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Soil Conservation for Mitigation and Adaptation to a Changing Climate: Sustainable Solutions in the Nigerian Savanna Ecology

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

Soil conservation and quality improvement under intensive land use and fast economic development has become a major challenge for sustainable natural resource use in developing countries such as Nigeria. Conventional tillage is commonly practiced at land preparation and effect of this on soil quality for sustainable productivity has been very discouraging. Therefore measures for mitigating soil degradation, adverse effects of climate change and encouraging adaptation/adoption under intensive agricultural land use were investigated in this study. Conservation Agriculture tillage-based practices with Nitrogen and Phosphorus fertilizer rates' application were studied in a Nigerian Savanna Alfisol. Results show that Conservation Tillage practices involving *in-situ* grown, incorporated and relayed legumes like *Centrosema pascuorum* and *Desmodium uncinatum* ameliorated soil acidity, enhanced soil carbon sequestration, improved cation exchange capacity of the soil, and resulted in higher maize and sorghum grain yields than Conventional tillage and No-Till practices. Conservation tillage (*C. pascuorum in-situ* grown, incorporated and relayed) combined with 100 $kgNha^{-1}$ and 26.4$kgPha^{-1}$ resulted in higher maize grain yield that increased from 2.58 tha^{-1} in 2010 to 3.67 $kgha^{-1}$ in 2011. Conservation tillage (*Desmodium uncinatum in-situ* grown, incorporated and relayed) combined with 50 $kgNha^{-1}$ and

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13.2 $kgPha^{-1}$ resulted in 1.48 tha^{-1} sorghum grain yield that was significantly higher than the other tillage practices.

Keywords: Soil conservation; soil quality; tillage practices; climate change mitigation.

1. INTRODUCTION

Soil conservation and quality improvement under intensive land use and fast economic development has become a major challenge (Friedrich et al. [1]) for sustainable natural resource use in developing countries such as Nigeria. The small-holder agricultural production systems in Nigeria for example, are constrained by numerous factors, including low soil fertility and quality, moisture stress resulting from frequent dry spell occurrence during cropping seasons, soil erosion and runoff (Smaling et al. [2]; Sanchez, [3]; Thierfelder et al. [4]; Odunze [5]; Odunze et al. [6,7]). In the arid and semi-arid regions of Nigeria however, soil moisture deficiencies largely limits sustainable crop production as moisture deficiency often occur in this zone due to dry spells when rainfall amount declines below a minimum threshold required to sustain ecological functions (Odunze et al. [7]; Mando, [8]). Moisture stress for sustainable crop production have become a prominent limitation as climate change, soil erosion, degrading soil fertility and quality status and intensive cultivation practices are common occurrences in the Nigerian Savanna zones. These have necessitated studies on soil conservation practices for sustainable crop production to mitigate soil degradation and encourage adaptation under a changing climate condition. Also, tillage is among important management practices affecting soil quality and crop yield under intensive cultivation practices. It contributes up to 20% of all crop production factors (Khurshid et al. [9), and appear indispensable if food crop production must balance food demand by the growing human and livestock populations and attain national food security on a sustainable basis. Therefore, Conservation Agriculture (CA) which employs minimum soil disturbance/reduced tillage, permanent soil cover/zero tillage and/or crop rotation and its associated practices (Derpsch, [10]; Kassam et al. [11]; Bundy et al. [12]; Friedrich et al. [13]) was adopted in this study. Tillage method affects sustainable use of soil resources through its influence on soil quality (den Biggelaar et al. [14]). Tillage systems; particularly conventional tillage system, adversely affect soil quality by damaging soil structure, decreasing soil moisture content, increasing soil bulk density and root penetration resistance (Rashidi and Keshavarzpour, [15]. Bationo et al. [16]) and Derspsch et al. [10]) reported that continuous cultivation under conventional or intensive tillage leaves soil bare and unprotected, thereby promoting accelerated soil erosion, soil nutrient depletion, soil structure deterioration and leading to excessive high soil temperature. However, No-tillage system improves the soil's moisture retention, aeration, infiltration and reduces runoff and evaporation (Duiker and Myers, [17]; Friedrich et al. [1]). Also, annual disturbance and pulverizing caused by conventional tillage produce a finer and loose soil structure; that could be easily eroded by water or wind, as compared to conservation and no-tillage methods which leaves the soil intact (Rashidi and Keshavarzpour, [18]).

