SHORT-TERM EFFECT OF TILLAGE, BRADYRHIZOBIUM INOCULATION AND NITROGEN FERTILIZER APPLICATION ON CARBON STOCK AND SOIL NITROGEN IN MAIZE-SOYBEAN CROPPING SYSTEMS IN NIGERIA ALFISOL

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Abstract

The role of soil carbon and nutrients conservation and management is gaining more attention in mitigating climate change, while enhancing sustainable food production. To such, short-term experiments (2011 and 2012) were conducted at the Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria to assess the role of some integrated soil management on soil health under maize-soybean cropping systems. Split-split plot design was used for establishment of the research with three replications using TGX-1448-2E and SAMMAZ 14 as test crops. The treatments were reduced and conventional tillage as main plot, rhizobium inoculated soybean-maize intercrop, rhizobium uninoculated soybean-maize intercrop, rhizobium inoculated soybean-maize rotation and rhizobium uninoculated soybean-maize rotation as sub plot and 0, 40, 80 and 120 kg N ha^{-1} application rates as sub-sub plot. The soil samples taken from each experimental plot were analysed. The results showed that organic carbon (OC) and nitrogen (TN) were consistently higher in reduced tillage (RT) (6.59 and 1.11 g/kg) than under conventional tillage (CT) (6.32 and 1.06 g/kg) respectively. Carbon stock obtained was 11.42 % higher in RT treatment. The values of OC, TN and carbon stock obtained under rhizobium inoculated soybean-maize rotation was significantly higher, followed by rhizobium inoculated soybean-maize intercrop and rhizobium uninoculated soybean-maize intercrop. Significant difference was found among effects of N rates on carbon stock and total nitrogen, which were consistently lower in control plots. The study demonstrated that integration of rhizobium inoculation in maize-soybean cropping systems under tillage practices; especially reduced tillage in combination with 80 kg N ha^{-1} improved soil productivity for mitigating climate change and global warming.

Keywords: Tillage, Rhizobium inoculation, Nitrogen fertilizer, carbon stock and nitrogen status

Introduction

Soil organic carbon (OC) influences nitrogen cycling; greatly influencing the productivity of savanna Alfisols. Soil organic C and total N (TN) contents play crucial roles in sustaining productivity of the soil and environmental quality Bauer and Black, (1994); Doran and Parkin, (1994); Robinson *et al.* (1994) due to their effects on soil physical, chemical, and biological properties, such as soil water retention, nutrient cycling, gas flux, and plant root growth (Sainju and Kalisz, 1990; Sainju and Good, 1993). Soil, as an open system, can be a net source of CO_2 released to the atmosphere due to elevated OC mineralization as a result of disruptive agricultural practices, especially during tillage operations. On the other hand, the soil can function as a net sink for sequestering atmospheric CO_2 under appropriate soil tillage practice and crop management; thus, reducing atmospheric CO_2 (Paustian *et al.,* 1992; Lal *et al.,* 1995). This would subsequently enhance SOCs and TN status of soil promoting productivity of savanna Alfisols.

The SOCs and TN status of a soil often influence soil fertility and productivity, depending also on their forms, sources, concentration, and cultivation practices. Tillage enhances the mineralization of soil organic C and nitrogen (N) by incorporating crop residues, disrupting soil aggregates, and increasing aeration (Tangyuan *et al*. 2009). Conservation tillage, allow deposition of crop residues on the soil surface which resulted to accumulation of soil organic matter, improved aggregate stability and water infiltration, and enhance biological efficiency (Liebig *et al*., 2004; Sundermeries *et al*., 2011). But conservation tillage though fairly adaptable to local conditions has been shown by Wall (2007) to promote slow SOCs and TN mineralization. But conservation tillage is a complex, fairly flexible agricultural system that can be widely adapted to local conditions Wall (2007) and also shown to promote slow mineralization of SOCs and TN. Nitrogen fertilization improves crop production and some soil quality attributes but also increases the potential for NO_3-N leaching and N_2O-N emissions, especially when applied in excess of crop requirements (Malhi and Lemke 2007). However, frequent tillage and excessive nitrogen fertilizer application not only reduces crop productivity but also exacerbates soil erosion, air and ground water pollution (Hundera *et al.*, 2001, Godfray *et al.*, 2010).

Declining SOCs and TN contents in Nigerian savanna soils was due to continuous cropping in combination with conventional tillage and total removal of plant residues after harvest, which is a threat to sustainability of maize-based cropping systems. To a large extent, this has contributed to soil fertility problems that are widely perceived and regarded as major limitations to increasing crop yields and a peril to sustainable maize-based cropping systems (Nkhuzenje *et al*., 2002). Use of chemical fertilizers is one of the conventional ways of managing soil fertility problems, but it has long-term effects on soil productivity. Its use has been proven to have two major shortcomings: inability of smallholder and resource-poor farmers to procure enough fertilizers and soil acidification (Jou *et al*., 1997). According to Cassman and Pingali (1995), fertilizers alone cannot sustain crop yield for a long period. In continuous maize cropping with two to three crops grown annually for example, the use of N fertilizer increases with time but yields often remain stagnant or decreases (Nkhuzenje *et al*., 2002). This implies that higher fertilizer use and sustainable cropping systems would produce the same yield level; and that decline in yield is a response to nutrient toxicity/or imbalance.

Legumes-cereal rotation or intercrop is often practised so as to make cereal crops benefit from the significant roles of legumes in maintaining organic carbon and nitrogen status of the soil (Amusat *et al.*, 2014). Rhizobium-inoculated soybean in the cropping systems under reduced tillage (minimum soil disturbances) can meet most of the crop’s N needs and contribute to soil N through a symbiotic nitrogen fixation (Omeke, 2016). Legumes have been shown to reduce N fertilizer application in maize production by 18-68 kg N ha^{-1}, when compared to fallow system (Petrickova, 1992; Yusuf, 2007). Studies have indicated that legumes can fix between 16 to 450 kg N ha^{-1} $year^{-1}$ under optimal field conditions (Giller, 2001; Yusuf *et al*., 2009). However, optimum legume N-benefits can only be achieved in the presence of efficient rhizobial strains, which can be native to the soil or introduced in the form of commercial inoculants. Studies in the northern Guinea savanna of Nigeria relating to soil fertility problems include responses to inoculation with rhizobium such as Sanginga, (2003); Vanlauwe *et al*. (2003); Okogun *et al*. (2005) and nitrogen fertilizer and legume-rotation effect on maize performance Yusuf *et al*. (2009). Study also pointed out that soil tillage and crop system effects on SOCs and soil N quality depend on the soil type and climatic variability. 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 (Balasubramanian and Nnadi 1980; Tanimu *et al.*, 2007), are not returned to restore soil carbon stock and fertility (Odunze *et al*., 2017). Also continued intensive cultivation, coupled with annual non-return of crop residues to the soil has conferred impoverished soil productivity status and necessitated the study on ‘soil sequestration and carbon stock under maize/legume cropping system in Alfisols of a Savanna zone, Nigeria (Odunze *et al*., 2017). Generally, maize-based cropping systems commonly practice in the Northern Guinea grassland savanna of Nigeria with reference to soybean/maize relays, strip, sole cropping of maize and soybean with or without rhizobium inoculation. The present study therefore intends to evaluate carbon stock and total nitrogen status under variable tillage practices in combination with soybean inoculated with rhizobium and nitrogen fertilizer application in maize-soybean cropping systems with a view to determine most sustainable management practice(s) best enhanced productivity of Northern Guinea Savanna Alfisols.

