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Assessment of Soil Organic Carbon and Grain Yields under Soybean-maize-based cropping systems and nitrogen fertilizer application in the Savanna Alfisol of Nigerian

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ABSTRACT

The study was conducted during the 2020 and 2021 cropping seasons at the experimental farm of the Institute for Agricultural Research (IAR), Samaru, Zaria in the Northern Guinea Savanna ecology of Nigeria. The study aimed to access the soil organic carbon and maize production in the Savanna Alfisol under Soybean-maize-based cropping systems and nitrogen fertilizer application. The experiment was a split-plot arrangement in a randomized complete block design with three replicates using an improved soybean variety (TGX-1448-2E) and maize variety (SAMMAZ 15). The treatments were four soybean-maize-based cropping systems (Soybean-maize intercrop, Soybean-maize rotation, continuous sole maize and continuous sole soybean) as main plot and four nitrogen fertilizer rates (0, 40, 80 and 120 kg N ha^{-1}). Soybean/maize rotation gave the highest amounts of OC soil, followed by inoculated soybean/maize intercrop and the lowest values were recorded under continuous sole maize cropping in both years and combined. The organic carbon content of the soil was influenced by N fertilizer application rates which significantly increases as N rate increased in both seasons and combined. The value of grain yield recorded under continuous sole maize was lower than other soybean-maize cropping with a difference of 51.51 % in 2020 and 68.48 % in 2021 for soybean-maize rotation, and 43.41 % in 2020 and 57.87 % in 2021 for soybean-maize intercrop. Stover yield under 120 kg N ha^{-1} was significantly higher than other treatments plots with a difference of 9.21% for 80 kg N ha^{-1}, 40.63 % for 40 kg N ha^{-1} and 76.20 % for 0 kg N ha^{-1} in 2020, and 1.63% for 80 kg N ha^{-1}, 38.25 % for 40 kg N ha^{-1} and 80.65 % for 0 kg N ha^{-1} in 2021. This implies that the integration of soybean in maize-based cropping systems in combination with nitrogen fertilizer management would improve the organic carbon status of the soil and maize yield.

1.0 Introduction

Declining productivity of Nigerian Savanna soils due to continuous cropping under conventional tillage is posing a threat to the sustainability of maize-based cropping systems. Soil chemical fertility problem is widely perceived and regarded as a major limitation to increasing crop yields and a peril to sustainable maize-based cropping systems (Nkhuzenje *et al*., 2002). The use of chemical fertilizer is one of the conventional ways of managing soil infertility problems, but it has long-term effects on soil productivity. Its use has two major shortcomings: the inability of smallholder and resource-poor farmers to procure the fertilizer, and soil acidification (Jou *et al*., 1997). According to Cassman and Pingali (1995), fertilizer alone cannot sustain crop yield. In continuous maize cropping with two to three crops grown annually, for example, the use of N fertilizer increases with time but the yields often remain stagnant or decrease (Nkhuzenje *et al*., 2002). This implies that higher fertilizer use and a sustainable cropping system would produce the same yield level; and that decline in yield is a response to nutrient deficiency, possibly due to overuse of fertilizer or cultivation practice.

Legumes-cereal rotation or intercrop is often practiced so as to make cereal benefit from the significant roles of legumes in maintaining soil fertility (Amusat *et al*., 2014) and productivity. Rhizobium-inoculated soybean in cropping systems under minimum soil disturbances can meet most of the crop's N needs and contribute to soil N through symbiotic nitrogen fixation. Legumes have been shown to reduce N fertilizer application in maize production by 18-68 kg N ha-1, when compared to the fallow system (Petrickova, 1992). Studies have indicated that legumes can fix up to 450 kg N ha^{-1} $year^{-1}$ under optimal field conditions (Giller, 2001). Also, legumes fixed between 16 to 50 kg N ha^{-1} of their total N and had an estimated N contribution to soil ranging from -22 to 3 kg N ha^{-1} depending on the ratio of N derived from atmosphere and N harvest index (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 with respect to soil productivity problems included responses to inoculation with rhizobium (Sanginga, 2003; Vanlauwe *et al*., 2003; Okogun *et al*., 2005, Omeke 2016) and nitrogen fertilizer and legume-rotation effect on maize performance (Yusuf *et al*., 2009; Omeke, 2016). But there is little information on the incorporation of legumes inoculated with rhizobia in the dominant maize-based cropping systems in combination with nitrogen fertilizer application. The current research, therefore, sought to investigate the effect of the integration of soybean maize-based cropping systems and nitrogen fertilizer application on soil carbon and crop yields of Nigerian Savanna Alfisol.