Objective of the present study was to investigate Conservation Agriculture tillage practices, N & P fertilizer rates for quality improvement of Alfisols in the Guinea Savanna of Nigeria, as well as the effect of these on yield of maize and sorghum. Specifically therefore, the study aims at:

- Assessing Conservation Agriculture tillage practices, Nitrogen and Phosphorus rates of applications for soil quality improvement potentials.
- Assessing effect of N & P rates of application on maize and sorghum grain yields under Conservation Agriculture tillage systems.
- To determine the Soil Conservation practice most suited for mitigation and adaptation to a changing climate in the Nigerian Guinea Savanna

2. MATERIALS AND METHODS

These studies were conducted at the Institute for Agriculture Research (IAR) experimental farm Samaru, Zaria (Longitude 7º30` and 7º50` E and latitude 11º00`and 11º10`, with an altitude of 686m above sea level) in the Guinea Savanna ecology of Northern Nigeria. Soils of the study area were classified as Typic Haplustalf according to USDA Soil Taxonomy (Soil Survey Staff, [19]) as cited by Ogunwole, et al. [20]) and

Acrisol in the FAO-UNESCO legend as cited by Valette and Ibanga, [21]) and Uyovbisere et al. [22]). Rainfall pattern of the area is mono modal, having a long term mean annual rainfall between 1979 and 2008 of 986.5 mm, received mainly between May and September with peak rainfall in August (Odunze, [23]). The mean daily air temperature of the area attains 24ºC (Oluwasemire and Alabi, [20]).

The main treatments of this study included tillage practices, N and P-rates as follows;

1. Sorghum mono crop under conventional tillage (SC)
2. Sorghum with *Desmodium uncinatum* live-mluch under No-till (SDNT)
3. Sorghum intercrops with *Desmodium uncinatum* on split old ridges (SDOR)
4. Sorghum intercropped with Desmodium under Conservation tillage after incorporation of previous years' D*esmodium* (SDIC), and for maize;

    1. Conservation Tillage plus *Centrosema pascuorum*(CT+Cp) incorporated and relayed.
    2. Conventional Tillage without *Centrosema pascuorum* (CT)
    3. Permanent Cover with *Centrosema pascuorum* (PC+Cp)

These treatments were replicated three times and three nitrogen rates (60, 80 and 100 $KgNha^{-1}$) treatments were applied in split plots of the main treatments (Tillage) for maize. Urea fertilizer was the source of nitrogen for this trial and was applied in two equal split doses (2 weeks after planting maize, and 6 weeks after planting maize). Also, three rates of phosphorus fertilizer (6.6, 13.3, and 26.4 $KgPha^{-1}$) were applied as a single dose in split plots of nitrogen subplots. Single super phosphate (SSP) was the source of phosphorus and was applied at two weeks after planting of maize. Also, for Sorghum, the Nitrogen rate treatments include 30, 40, 50 and 60 $kgNha^{-1}$ and were each randomized into three contiguous ridges/plot/treatment in the main treatment (Tillage) plots. The sub sub plot treatments include three Phosphorous rates; i.e. 6.6, 13.2 and 26.4 $kgPha^{-1}$ that were randomized, each in one ridge/N rate sub plot.

Main plot size for maize-based treatments was 20 by 15 m^2, or 300 m^2. Two maize (quality protein maize) seeds were planted on ridge peak at 25 cm between stands and 75 cm between ridges in the third week of June 2010 and 2011, and thinned to one plant per hill two weeks later. For sorghum-based treatments, the main plot size was 10 m by 32 m (320 m^2 or 0.032 ha) and replicated four times. Each replicate contained four sub plots and one control plot, each measuring 10 m by 8 m with twelve ridges/rows.

2.1 Climate Change Index/Agro-Climatological Data Analysis

Data for agro-climatological data was obtained from the Agro-meteorological station of the Institute for Agricultural Research, Ahmadu Bello University, Zaria and analyzed for monthly, annual and fifteen years period rainfall totals spanning from 2000 to 2014.

2.2 Soil Analysis

Initial and end of year soil samples obtained at depths 0-15 and 15-30 cm from the field, were air dried, sieved through 2 mm diameter sieve and subjected to laboratory analysis. Parameters evaluated in the laboratory of Department of Soil Science Ahmadu Bello University include Soil particle size distribution by hydrometer method (Gee and Bauder, [24]; Andrew and Carroll,[25]), Soil pH in water at water: Soil ratio of 2:1 using the Pyeunican pH meter (Mc Lean, [26]), Soil organic carbon; by Walkley Black wet oxidation method (Nelson and Sommers, [27]), Available phosphorus; by Bray 1 method (Nelson and Sommers, [27]), Total nitrogen was analyzed by the Kjeidahl digestion method (Bremner and Mulvaney, [28]), Cation exchange capacity of the soils were determined using the 1 NNH_4OAC method (Rhoades, [18]).