Materials and Methods

A field study was conducted at the Research Farm of the Institute for Agricultural Research, Ahmadu Bello University (IAR/ABU), Samaru, Zaria during the 2011 and 2012 cropping seasons. The research field was located within longitudes 11^{o} 11' N and latitudes 007^{o} 37' E (Figure 1). Samaru has an average of 686 m above sea level and is located in the Northern Guinea savanna ecological zone of Nigeria. Samaru receives a total rainfall of 1207 mm in 2011 and 1333 mm in 2012. The temperature and rainfall data for 2011 and 2012 (Figure 2 and 3) were obtained from the Meteorological Unit of the Institute for Agricultural Research, Ahmadu Bello University, Samaru, Zaria. The weather station is located about 100 m away from the experimental field. The rainfall and temperature data obtained for both seasons fell within the long-term range, with temperature of 21.05^{o}C (minimum) and 33.47^{o}C (maximum) and annual rainfall of 1011 ± 161 mm. The main soil sub-group is Typic Haplustalf (Awujoola, 1979) or Chromic Cambisols according to the FAO system of soil classification (FAO, 2001).

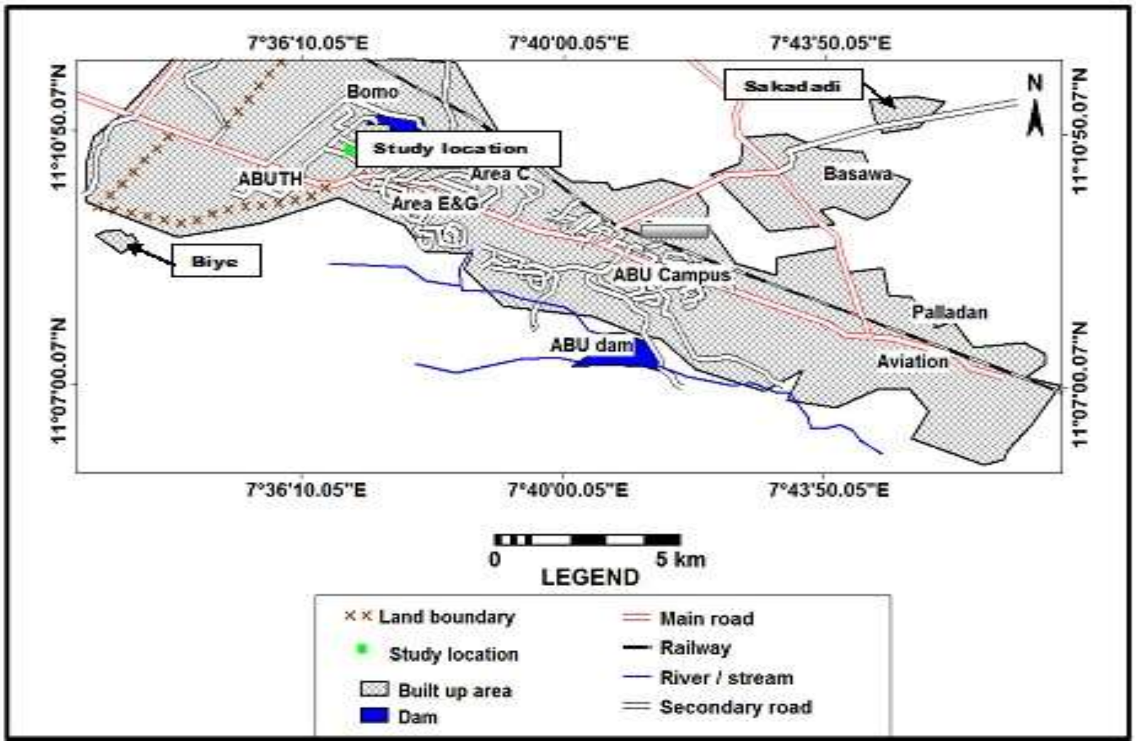


Fig. 1: Map of Samaru, Zaria showing the study location

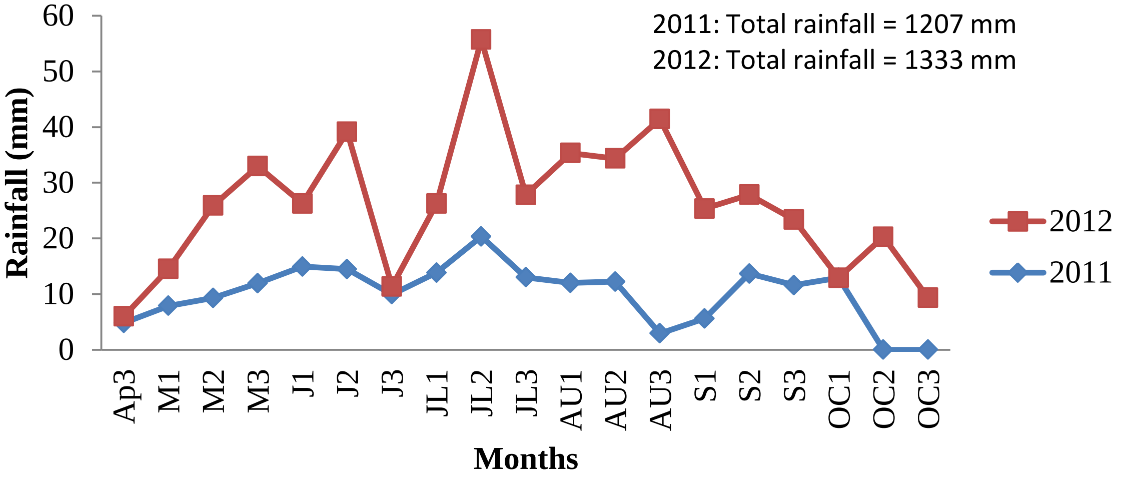


Fig. 2: Decadal rainfall patterns in Samaru during 2011 and 2012 cropping seasons