2.0 Materials and methods

2.1 Description of the Study Area

The study was conducted during the 2020 and 2021 rainfed cropping seasons at the experimental farm of the Institute for Agricultural Research (IAR), Samaru, Zaria (latitude 11°11'19.3"N and Longitude 7°37'02"E) in the Northern Guinea Savanna ecology of Nigeria. The long-term mean annual rainfall of the study area is 986.5mm and is concentrated between May and October with a peak in August (Odunze et al., 2011). The mean daily air temperature (maximum and minimum) ranges between 15°C and 38°C (Oluwasemire and Alabi 2004). Soil type of the study area was classified as Typic Haplustalf according to USDA Soil Taxonomy (Soil Survey Staff, 2004) as cited by (Ogunwole and Ogunleye 2004) and Acrisol in the FAO-UNESCO legend as cited by (Valette and Ibanga, 1984) and (Uyovbisere et al., 2000). The soils are low in inherent fertility, organic matter, and cation exchange capacity (CEC) and dominated by low-activity clays (Jone and Wild, 1975; Odunze, 2003).

2.2 Treatments

The experiment was a split-plot arrangement in a randomized complete block design with three replicates using an improved soybean variety (TGX-1448-2E) and maize variety (SAMMAZ 15). The treatments were seven maize-soybean-based cropping systems (inoculated intercrop, inoculated rotation, continuous sole maize, uninoculated intercrop, uninoculated rotation, continuous sole soybean inoculated and uninoculated) as main and four nitrogen fertilizer rates (0, 40, 80 and 120 kg N ha^{-1}). Each plot size was measured 5 m x 8 ridges with a total of 84 plots and planting pattern of 2 rows maize and 2 rows soybean (2:2). Nitrogen fertilizer (Urea) and potassium (Muriate of potash; MOP) were applied to all the plots at the rate of 20 kg N ha^{-1} and 20 kg K_2O ha^{-1} respectively. The field was plowed, harrowed and ridged at 75 cm between ridge distances and 96 plots. The plot size was 8 ridges by 10 m (60 m^2).

2.3 Sampling and Analysis

All plants within the net ridges of each plot at crop physiological maturity (when 95 % of plants were brown) were cut at ground level, bagged, air-dried and manually threshed for both seasons. The following measurements were obtained: weight of stover yield, and grain yield per plot. The grain and stover yields were recorded in kg ha^{-1}. Also, soil samples were collected in each plot at 0-15 cm depth using a soil auger, air dried, sieved and bagged in readiness to soil laboratory analysis.

Soil pH was measured in the supernatant suspension of 1: 2.5 soils and water mixture by using a pH meter. Soil organic carbon was determined by using Walkley and Black method as described by Okalebo *et. al*., 2002. While total nitrogen of the soil was determined by the Kjeldahl method (Bremner and Mulvaney, 1982; Okalebo *et. al*., 2002). Available phosphorus was determined by the Bray 1 method (Bray and Kurtz, 1945).

2.4 Statistical Analysis

Data collected were subjected to analysis of variance (ANOVA) using the mixed linear model Procedure (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 productivity of the soil was assessed using the productivity index

3.0 Result and discussion

3.1 Characterization of the soil properties of the experimental site

Some of the physical and chemical properties of the studied site are presented in Table 1. The soil reaction was slightly acidic. The Organic carbon (3.72 gkg^{-1}), nitrogen (0.46 gkg^{-1}) and available P (4.27 $mgkg^{-1}$), exchangeable bases, and exchangeable acidity were all low (Table 4.1). This is not surprising as the Guinea Savana soils are known to be low in organic matter, CEC, N and P (Odunze, 2003). This has been attributed largely to the rapid mineralization rate under high temperatures and rainfall in this agroecological zone. Exchangeable bases: Ca^{2+} (2.50 cmol kg^{-1}), Mg^{2+} (0.70 cmol kg^{-1}), K^{+} (0.18 cmol kg^{-1}) and Na^{+} (0.11 cmol kg^{-1}) were all of low to moderate concentration in the soil. The exchangeable acidity (1.50 cmol kg^{-1}) and effective cation exchange capacity ECEC (3.50 cmol kg^{-1}) were all low. This low ECEC will make the soil susceptible to soil acidification because the ability to hold on to the basic cations is low. The slightly acidic nature of the soil, low TN and OC reflected the true characteristic of a savanna Alfisol, which was due to the uptake of basic cation by plants through cultivation and, partly, to the overall removal of crop residues by the farmer after harvest (Omeke, 2017). 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 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 (Omeke, 2017). 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 status of Nigerian Savanna Alfisol (Oyinlola and Chude, 2010; Omeke *et al.,* 2016).