2.3 Soil Quality and Changing Trends

Basic indicators selected for a minimum data set were relevant soil data (Andrew and Carroll, [29]) and cereal grain yield obtained in this study for the Nigerian Northern Guinea Savanna zone Alfisols. They were:

i. Data on total carbon, nitrogen, available phosphorus and pH of the soils after crop harvest.
ii. Data on maize and sorghum grain yields for the study period

Soil quality was assessed by using the Parr *et al*. [30] equation; i.e.

$$SQ= f(SP,P,E,H,ER,BD,FQ,MI),$$

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. However, E, H, ER, FQ, and MI were each scored 1.0 because the research field used for the experiment had been on 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. Therefore, SQ= f(SP,P) was used to assess quality of the Alfisols in the Nigerian Guinea Savanna zone.

2.4 Yield Analysis

At physiological maturity, maize and sorghum were harvested from the treatment plots in each replicate. The cobs/heads were air-dried, shelled to separate grains from husks. The grains were further air-dried to 12.5% moisture content, weighed and calculated for an hectare. All maize stalks for each treatment were harvested, air-dried for four weeks, weighed to obtain Stover weights per treatment and calculated for an hectare.

Data obtained were subjected to analysis of variance and significant ($P<0.05$) mean values were separated using Tukey's Honesty Significant Difference test (HSD).

3. RESULTS AND DISCUSSION

3.1 Monthly Rainfall Pattern: 2000-2014

Fig. 1 present’s data on monthly rainfall amounts (mm) in Samaru, Nigeria in the Northern Guinea Savanna from 2000-2014. Rainfall events were largely not recorded in the months of November, December, January, February and March, but were mostly concentrated between June and September. Rain-fed cropping occur dominantly between the months of late May and June for field harvests to occur in October. Therefore the low rainfall amounts of June in 2000 (43.2 mm), 2003 (69.2 mm) and 2009 (80.6 mm); resulting from the occurrence dry spells in June (Fig. 1), would cause insufficient soil moisture availability for crop roots uptake and seed germination.

However, monthly rainfall amounts regularly increased from the months of May to attain a peak in August in 2001, 2002, 2004, 2007, 2008, 2009, 2010, 2011 and 2012 (Fig. 1); suggesting that these increases in monthly rainfall amounts could cause soil erosion, soil degradation, flooding in farmlands and impaired harvest if adequate conservation measures are not taken. The increase in rainfall amounts for July and August as witnessed in 2003, 2009, 2011 and 2012 (300 mm to ≥400 mm) could be accounted for by climate change effects in the zone. Currently, 15 year (2000-2014) mean annual rainfall amount (Table 1) was 1141.78 mm, which differed from the 1979-2008 mean annual rainfall amount of 986.5 mm (Odunze, [31]), suggesting perhaps, that climate change could have caused more total rainfall amounts to be received in the zone than used to be witnessed. The high rainfall amounts of 2001, 2009, 2011 and 2012 (Fig. 2) lends credence to climate change occurrence in the NGS of Nigeria. Therefore, appropriate soil and water conservation measures to ensure sustainable environment, agricultural production and mitigate climate change effects in the ecology are vital.

3.2 Effect of One Year Fallow on Soil Properties

3.2.1 Soil physicochemical properties of trial site under *C. pascuorum*/maize management

Table 2 shows that the soils improved in acidity status (pH in water) when under one year planted fallow with *Centrosema pascuorum* (pH 6.15 at 5-15 cm and pH 5.9 at 15-30 cm depths) than when under natural fallow (pH 5.5 at 5-15 cm and pH 5.75 at 15-30 cm depths. Similarly, available phosphorus, cation exchange capacity, organic carbon and total nitrogen conditions improved under *C. pascuorum* one year planted fallow and at 15-30 cm depths than under Natural Fallow and at 5-15 cm depths (Table 2). This suggests that the soils improved (Friedrich [32]) in their fertility status over a one year *C. pascuorum* planted fallow conditions better than when left fallow with natural vegetation re-growths. However, available Phosphorus, cation exchange capacity, soil organic carbon and total nitrogen contents of the soil improved better at the 15-30 cm depth; perhaps indicating the zone of roots’ utmost activity. The soils were sandy loam in texture, with dominant clay fractions even at the surface layers.