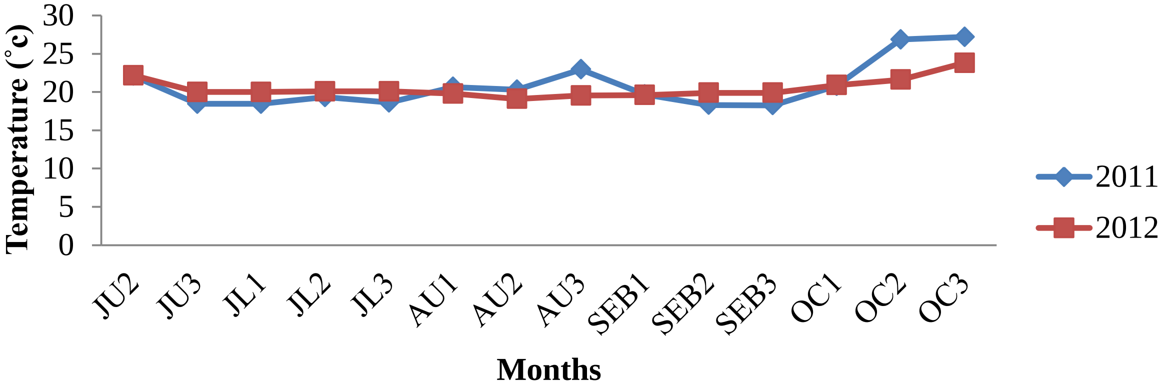


Fig. 3: Decadal temperature patterns in Samaru during 2011 and 2012 cropping seasons

Treatments and Experimental Design

The experiment was a split-split plot design in a randomized complete block design with three replicates in both 2011 and 2012 cropping seasons. The 2011 field experiment was established mainly to create enabling soil environment to carry out effect of the following rhizobium inoculation in soybean-maize-based cropping systems; inoculated rotation, uninoculated rotation, inoculated intercrop and uinoculated intercrop in 2012 field experiment. It was for this reason that no soil and plant samples were collected in 2011 field experiment. The treatments were two tillage practice as main plots (reduced and conventional tillage), four rhizobium inoculation in soybean-maize-based cropping systems; as sub plots (inoculated soybean-maize intercrop, uninoculated soybean-maize intercrop, inoculated soybean-maize rotation and uninoculated soybean-maize rotation) and four nitrogen fertilizer rates as sub-sub plots (0, 40, 80 and 120 kg N ha^{-1}). The conventional tillage (CT) was manually ridged at 0.75 m row spacing using the hoe and remoulded at 8 weeks after sowing. For reduced tillage (RT) treated seeds were sown directly without ridging at 0.75 m spacing between the rows after the field was demarcated into plots. Each plot measured 6 m by 5 m (eight ridges; 5 m long), and a total of 96 plots were used for the research. The intercropping system was maize/soybean intercrop in the order of 2 rows maize to 2 rows soybean (2:2); this was maintained for both seasons. The crop rotation system was soybean–maize rotation, with soybean planted in 2011 (1:0), followed by maize in 2012 (0:1). Soybean (TGx 1448-2E) and maize (SAMMAZ 14) were used as test crops. However, no plant residues management after harvest was employed in both seasons rather the residues left after harvest were completely removed by farmers within the location as fire wood and animal fodder (feeding their animals).

Soybean seed inoculation and planting

The soybean seeds were inoculated with commercial rhizobium inoculants, Legume-fixed at 400 g ha^{-1} (inoculated soybean), while some seeds were not inoculated with rhizobium inoculants (uninoculated soybean). Before inoculation, the soybean seeds were sterilized, as outline by Vicent (1970). Both maize and soybean seeds were sown on 1st July 2011 and 16th July 2012 respectively. The maize seeds were sown manually, two seeds per hole at an intra-line or intra-row spacing of 25 cm. The seedlings were thinned to one plant per stand at two weeks after sowing to give a plant population of approximately 53,333 plants ha^{-1}. Soybean seeds were drilled on the lines or ridges and covered lightly with soil. The uninoculated soybean treatment rows were sown first in order to avoid cross contamination. The seedlings were thinned to one plant per hill at a spacing of 5cm to achieve a population of approximately 266,667 plants ha^{-1}.

Fertilizer application

Phosphorus fertilizer (single super phosphate; SSP) and potassium (Muriate of potash; MOP) were applied to all the plots planted to maize at the rate of 60 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1}, whereas those of soybean received 40 kg P_2O_5 ha^{-1} and 20 kg K_2O ha^{-1} at planting in both seasons, respectively. The sub plots were divided into four; only maize plots in both cropping seasons received urea fertilizer application at the rates of 0 kg N/ha, 40 kg N/ha, 80 kg N/ha and 120 kg N/ha. Nitrogen fertilizer rate was applied in two splits; first application (1/3) was done at four weeks after sowing, while the remaining part (2/3) was done as second application at eight weeks after sowing.

Soil sampling

Initial soil samples were collected systematically by dividing the field into eight sections. A total of 16 points; two points per division within the field were sampled using the soil auger at 0-15 cm depth before trial establishment. The samples were bulked and thoroughly mixed and a composite sample was taken, processed and stored for analysis. At the end of the field experiments in 2012, four disturbed surface soil samples (0-15 cm depth) were taken at alternate points from four inner ridges per plot (96 soil samples) using a soil auger. The samples were bulked to form a composite sample per plot. The sub-samples taken were bagged and properly labelled. A part was air-dried, crushed lightly and sieved through the 2 mm and 0.5 mm sieves in readiness for carbon and nitrogen analysis. Undisturbed soil samples were taken from the net plot, comprising two inner rows per plot using core sampler; these were used to determine the bulk density and soil depth.

