13	0.04	
Interaction			
T × N	NS	*	
T × P	NS	**	
N × P	NS	*	

P-rates to be superior in enhancing maize production under this Maize-Desmodium intercrop/Tillage technology.

Table 6 shows the minimum data set (MDS) for soils of the study area and that least bulk density of 1.53 Mg m^{-3} was observed under the zero tillage with *Desmodium intortum* intercrop (MDNT) to suggest improved soil condition for crop roots ramification better than mono crop maize production with conventional tillage (MC) and the other tillage treatments. Also, pH soils at harvest was best under minimum tillage with *D. intortum* incorporated and relayed (MDIC), followed by MDNT (**Table 6**). Similarly, MDNT resulted in highest organic carbon content in soils when compared with the other treatments, but was followed by MDIC. Also, MDNT, followed by MDIC treatments resulted in highest total nitrogen in soils in this study. Subsequently, MDNT sequestered 18.06 t Cha^{-1} carbon stock to outperform the other treatments but was followed by MDIC that sequestered 15.99 t C ha^{-1}. Highest available phosphorus content was contributed by MDIC (7.17 mg·kg^{-1}) and was followed by MDNT (6.77 mg·kg^{-1}), while the least available phosphorus was obtained under MC (4.74 mg·kg^{-1}). Cation exchange capacity was best under MDNT, and followed by MDIC (**Table 6**). The net effect of these physical, biological and chemical interactions on the soil resulted in highest grain yield of 2.61 tha^{-1} under MDIC and MDNT, followed by MDST and least under MC. In summary, total score of the quality assessment gave least score values of 13 under MDIC and MDNT; thus best soil quality (SQ_1) was ascribed to the minimum tillage with *D. intortum* intercrop and relayed (MDIC) and Zero tillage with *D. intortum* (MDNT) treatments. Maize Strip cropped with *D. intortum* treatment (MDST) was ranked SQ_2 as it was assessed next after SQ_1. The Maize under conventional tillage (MC) performed very poorly in the quality assessment and was ranked SQ_3.

Table 6. Mean values of Minimum data set of maize-Desmodium/Tillage technology for soil quality assessment.

Parameters	Units	MC	MDIC	MDNT	MDST
Bulk density	Mg m^{-3}	1.55 (1)	1.54 (2)	1.53 (3)	1.55 (1)
pH		5.40 (4)	5.43 (1)	5.42 (2)	5.41 (3)
Org. C	g·kg^{-1}	5.8 (4)	6.92 (2)	7.87 (1)	6.10 (3)
Total N	g·kg^{-1}	0.52 (4)	0.61 (2)	0.77 (1)	0.53 (3)
SOC	t Cha^{-1}	13.49 (4)	15.99 (2)	18.06 (1)	14.09 (3)
Avail. P	mg·kg^{-1}	4.74 (4)	7.17 (1)	6.77 (2)	5.55 (3)
CEC	C mol kg^{-1}	0.64 (4)	1.33 (2)	1.40 (1)	0.89 (3)
Maize Grain yield	tha^{-1}	2.05 (4)	2.61 (1)	2.57 (2)	2.20 (3)
Total		29	13	13	22
Rank		3	1	1	2

Values in bracket and in red = scores between parameters, those in red and not in brackets = score totals and their ranks among treatments. Values in black represent means of parameters obtained from Tables in text.

4. Conclusions

Soils of Northern Guinea Savanna of Nigeria are continuously and intensively cultivated, resulting in soil quality degradation, carbon stock depletion, accelerated soil erosion and soil nutrient depletion. Therefore, prudent use and management of organic matter in soils are more important now than ever before to meet the high demands for food and fiber production and satisfy the needs of an increasing world population and industrialization. Therefore, managing soils under intensive use and restoring degraded soils have become top priorities for a sustained agronomic and forestry production while conserving soil and water resources. Hence, this study "Tillage with *Desmodium intortum* and fertilizer rates for carbon stock and quality improvement of soils in Northern Guinea Savanna" is aimed at devising possible means of ameliorating identified problems using *Zea mays* as test crop under tillage practices, using *Desmodium intortum* as live mulch.

From this study, it was inferred that the significantly improved soil organic matter content under the minimum tillage practices (MDIC & MDST) and zero tillage (MDNT) treatments when compared with conventional tillage with maize sole cropping (MC) accounted for the reduced bulk density values under the minimum tillage practices. Also, zero tillage practice (MDNT) sequestered significantly ($P < 0.05$) higher carbon stock (18.06 t C ha^{-1}), followed by minimum tillage (MDIC) that sequestered 15.99 t C ha^{-1} than the other treatments. Similarly, 100 kg N ha^{-1} and 26 kg P ha^{-1} sequestered significantly higher carbon stock in soils than the other treatments to suggest this minimum tillage and/or zero tillage practices for farmer adoption and environmental sustainability. The MDNT treatment (zero tillage) imparted significantly higher CEC (2.02 C mol kg^{-1}) than other treatments followed by MDIC. Mean grain yields under the minimum tillage with Desmodium intercrops (MDIC) yielded 2.61 tha^{-1}, MDNT yielded 2.57 tha^{-1} and MDST yielded 2.20 tha^{-1} to be preferred for sustainable maize grain production, mitigation of global warming, climate change and environmental conservation over the 2.05 tha^{-1} yield of mono crop maize under conventional tillage (MC). In conclusion, net assessment of the minimum data set (MDS) effect on the soil resulted in highest grain yield of 2.61 tha^{-1} under MDIC and MDNT, followed by MDST and least under MC. Therefore, total score of the quality assessment judged least score (best) values of 13 under MDIC and MDNT; thus best soil quality (SQ_1) was ascribed to the minimum tillage with *D. intortum* intercrop and relayed (MDIC) and Zero tillage with *D. intortum* (MDNT) treatments. Maize Strip cropped with *D. intortum* treatment (MDST) was ranked SQ_2. The Maize under conventional tillage (MC) performed very poorly in the quality assessment and was ranked SQ_3.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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