Table 1. Monthly mean rainfall amounts (mm) 2000-2014

Months	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4
Feb	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mar	0	0	19.9	0	13.6	0	0	1.7	0	0	0	0	0	0	0
Apr	0	83.9	69.6	31.0	7.8	63.1	1.8	58.7	72.6	20.3	28.4	13.9	7.3	73.8	101.2
May	136.4	160.4	10.6	78.1	135.1	113.0	202.5	169.4	82.0	62.9	100.0	137.2	417.2	66.5	183.9
Jun	43.2	177.7	133.1	69.2	218.2	160.2	130.1	220.2	120.1	80.6	165.4	257.0	146.4	111.0	119.1
Jul	194.3	267.8	229	243.1	240.7	152.6	232.2	228.8	201.4	169.0	192.9	379.6	124.0	366.9	115.7
Aug	272	360.9	199.8	427.1	306.6	235.5	222.0	374.3	321.5	475.5	278.6	492.6	469.4	132.6	397.4
Sep	182.1	271.7	218.8	219.5	132.1	122.4	275.0	31.9	263.1	261.3	262.4	108.0	256.0	252.4	186.5
Oct	78.2	0	125.2	67.1	20.8	16.8	28.5	8.3	114.4	158.8	89.2	65.6	93.9	25.6	9.8
Nov	0	0	0	0	0	0	0	0	0	0	1.2	0	0	0	0
Dec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	906.2	1323.4	1006.0	1135.1	1074.9	863.6	1092.1	1093.3	1175.1	1228.4	1118.1	1453.9	1514.2	1028.8	1113.6