Laboratory analysis

Particle size distribution was determined by the hydrometer method, as described by Gee and Bauder (1986), using sodium hexametaphosphate as a dispersing agent. The textural classes were obtained from the USDA textural triangle. The bulk density was measured using core method (Grossman and Reinsch, 2002). The moist core soil sample was oven-dried at 105°C for 24 h, until a constant dried weight was obtained.

$$Bulk\ density\ (BD\ g/cm) = \frac{\text{Oven dry soil sample (g)}}{\text{Volume of core cylinder } (cm^3)} \qquad (1)$$

Soil porosity was calculated using a mathematical relationship between bulk density and particle density (Foth, 1984). Porosity (P) was computed as follows:

$$\text{P (\%)} = 1 - \frac{BD}{PD} \text{x} 100 \qquad (2)$$

Where P= Porosity, BD=Bulk density (g cm^{-3}) and PD=Particle density (2.65 g/cm^3).

Soil pH was determined electrometrically in duplicates both in distilled water and 0.01M calcium chloride solution. A soil-solution ratio of 1:2.5 was used and read on a pH meter (Hendershot *et al.*, 1993). The total nitrogen in soil was determined by micro-Kjeldahl digestion method as described by Bremner and Mulvaney (1982). Organic carbon was measured using the Walkley-Black method as described by Nelson and Sommers (1982). The carbon nitrogen (C/N) ratio was computed by dividing percent organic carbon by percent total nitrogen. While carbon stock (***SOCs)*** as a product of *bulk density*, OC concentration, and layer thickness (soil depth). This was estimated by the following equation:

$$\text{SOCs} = \Sigma\, Db_i\, C_i\, D_i \qquad (3)$$

Where;

SOCs is the carbon stock (kg C m^{-2}), Db_i is the bulk density (g cm^{-3}) of layer i, C_i is the proportion of organic carbon (g C/g) in layer i, D_i is the thickness of this layer (cm).

Statistical analysis

Data collected were subjected to analysis of variance (ANOVA) using the mixed linear model Procedure of SAS, Institute Inc., (2009). Effects of the various factors and their interactions were compared by computing least square means and standard errors of difference (SED) at 5 % level of probability. The relationship between carbon stock, total nitrogen and some soil properties were evaluated using correlation (r) analysis.

Results and Discussion

Initial soil characterization

The initial characteristics of soils at the experimental site are presented in Table 1. Results showed that the textural class was sandy loam with 9.9 % clay. The values of bulk density 1.41 g cm^{-3} and total porosity 52.83 % were medium in the soil (Esu, 1991).

Table 1: Initial soil properties of the experimental site

Soil properties	Unit	Test value
Bulk density	Mg m^{-3}	1.41
Moisture content	g kg^{-1}	229.55
Total porosity	%	52.83
Sand	g kg^{-1}	671.20
Silt	g kg^{-1}	230.00
Clay	g kg^{-1}	98.80
Texturalclass		Sandy loam
pH in H_2O		5.40
pH ($CaCL_2$)		4.50
Available phosphorus	g kg^{-1}	9.14
Total nitrogen	g kg^{-1}	0.46
Organic carbon	g kg^{-1}	5.50
Carbon nitrogen ratio		12
Bacteria	$cfug^{-1}$ soil	8.50×10^6
Fungi	$cfug^{-1}$ soil	3.44×10^6
Microbial biomass carbon	mg kg^{-1}	188.68
Microbial biomass nitrogen	mg kg^{-1}	16.98
$C_{mic}:N_{mic}$		11:1

The soil reaction was slightly acidic, while available P was medium (9.14 mg kg^{-1}) (Esu, 1991). The soil was characterized by low organic carbon 5.50 g kg^{-1}, total nitrogen 0.46 g kg^{-1} and carbon nitrogen ratio 12, indicating that the soil was low in fertility (Esu, 1991). Enumeration of soil microorganisms revealed the presence of more bacteria than fungi. The result obtained from the soil on microbial biomass carbon was higher than microbial biomass nitrogen with a ratio of 11:1.

Soil organic carbon

Data on the effect of tillage practices on soil organic carbon are presented in Table 2. Soil organic carbon (OC) was not significantly different among the tillage systems. However, the initial value of OC of the soil was lower than that obtained under both tillage systems, with a difference of 21.63 % for CT and 28.36 % for RT. Cropping system had a significant effect on soil organic carbon (Table 2). The four cropping systems evaluated in this study revealed substantially greater OC contents than initial OC contents obtained at the same 0-15 cm depth before the commencement of the experiment. The soil under inoculated soybean-maize rotation had the highest OC content, which was significantly different from other cropping systems. The soil under uninoculated soybean-maize intercropping had the lowest OC content, and was not significantly ($P>0.05$) different from that of uninoculated soybean-maize rotation.Data on the effect of nitrogen fertilizer rate on soil organic carbon content indicated a significant difference (Table 2). The result revealed a value greater than the initial value of 5.50 g kg^{-1} obtained from the experimental field. The plots treated with 120 kg N ha^{-1} resulted in higher OC content, followed by 80 kg N ha^{-1}. The least was found in soil under 0 kg N ha^{-1} application, which increased with increase in N fertilizer rate (Table 2).

Soil total nitrogen (TN)

Soil tillage systems had a significant effect on TN in 2012 (Table 2). Values of soil TN were lower in soil under CT plots, compared to that under RT plots. The percentage difference between RT and CT was 6 .31 %, whereas the value increase in both tillage practices when compared with the initial TN of the soils before the experiment. The results on the effects of various cropping systems on total soil N at 0 to 15 cm depth indicated significant difference at 5 % level of probability (Table 2). The total N in inoculated soybean-maize rotation and inoculated soybean/maize intercrop was higher than those in the other two cropping systems involving soybean without inoculation. Total N in the plots previously cropped with inoculated soybean (rotation) or maize/inoculated soybean (intercrop) was 57.97 % and 48.28 % higher than those in rotation plots with uninoculated soybean, and intercrop with uninoculated soybean, respectively. The results showed significant differences between the cropping systems with inoculated soybean, as well as those without inoculation. Cropping systems with inoculated soybean in rotation contributed the highest amounts of N (1.49 g kg^{-1}) to the soil, followed by inoculated soybean intercropped with maize (1.09 g kg^{-1}); the lowest amount was recorded for uninoculated soybean intercropped with maize 0.78 g kg^{-1}), considering the initial TN in soil. Furthermore, data on the effects of nitrogen fertilizer application on soil TN content are presented in Table 2. Total N in soil was significantly affected by N fertilizer rates at probability level of 5 %. The value was higher in soil with 120 kg N ha^{-1} (1.14 g kg^{-1}), followed by 80 kg N ha^{-1} (1.10 g kg^{-1}). The least was obtained for plots without N fertilizer. The result revealed that TN in soil increases with an increase in N fertilizer rate. The values of TN ranged from 1.04 to 1.14 g kg^{-1} across the N fertilizer rates. Thus, soil TN content indicated a consistent increase with corresponding N fertilizer application rate, with a significant difference between 120 kg N ha^{-1}and other treatments, but at par with 80 kg N ha^{-1}. Similar trend was observed at 40 kg N ha^{-1} (1.06 g kg^{-1}) and 0 kg N ha^{-1} (1.04 g kg^{-1}) application rates.