Long-term mean: 1141.78 mm

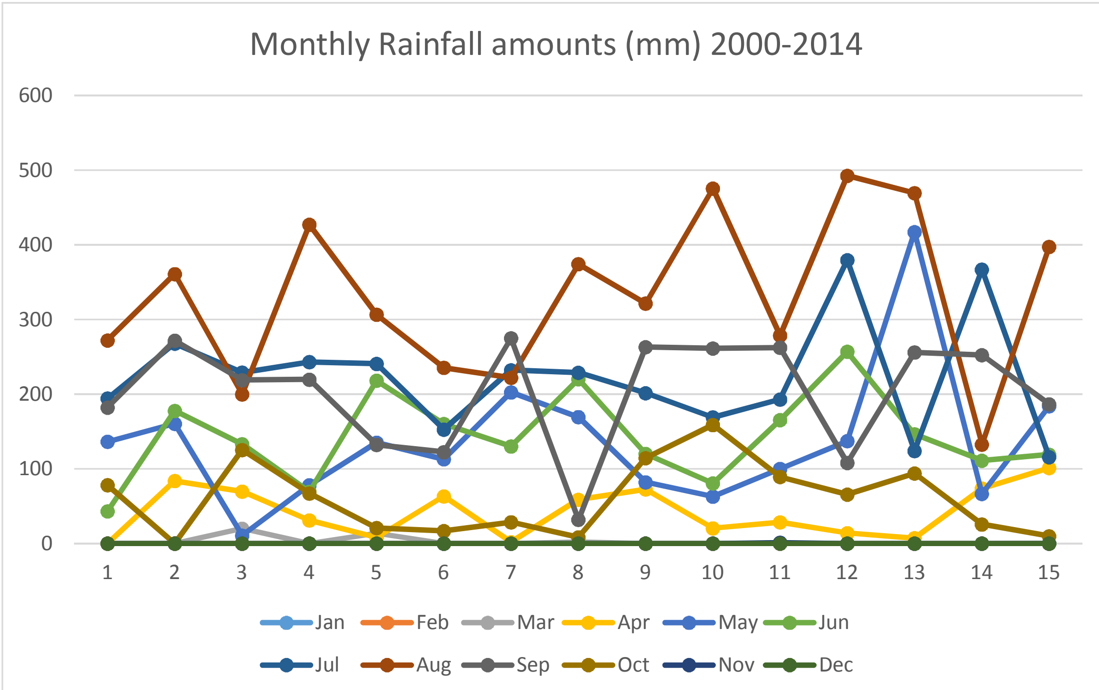

Fig. 1. Rainfall pattern in Samaru, Northern Guinea Savanna of Nigeria

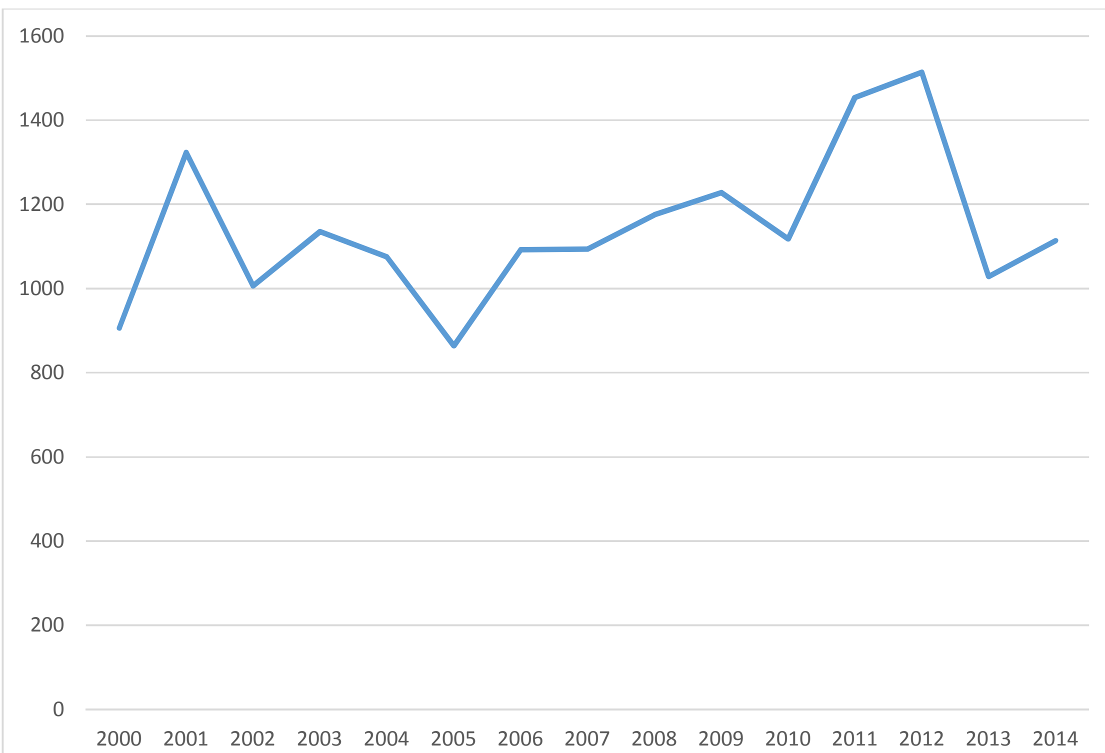

Fig. 2. Annual Rainfall totals (mm) in Samaru, Zaria Nigeria 2000-2014

3.2.2 Chemical properties of soils under *D. uncinatum*/sorghum intercrop

Table 3 also shows that soils at this site were more acid under natural fallow at 0-5 cm (pH 5.9), decreased in acidity at 5-15 cm (pH 6.0) and further increased in acidity at 15-30 cm depth (pH 5.6). Under *Desmodium uncinatum* one year planted fallow, soil acidity decreased at 0-5 cm (pH 6.0) and regularly decreased with depths 5-15 and 15-30 cm depths respectively (Table 3). Also pH under $CaCl_2$ showed increasing acidity with increase in depth under both natural fallow and *D. uncinatum* planted fallow. However, soils under *D. uncinatum* were less acid at comparable depths. Available phosphorus values were low, though relatively higher at 5-15 Cm depth under natural Fallow conditions than under *D. uncinatum* (Table 3). Perhaps, *D. uncinatum* extracted and utilized more phosphorus for protein synthesis, than natural fallow plants (Marschner, [8]. Cation exchange capacity of the soils were generally low (<10 cmolkg^{-1}) and are therefore dominated with kaolinitic clays and sesquioxides of iron, manganese and aluminum and have inherently low fertility status (Odunze [5,23]).

The surface layers (0-5 and 5-15 Cm) of the soil under *D. uncinatum* showed less acidity (in H_2O and $CaCl_2$), improved available phosphorus, cation exchange capacity, soil organic carbon, and total nitrogen.

3.3 Tillage, N & P Effects on the Soils and Yield of Maize

The trial sites were subjected to conservation tillage, nitrogen and phosphorus fertilizer rates treatments to determine most appropriate conservation tillage, nitrogen and fertilizer rates for mitigating inherent poor fertility status of the soils, effects of climate change, ensuring sustainable crop production and environmental conservation. Table 4 shows that relaying *C. pascuorum* and incorporating the past year *in-situ* grown under a reduced tillage practice; referred to as conservation tillage (CT+Cp), caused significantly (P<0.05) less acidity (pH 5.75 and 4.87 in 2010 and 2011 respectively) and improved soil organic carbon from 5.20 gkg^{-1} in 2010 to 5.60 gkg^{-1} in 2011 to be better than the Conventional Tillage (CT) and Zero till with *C. pascuorum* permanent ground cover (PC+Cp). Also, CT+Cp improved in cation exchange capacity from 7.42 cmolkg^{-1} in 2010 to 8.54 cmolkg^{-1} in 2011. However, the zero tillage practice (PC+Cp) showed significantly higher cation exchange capacity (8.54 cmolkg^{-1}) in 2010, but decreased to 8.10 cmolkg-1 in 2011 (Table 4).

Table 2. Initial physicochemical properties of soils under *C. pascuorum*/maize intercrop 2010

Parameters	Depths (cm) natural fallow			Depths (cm) *C. pascuorum* planted fallow		
	0-5	5-15	15-30	0-5	5-15	15-30
pH (H_20)	-	5.50	5.75	-	6.15	5.9
pH ($CaCl_2$)						
Avail. P (mgkg^{-1})	-	5.25	7.44	-	7.0	9.19
CEC (Cmolkg^{-1})	-	6.9	7.9	-	8.6	9.6
Org. C (gkg^{-1})	-	5.40	7.40	-	6.40	8.30
Total N (gkg^{-1})		0.5	0.6	-	0.7	0.8
Particle size (gkg^{-1})						
Sand		160	180		170	170
Silt		280	170		270	280
Clay		560	550		560	550

Textural class: Sandy loam

Table 3. Chemical properties of soils under *D. uncinatum*/sorghum intercrop

Parameters	Depth (cm) natural fallow			Depth (cm) *D. uncinatum* planted fallow		
	0-5	5-15	15-30	0-5	5-15	15-30
pH (H_20)	5.9	6.0	5.6	6.0	5.8	5.7
pH ($CaCl_2$)	5.2	5.0	5.0	5.3	5.3	5.2
Avail. P (mgkg^{-1})	8.3	8.7	7.1	8.5	8.5	6.7
CEC (Cmolkg^{-1})	4.6	5.2	5.3	6.8	5.1	4.8
Org. C (gkg^{-1})	2.4	2.4	2.5	5.3	2.1	1.9
Total N (gkg^{-1})	0.50	0.5	0.5	1.2	1.2	0.5

Table 4. Effect of tillage, N and P on selected soil chemical properties and maize grain yield

Treatments	Soil pH (H_20)		Organic carbon (gkg^{-1})		Total nitrogen (gkg^{-1})		Available phosphorus ($mgkg^{-1}$)		Cation exchange capacity ($Cmolkg^{-1}$)		Maize yield (tha^{-1})	
	2010	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**
Tillage												
PC+ Cp	4.86b	4.10b	5.60a	5.70a	0.40a	0.40a	2.72b	2.92b	8.54a	8.10b	1.54c	2.08c
CT	4.92b	4.09b	4.90b	5.50a	0.40a	0.40a	4.50a	4.85a	7.39b	7.39c	2.42b	3.58b
CT+ Cp	5.75a	4.87a	5.20ab	5.60a	0.40a	0.40a	2.73b	2.93b	7.42b	8.54a	2.58a	3.67a
SE±	0.03	0.03	0.01	0.01	0.02	0.02	0.15	0.15	0.11	0.13	0.08	0.97
N levels ($Kgha^{-1}$)												
60	5.24a	4.32b	5.00b	5.40a	0.40a	0.40a	4.24a	3.63a	8.03a	8.40a	1.62c	2.57c
80	5.10a	4.44a	5.20ab	5.60a	0.40a	0.40a	3.71b	3.09b	7.95a	7.64b	2.03b	2.99b
100	5.15a	4.30b	5.60a	5.60a	0.40a	0.40a	4.00ab	3.99a	7.37b	7.99ab	2.87a	3.77a
SE±	0.03	0.03	0.01	0.01	0.02	0.02	0.15	0.15	0.11	0.13	0.08	0.97
P levels ($Kgha^{-1}$)												
6.6	5.19a	4.38a	5.40ab	5.70a	0.40a	0.40a	4.04ab	3.24b	7.70b	8.16a	1.87c	2.86c
13.2	5.19a	4.35a	4.90b	5.30a	0.40	0.40	4.35a	3.35b	8.07a	8.02a	2.14b	3.17b
26.4	5.15a	4.33a	5.54a	5.70a	0.30b	0.30b	3.56b	4.10a	7.58b	7.86b	2.50a	3.30a
SE±	0.03	0.03	0.01	0.01	0.02	0.02	0.15	0.15	0.11	0.13	0.08	0.97

*Means with the same letter are not significantly different at P<0.05 using Tukey's Honesty Significant difference (HSD) *=Significant at P<0.05; NS= Not significant*

Under the tillage practices, Conservation tillage (CT+Cp) treatment increasingly sequestered significantly ($P<0.05$) soil organic carbon from 2010 (5.20 gkg^{-1}) to 2011 (5.6 gkg^{-1}), to support increasing maize grain yield from 2.58 tha^{-1} in 2010 to 3.67 tha^{-1} in 2011. Also between the N-rates, 100 $kgNha^{-1}$ supported significantly higher maize grain yields in both 2010 and 2011 (Table 4). Similarly, 26.4 $kgPha^{-1}$ rate supported significantly higher maize grain yield that increased from 2.50 tha^{-1} in 2010 to 3.30 tha^{-1} in 2011 to be better than the other treatments. These findings suggests that the combination of Conservation tillage (CT+Cp), 100 $kgNha^{-1}$ and 26.4 $kgPha^{-1}$ would improve quality of the soils (Van Bevel [33]) to support sustainable maize grain yield, conserve the environment, mitigate effects of climate change; thus sustainably improving farmer income and livelihoods while conserving the environment.