Table 2 Properties of soil productivity indicators as influence by tillage, cropping systems and nitrogen fertilizer application

Treatment	OC (g/kg)	TN (g/kg)	C/N Ratio	SOCs (kg C m^{-2})
		Tillage (TS)		
Conventional tillage	6.02^{b}	1.02^{b}	5.90^{a}	11.65^{b}
Reduced tillage	6.89^{a}	1.11^{a}	6.21^{a}	12.98^{a}
SE±	0.09	0.03	0.20	0.11
		Cropping system (CS)		
Rotation inoculated	8.05^{a}	1.49^{a}	5.40^{b}	15.09^{a}
Rotation uninoculated	5.84^{c}	0.99^{c}	5.90^{b}	10.95^{c}
Intercrop inoculated	6.75^{b}	1.09^{b}	6.19^{a}	13.06^{b}
Intercrop uninoculated	5.18^{c}	0.78^{d}	6.56^{a}	9.87^{c}
SE±	0.30	0.02	0.14	0.30
		N Rate (kg ha^{-1})		
0	5.36^{c}	1.04^{b}	5.15^{c}	6.35^{d}
40	6.39^{b}	1.06^{b}	6.03^{ab}	10.27^{c}
80	6.57^{b}	1.10^{ab}	5.97^{b}	12.42^{b}
120	7.51^{a}	1.14^{a}	6.59^{a}	14.31^{a}
SE±	0.27	0.01	0.1	0.21
		Interaction		
TS*CS	NS	*	*	*
TS*Nrate	NS	NS	NS	
CS*Nrate	NS	NS	NS	*
TS*CS*Nrate	NS	NS	NS	NS

OC = Organic carbon, TN = Total nitrogen, C/N = Carbon : nitrogen ratio, SOCs = Carbon stock, NS = Not significant at $P<0.05$, * = significant at $P<0.05$; Values with different letters (a or b or c) are significantly ($P<0.05$) different and Values with same letters (a or b or c) are not significantly ($P<0.05$) different

Soil carbon to nitrogen ratio (C/N ratio)

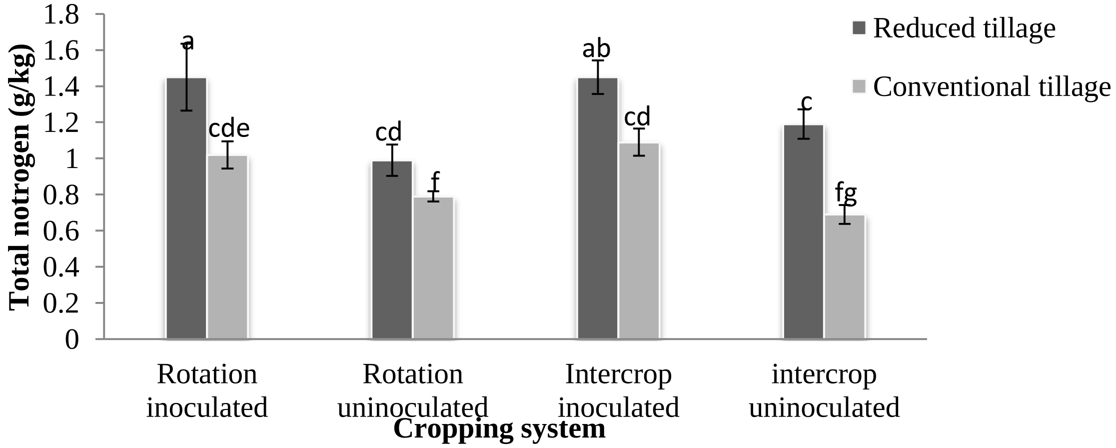
The data presented in Table 2 also showed no significant difference between the tillage systems on C/N ratio in the soil studied. The values were lower in soil under RT than CT with 0.34 %. Generally, the soil C/N ratios under the two tillage systems were lower than the values obtained before the experiment. The soil C/N ratios under the various cropping systems ranged from 5.40 to 6.56, with a mean of 6.01 (Table 2). The C/N ratio obtained in soil under cropping systems were significantly different ($P<0.05$). The ratio were also generally low, with the highest value occurring for both inoculated and uninoculted soybean-maize intercropping system. However, there were significant differences in the results for inoculated and uninoculated soybean-maize rotation. The same trend was recorded for inoculated and uninoculated soybean-maize intercropping system. There was also a significant difference in the results for N fertilizer application rates on C/N ratio (Table 2). The values were generally low compared to the initial value obtained before field establishment, the highest value being for soil treated with 120 kg N ha^{-1}, which was significantly at par with that for 40 kg N ha^{-1}. The values ranged from 5.15 to 6.59, with a mean of 5.93. Generally, the value obtained at 0 kg N ha^{-1} application was significantly lower than those of other N treatment plots, having percent differences of 17.08 % for 40 kg N ha^{-1}, 15.92 % for 80 kg N ha^{-1} and 27.96 % for 120 kg N ha^{-1}.

Soil Carbon Stock (SOCs)

The amount of carbon stock (SOCs) obtained in soil under tillage is presented in Table 2. The values were significantly affected by tillage systems. Reduced tillage (RT) had greater SOCs than conventional tillage (CT) with 11.42 % difference. Cropping systems had a significant effect on SOCs (Table 2). The values obtained under inoculated soybean-maize rotation system were higher followed by inoculated soybean-maize intercrop and least in uninoculated soybean-maize intercrop. The percentage difference between the inoculated soybean-maize rotation and uninoculated soybean-maize rotation system was 37.81 %. Whereas, that of inoculated soybean-maize intercrop and uninoculated soybean-maize intercrop system was 32.32 %. The result obtained on SOCs differ significantly between N fertilizer application rates which was significantly lower in soil under control as presented in Table 2. The SOCs values were consistently lower in soil under control plots which gradually increases as N fertilizer rates increased. The differences between control plots and others N treatment plots were 61.73 % for 40 kg N ha^{-1}, 95.59 % for 80 kg ha^{-1} and 125.35 % for 120 kg N ha^{-1}.

Interaction of tillage, cropping systems and N fertilizer application on TN, C/N ratio and SOCs

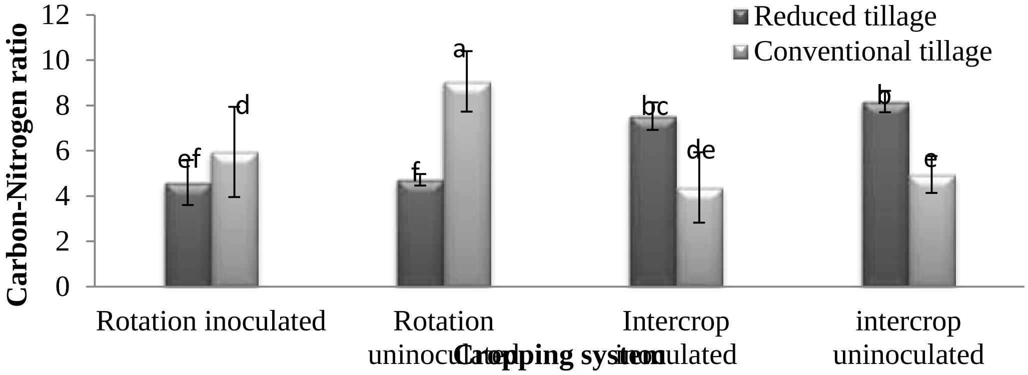
Significant interactions between tillage and cropping systems were only observed for TN (Figure 4), C/N ratio (Figure 5) and SOCs (Figure 6). Similar observations were found but between cropping systems and N fertilizer application rates on SOCs (Figure 7). The TN content of the soil found under RT was significantly higher in combination with inoculated soybean-maize rotation which was at par with inoculated soybean-maize intercropped under same tillage practice compared to other tillage and cropping system combinations. The result also revealed that uninoculated soybean-maize rotation under reduced tillage practice combination had no significant ($P< 0.05$) difference on soil total N contents under inoculated soybean-maize rotation and inoculated soybean-maize intercropped in combination with conventional tillage. Reduced tillage with inoculated soybean-maize rotation and uninoculated soybean-maize rotation recorded lower C/N ratio which was similar to the value obtained in inoculated soybean-maize intercropping under conventional tillage. Whereas, higher C/N ratio was found under uninoculated soybean-maize rotation with conventional tillage followed by uninoculated soybean-maize intercropped under reduced tillage practice.



Standard error = Error bar

Fig. 4: Tillage and cropping systems interaction on TN in soil

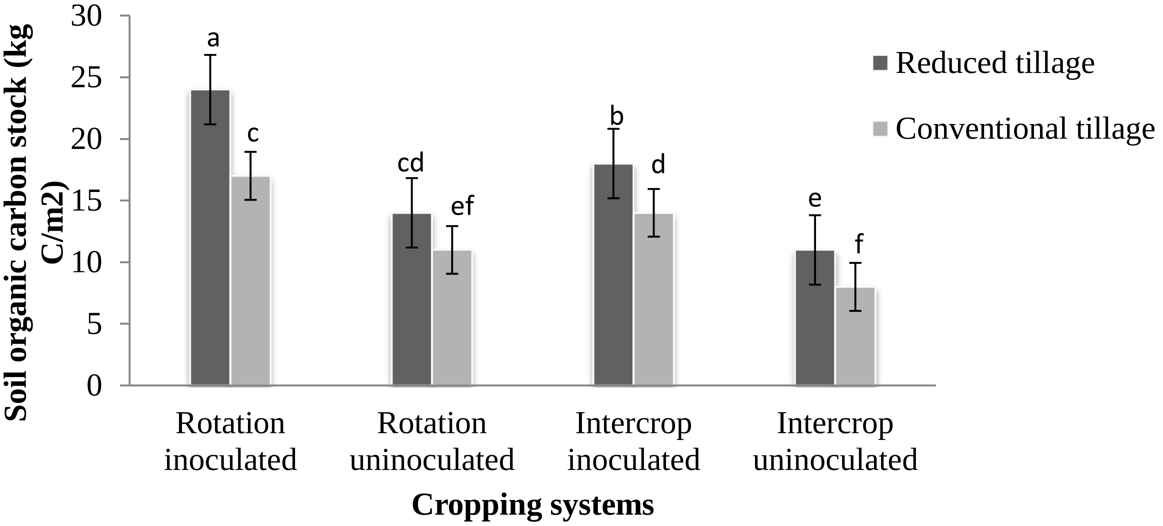
Bars with different letters are significantly (P<0.05) different, Values with different letters (a or b or c) are significantly (P<0.05) different and Values with same letters (a or b or c) are not significantly (P<0.05) different



Standard error = Error bar

Fig. 5: Tillage and cropping systems interaction on carbon-nitrogen ratio in soil

Bars with different letters are significantly (P<0.05) different, Values with different letters (a or b or c) are significantly (P<0.05) different and Values with same letters (a or b or c) are not significantly (P<0.05) different



Standard error = Error bar

Fig. 6: Tillage and cropping systems interaction on soil organic carbon stock in soil

Bars with different letters are significantly (P<0.05) different, Values with different letters (a or b or c) are significantly (P<0.05) different and Values with same letters (a or b or c, or d, or f) are not significantly (P<0.05) different