3.4 Tillage, N and P Effects on Soil and Yield of Sorghum

Table 5 reveals that the tillage practices with or without *Desmodium uncinatum* resulted in reduced soil pH (increased acidity) though mean values were not significantly different between treatments. The No-till (SDNT) treatment with *D. uncinatum* permanent cover sequestered significantly ($P<0.05$) higher organic carbon (6.90 gkg^{-1}) but was followed by Conservation tillage with incorporated and relayed *D. uncinatum* (SDIC- 5.8 gkg^{-1}) that was also significantly higher than Conventional tillage (SC-3.60 gkg^{-1}) and split old ridge with relayed *D. uncinatum* (4.90 gkg^{-1}). Sorghum grain yield under SDIC was also significantly higher (1.48 tha^{-1}) and was followed by SDNT (1.32 tha^{-1}); both of which were significantly higher than SC (1.17 tha^{-1}) and SDOR (1.20 tha^{-1}). The P-rates appear not have influenced any significant change on the soil pH, organic carbon, total nitrogen and sorghum grain yield. However, 13.2 $kgPha^{-1}$ resulted in significantly higher soil pH (5.50 in water, 4.72 in $CaCl_2$), organic carbon (5.50 gkg^{-1}), total nitrogen (1.60 gkg^{-1}) and available phosphorus (9.21 $mgkg^{-1}$) than the other treatment, and followed by 26.4 $kgPha^{-1}$ (8.95 $mgkg^{-1}$). The 50 $kgNha^{-1}$ rate resulted in optimal soil pH (pH 5.50 in water and 4.75 in $CaCl_2$), organic carbon (6.80 gkg^{-1}), total nitrogen (1.60 gkg^{-1}) and sorghum grain yield (1.35 tha^{-1}) that were significantly higher than the other treatments (Table 5). These findings suggest that the combination of Conservation tillage, 13.2 $kgPha^{-1}$ and 50 $kgNha^{-1}$ would ensure sustainable sorghum grain production, restore soil quality, conserve the environment and mitigate effects of climate change while affording higher financial returns to the farmer and enhancing their livelihoods.

3.5 Soil Quality Rankings

The soils were ranked from 1 to 5 on the values of pH, organic carbon, available phosphorus, total nitrogen grain yields (Table 6 above), where 1 is best or highest % value and 5 is least % value for avail. P, Org. C., total N, and grain

Table 5. Effect of Management (Mgt.) practices on selected soil chemical properties and sorghum yield at the *D. uncinatum*/sorghum site: 2011- 2012

Treatments	pH		Org. C	Avail. P	Total N	Sorghum yield
	H_20	$CaCl_2$	gkg^{-1}	$mgkg^{-1}$	gkg^{-1}	tha^{-1}
SDOR	5.54a	4.80ab	4.90b	8.14c	1.60a	1.20c
SDIC	5.53a	4.75ab	5.80ab	9.48b	1.70a	1.48a
SDNT	5.46a	4.78ab	6.90a	10.19a	1.30c	1.32b
SC	5.38a	4.69b	3.60c	8.21c	1.50b	1.17d
SE±	0.031	0.024	0.19	0.27	0.05	0.08
P rates ($kgha^{-1}$)						
6.6	5.47a	4.74a	5.10a	8.84b	1.50a	1.30a
13.2	5.50a	4.72a	5.50a	9.21a	1.60a	1.28a
26.4	5.46a	4.73a	5.40a	8.95b	1.50a	1.30a
SE ±	0.027	0.021	0.17	0.234	0.04	0.07
N rates ($kgha^{-1}$)						
30	5.50a	4.71a	4.50c	8.83ab	1.60a	1.30a
40	5.10b	4.70a	4.80c	9.35a	1.40c	1.20a
50	5.50a	4.75a	6.80a	8.81ab	1.60a	1.35a
60	5.41ab	4.72a	5.40b	9.01a	1.50b	1.32a
SE ±	0.031	0.024	0.190	0.270	0.05	0.08