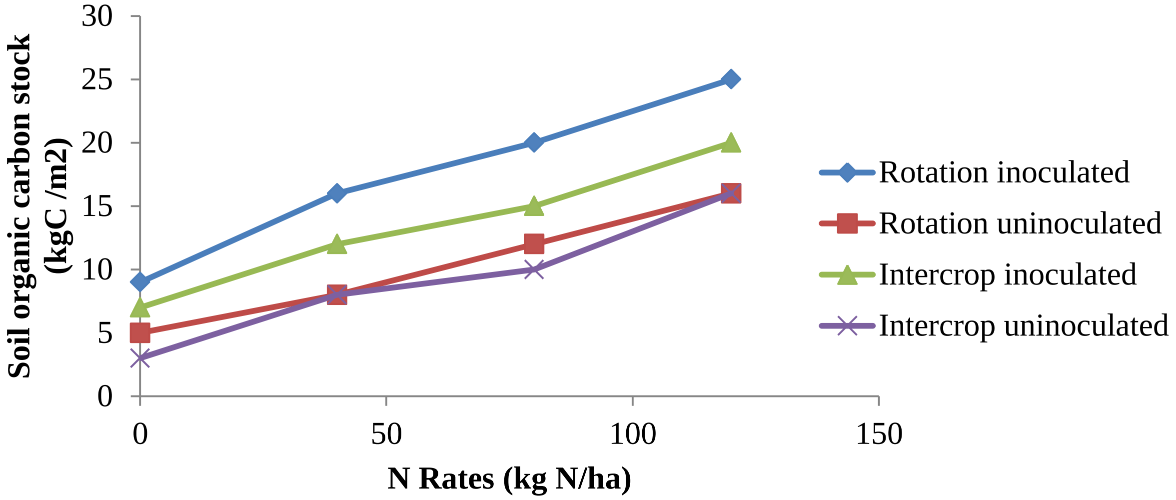


Fig. 7: Cropping systems and N fertilizer application rates interaction on soil organic carbon stock in soil

Correlation (r) analysis between SOCs, TN and some soil properties

The results of correlation coefficient between selected SOCs, TN and selected soil properties are presented in Table 3. Carbon stock (SOCs) was significantly and positively related to TN; r=0.79*, OC; r=0.58*, MBN; r=0.66* and MBC; r=0.71** and negatively correlated with C:N ratio; -0.68**, Av. Phosphorus r = - 0.65** and BD; r = - 0.73*. However, OC and TN ratio significantly ($P < 0.05$) correlated with MBN and MBC which were positive.

Table 3 Correlation coefficient (r) between organic carbon stock and selected soil properties

	TN	OC	C:N	SOCs	Av. P	BD	MBN	MBC
OC	0.77**							
C:N	-0.55**	0.68*						
SOCs	0.79*	0.58*	-0.68**					
Av. P	-0.65^{ns}	-0.44^{*}	-0.42	-0.65^{**}				
BD	-0.66*	-0.44^{*}	0.56^{*}	-0.73**	-0.92**			
MBN	0.65**	0.60*	-0.71**	0.66^{*}	0.61^{*}	-0.63^{**}		
MBC	0.78*	0.58*	-0.64**	0.71**	0.76^{**}	-0.68^{**}	0.71**	

TN =Total nitrogen, OC=Organic carbon, C:N =Carbon : nitrogen ratio, SOCs= Soil organic carbon stock, Av. P = Available phosphorus, MBN=Microbial biomass nitrogen, MBC= Microbial biomass carbon, ** = Significant at 1 %, * = significant at 5 % and ns = Not significant

Initial Soil Characterization

The results showed that the textural class was sandy loam with 9.9 % clay. The values of bulk density was slightly above 1.39 Mg m^{-3} reported for surface soil of the same Northern Guinea Savanna (Oikeh *et al.*, 1998). The slightly acidic nature of the soil, low TN and OC reflected the true characteristic of a savanna Alfisol, which was due to uptake of basic cation by plant through cultivation and, partly, to the overall removal of crop residues by farmer after harvest. The available P in the study soil was medium, which falls below the critical level of 10 to 15 mg kg^{-1} according to the ratings of Esu (1991) and NSPFS (2005). The northern Guinea savanna of Nigeria is characterized by intensive cultivation, coupled with low input use and low capital base, resulting in reduced soil fertility and productivity. Extensive leaching and uptake of basic cation without replacement, rapid decomposition of organic matter due to high temperature, short fallow periods characterized by intensive cultivation and low input use and low capital base are largely responsible for low fertility in the Nigerian savanna (Omeke *et al.*, 2016). The higher number of bacteria than fungi in the soil suggested a normal arable soil condition of the studied site. This could be attributed to more of arable soil resources than forestry that largely support the growth of bacteria in the soil. Isirimah *et al.* (2010) revealed that fungi are more in population in forest soils than arable soils. This could also be attributed to availability of lignin and cellulose rich substrates in forest ecosystems.

Soil organic carbon (OC) and total nitrogen

The significantly higher value of organic carbon and total nitrogen found in reduced tillage could be attributed to reduced mineralization rate of soil organic matter due to less soil disturbance and greater protection of OC fractions within soil aggregate (Al-Kaisi *et al.*, 2005). However, the differences found in soil organic carbon and TN content in response to tillage practices at surface soil of 0-15 cm depth, compared to initial value, were most likely due to the short-term implementation of the tillage, and the quantity of plant residues returned to the soil. The soil organic carbon impacted by tillage within the short-term are small, relative to the pool of soil organic carbon already present in the soil (Ellert *et al.,* 2001). However, greater total N contents in soil under RT may have accrued from more ground cover and slow decomposition rate due to settlement of crop residues on the soil surface and decreased contact of crop residues with soil microorganisms (Schomberg and Steiner, 1999; Omeke *et al.*, 2016). This implies that RT enhances redistribution of SOCs and TN protection closer to the soil surface than CT. Cropping systems with inoculated soybean in rotation contributed greatest amounts of OC and TN to the soil, followed by inoculated soybean intercrop with maize. The least contributor was uninoculated soybean intercrop with maize, considering the initial soil TN. This could be attributed to additional N_2 fixed (residual effect of rotation) due to effectiveness of rhizobium strain used as inoculants and possibly supported by low nitrogen content and C/N ratio of the soil. Thus, a low C/N ratio suggests the release of soil nitrogen in available form to plants due to high microbial activity, while the reverse is the case for high C/N ratio. Other factors that can increase OC content in the cropping system are crop residues accruing from nodule mass, root and in-season fall-off leaves, as well as leftover shoot system after harvest for improvement of carbon stock. Plant root system may be more important than above-ground crop residues in sustaining soil organic carbon (Al-Kaisi *et al*., 2005) and enhanced mitigation of climate change. This would be more enhanced under inoculated soybean-maize cropping systems, suggesting higher soil productivity improvement and climate change mitigation, compared to other cropping systems without inoculated soybean. The result also showed that soil OC and TN increased with corresponding N fertilizer rate and was significantly higher in plots that received 120 kg N ha^{-1} than other N treatments, but was at par with 80 kg N ha^{-1}. The implication is that N fertilizer application improves OC and N status of the soil. This can partly be explained by the changes in composition of SOM; suggesting that addition of inorganic N reversed immobilization of mineral N by microorganisms (Karborzova-Saljnikov, 2004) due to a reduction in C/N ratio. It is an indication that the N mineralization process exceeded immobilization process, which raises N in the study soil. This may be supported by low C/N ratio obtained in soil under N treatments that reflected increase in microbes (bacteria) activity due to N application, which invariably enhanced decomposition and mineralization.

Soil organic carbon stock (SOCs)

Significantly high values of SOCs (12.98 kg C m^{-2}) found in soil under RT might be attributed to less interruption of soil during land preparation which favours accumulation of plant residues on the top soil. The result agrees with previous reports that higher levels of SOCs are found under reduced tillage (conservation tillage), compared with conventional tillage (Mahdi *et al.*, 2005). In contrast, conventional tillage can reduce the storage of this component, because it incorporates crop residue into the soil, disrupts soil aggregates, and increases soil aeration (Cambardella and Elliott, 1992). It would therefore be inferred that conventional tillage promotes negative change in carbon stock, to advocate that continuous land preparation by conventional tillage practice; would cause adverse organic carbon depletion and impoverished carbon stock and subsequently enhanced global warming, climate change and degraded soil quality for sustainable crop production (Odunze et al., 2017). The variability in carbon stock in soil among the cropping systems could be attributed to the differences in biomass production and C/N ratio of the residues accrued from either soybean or maize or both crops, which influences microbial activity and carbon sequestration (stock). Rate of organic carbon input from plant biomass is generally considered the dominant factor controlling the amount of SOCs present in the soil (Campbell *et al.,* 2000). This implies that the higher plant biomass observed for inoculated soybean-maize intercrop and rotation than uninoculated intercrop and rotation might be attributed to the greater residues accruing from in-season and after harvest activities, which also serve as substrate for SOCs pool. Carbon sequestration (stocks) are commonly high when large amounts of organic C are returned to the soil either after harvest (Adeboye, 2009) or in-season leaves fall and root biomass which was reflected under inoculated rotation. Therefore, continuous supply of C source with low C/N ratio like soybean in maize-based cropping system would serve as an energy source for microbial activity in the soil (Gouaerts *et al*., 2007). To a large extent; this would also contribute to improvement of soil productivity and mitigation of climate change and global warming. Differences observed on carbon stock under N fertilizer treatments could be due to the fact that N fertilizer applied enhanced below ground biomass and residue production either by maize and soybean crops which serves as source of C for microbial activity. Subsequently, enhanced carbon stock especially on the top soil due to N fertilization as a result of increased plant biomass production, which stimulates soil biological activity (Dick, 1992). Nitrogen fertilization could also increase SOCSs due to availability of readily available soil nitrogen which could provide a food source for soil bacteria increasing their population. The lower plant below ground biomass under control treatments may reduce the amount of root exudates released to soil, which have important functions in promoting growth of soil microorganisms (Zhong *et al*., 2010). Nitrogen fertilization, therefore, has the potential to increase SOCs by increasing crop residue input (Brown, 2013) and due to the flexible nature of plant stoichiometry, N fertilization usually also results in higher residue quality (low C:N ratio; Russell *et al*., 2009). Therefore, the soil of the study area needs N fertilizer for sustainability of its productivity.

Effect of tillage, cropping systems and N application interaction on TN, C/N ratio and SOCs

Significant interaction observed between tillage and cropping systems on TN and C/N ratio as well as N rate and cropping systems implies that agronomic practices like integration of soybean inoculated or uninoculated in the maize-based cropping system under tillage practices influences SOCs and N status of the soil. Differences observed among the cropping systems in combination with tillage practices could be a result of higher soil pulverization by CT, which accelerates decomposition of soil organic matter (Rahman *et al.,* 2008) and possibly TN losses through leaching and plant uptake. Generally, the high TN in inoculated soybean-maize rotation under RT can be attributed to low C/N ratio of the soil and soil N improvement due to residual effect of effectiveness of inoculants used. The improvement of N content of the soil in legume–cereal cropping system could mainly be attributed to N contained in the legume roots and nodules since the grains and haulms were removed at harvest and in-season falling of leaves, as well as residues after harvest. The higher SOCs observed in inoculated soybean-maize rotation cropping system under N fertilizer application rates at 80 and 120 kg N ha^{-1} interaction may be due to response of N fertilizer application by maize following soybean which enhances carbon stock in the soil. Different fertilization regimes resulted in significantly higher carbon stocks and total N in the soils with mineral fertilizer additions compared with those without additions of N fertilizer (Blair *et al.*, 2006; Ludwig *et al.,* 2007), suggests that Northern Guinea savanna Alfisol needs N fertilizer for sustainable crop production.

Correlation (r) analysis between soil SOCs, TN and some soil properties

The implication of positive correlation is that, as the soil organic carbon stock increases, other soil properties (TN, OC, MBN, MBC) increases. Whereas the negative correlation suggests that as the soil properties (C:N ratio, Ava. Phosphorus and BD) decreases the soil organic carbon increases. This relationship suggests that amounts of SOCs in the soil significantly influenced the levels of TN, OC in soil due to crops competition with microbes for N. Generally, the nature of correlation relationship found in this study might be due to improvement of soil properties especially TN and OC of the soil by integration of inoculated soybean in the cropping systems in combination of reduced tillage and N fertilizer application. Similar correlation relationship of MBC and MBN with soil properties was earlier reported by Moore *et al*. (2000); Bala *et al*. (2010) and pH and clay with heavy metal by Orhue *et al*. (2011).

Conclusion

The study revealed that reduced tillage promotes higher organic carbon (OC), soil organic carbon stock (SOCs) and nitrogen (TN) content of the soil than conventional tillage. Results also show that values of OC, SOCs and TN content of the soil were improved under inoculated soybean-maize rotation by 49.48 % for OC, 57.97 % for TN, higher than the uninoculated soybean-maize rotation. Similar observation was obtained between inoculated and uninoculated soybean-maize intercropping system. Those cropping systems with soybean inoculated with rhizobium were inferred to have best improved soil health for sustainable soil productivity and climate change mitigation. Integration of inoculated soybean with rhizobium in the maize-based cropping systems in combination with N fertilizer application at 80 kg N ha^{-1} promotes higher carbon sequestration (stock) and soil N as compared to other treatments combination. This could cause improve carbon stock and N content of the Northern Nigeria savanna Alfisol for sustainable crop production, mitigate climate change and global warming.

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