Table 6. Soil quality rankings for *C. pascuorum*/ maize and *D. uncinatum*/sorghum tillage treatments

Treatments	SDOR	SDIC	SDNT	PC+Cp	CT+Cp
pH (H_20)	5.54 (2.97%) 1	5.53 (2.79%) 2	5.46 (8%) 3	4.10 (25%) 5	4.87 (19.07%) 4
Org. C	4.90 (36.11%) 3	5.8 (61.1%) 2	6.9 (91.67%) 1	5.7 (3.64%) 4	5.6 (1.82%) 5
Avail.P	8.14 (-0.85%) 4	9.48 (15.47%) 2	10.19 (24.12%) 1	2.92 (-8.21%) 5	2.93 (0.34%) 3
Total N	1.60 (6.67%) 2	1.70 (13.33%) 1	1.30 (-13.33%) 4	0.4 (0.00)3	0.40 (0.00) 3
Grain	1.20 (2.56%) 3	1.48 (26.50%) 1	1.32 (12.82%) 2	2.08 (-41.90%) 5	3.67 (2.51%) 1
Total score	13	8	11	22	16
SQ ranks	3	1	2	2	1

value for avail. P, Org. C., total N, and grain yield. For pH, best (1) is least value and 5 is worst. Soils under SDIC for sorghum production and CT+Cp for maize production were rank best soil quality (SQ1) but were followed by No-Till treatments (SDNT & PC+Cp) rated SQ2. The tillage SDOR was rated SQ3. Therefore, the conventional tillage practices (SC & CT) least improved the soils (SQ5).

4. SUMMARY AND CONCLUSION

4.1 Summary

Common crops grown in the Nigerian savannah zone include maize, sorghum, millet, cowpea, soybean, groundnut and cotton. However the soils are inherently poor in fertility status, have poor water holding capacity and witness incessant dry spells during the cropping season. Sustainable solutions for mitigating inherent poor fertility status and moisture stress, while adapting to climate change and conserving soils of the Nigerian savanna zone for sustainable agricultural production require that conservation measures be advanced and adopted in the zones. From this study, fertility status of the soils improved over a one year *C. pascuorum* and *D. uncinatum* planted fallow conditions better than when left fallow with natural vegetation re-growths. Available phosphorus, cation exchange capacity, soil organic carbon and total nitrogen contents of the soil improved better at the 15-30 cm depth; perhaps indicating the zone of *C. pascuorum* root utmost activities. Surface layers (0-5 and 5-15 Cm) of soils under *D. uncinatum* one year planted fallow showed less acidity (in H_2O and $CaCl_2$), improved available phosphorus, cation exchange capacity, soil organic carbon, and total nitrogen; thus indicating that low soil fertility could be mitigated when put under planted fallow with appropriate legume even for one year.

Conservation tillage practices evaluated in this study show that for maize, the practice involving incorporation of relayed *in-situ* grown legumes (*Centrosema pascuorum*) of the previous year and relaying same legume as live-mulch (CT+Cp) in combination with 100 $kgNha^{-1}$ and 26.4 $kgPha^{-1}$ fertilizers better enhanced maize grain yield. Also for sorghum production, conservation tillage practice involving incorporation of the previous year *in-situ* grown *Desmodium uncinatum* and relaying it again (SDIC), combined with 50$kgNha^{-1}$ and 13.2 $kgPha^{-1}$ best enhanced sustainable sorghum grain production in the savanna Zone Alfisols than the other treatments. Also the conservation tillage practices using *C. pascuorum* and *D. uncinatum* best improved soil quality at harvest better than the other treatments.

4.2 Conclusion

It would therefore be concluded from this study, that one year planted fallow with appropriate herbaceous legume improved soil fertility conditions. Also, conservation tillage practice involving incorporation of previous year *in-situ* grown herbaceous legume like *Centrosema pascuorum* and *Desmodium unicinatum*, and relaying same, combined with 100 $kgNha^{-1}$ and 26.4 $kgPha^{-1}$ for maize and 50 $kgNha^{-1}$ and 13.2 $kgPha^{-1}$ for sorghum production would mitigate the low soil fertility condition of the soils, effects of climate change, conserve the soils and ensure sustainable grains production in the Nigerian savannah zone Alfisols. Also, the conservation tillage practices using *C. pascuorum* and *D. uncinatum* best improved soil quality (SQ1) better than the other treatments. Adopted conservation agriculture tillage practices rated SQ1 did not constrain land tenure systems being practiced, enhanced soil quality for sustainable grain yields and are therefore plausible solutions for mitigation and adaptation/adoption in the Nigerian Savanna ecologies.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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