Table 1: Initial Soil Properties of the Experimental Site

Soil properties	Unit	Test value
Bulk density	Mg m-3	1.31
Moisture content	g kg-1	231
Total porosity	%	53
pH in H_2O		5.44
Available P	mg kg^{-1}	4.98
Total nitrogen	g kg^{-1}	0.51
Organic carbon	g kg^{-1}	3.72
Exchangeable Cations	cmol kg^{-1}	
Ca	"	2.52
Mg	"	0.74
K	"	0.22
Na	"	0.14
Exchangeable acidity	"	1.48

3.1.1 Soil Organic Carbon

Maize/soybean cropping systems had a significant effect on soil organic carbon in both years as presented in Table 2. The four cropping systems assessed in both years of the studied revealed considerably more OC contents than initial OC contents (0.50 g kg^{-1}) obtained at the same 0-15 cm depth before the experiment. The same trends were obtained for combined results. Soil under soybean-maize rotation had the highest OC contents, which were significantly different from other cropping systems in both years and combined. Soybean/maize rotation gave the highest amounts of OC soil, followed by inoculated soybean/maize intercrop and the lowest values were recorded under continuous sole maize cropping in both years and combined. Significantly higher OC content in soil found under soybean-maize rotation and intercrop could be due to high maize-soybean biomass production with a low C/N ratio, compared to sole maize and sole soybean in both seasons and combined. Similar observation was reported by Adebayo (2011) and Omeke (2016) who studied cereal/legume rotation in a Guinea savanna Alfisol of Nigeria. Other factors that contributed to the increased OC content in the cropping system are crop residues accruing from nodule mass, root and in-season fall-off leaves, as well as the leftover shoot system after harvest (Omeke *et al.,* 2019). The increases in N supply in previous soybean treatments and yield of subsequent maize was probably due to additional N fixed and left in the soil for the subsequent maize crop (Omeke, 2017) as against continuous sole cropping system.

The organic carbon content of the soil as influenced by N fertilizer application rates was also presented in Table 2. Rates of N fertilizer application significantly affect soil organic carbon (OC), which increases as the N rate increases in both seasons and combined. Consistently, plots treated with 0 kg N ha^{-1} recorded a lower value followed by a 40 kg N ha^{-1} rate of application. The implication this is that N fertilizer application improves OC status of the soil due to better performance of the crops (Omeke, 2016) as compared to those crops obtained in the plots without N fertilizer application.

Table 2: Effect of soybean/maize cropping system and N fertilizer on soil organic carbon

	OC	OC	Combined
	(g kg^{-1})	(g kg^{-1})	(g kg^{-1})
Treatment	2020	2021	2020
Soybean-maize-based Cropping system			
Rotation	5.31a	6.43a	3785a
Intercrop rotation	3.98b	4.32b	2912b
Continuous sole maize	0.61cd	1.31cd	881e
Continuous sole soybean	3.01c	3.98c	881e
SE±	2.33	3.02	131.02
Nitrogen Rate (kg ha^{-1})			
0	0.40d	0.44d	597d
40	1.87c	2.25c	1489c
80	1.62ab	3.41ab	2277b
120	1.78a	3.48a	2508a
SE±	1.31	1.66	98.67
SMCS*NR	*	*	NS

NS - not significant at $p < 0.05$, *significant at $p < 0.05$

3.2 Grain yields

Maize grain yield components and soil samples were collected per plot at harvest in both seasons. The data obtained for grain and Stover yields were significantly (P< 0.05) higher under soybean-maize rotation plots as compared to those plots with or without soybean in 2the 020 and 2021 cropping seasons (Table 3). The value of grain yield recorded under continuous sole maize was lower than other soybean-maize cropping with a difference of 51.51 % in 2020 and 68.48 % in 2021 for soybean-maize rotation, 43.41 % in 2020 and 57.87 % in 2021 for soybean-maize intercrop. Similar trend obtained for grain yield was found in stover yield between continues sole maize and other soybean-maize cropping systems in both years. However, values of grain and stover yields obtained for 2022 were higher as compared with 2021 data. The variation could be attributed to late planting as a result of dry spare observed in the 2021 cropping season at the peak of planting. However, the higher yields found under rotation plots could be attributed to the beneficial effects of the previous crop (soybean) on the succeeding crop (maize). The differences in yield attributes amongst the cropping systems might have been due to the variation in the contribution of residual nitrogen by soybean in the cropping systems, which created positive soil conditions and subsequently improved the soil organic carbon (Omeke, 2016). Giller (2011) found that maize planted following soybean as rotation benefits more, compared to continuous sole maize or soybean or intercrop, largely due to the effects of improved soil fertility.

The results also show significant differences among the nitrogen fertilizer application rates on grain and stover yields which were significantly lower under 0 kg N ha^{-1} (408 kg ha^{-1} for grain yield in 2020 and 651 kg ha^{-1} for grain yield in 2022). The results indicated better maize production at 80 kg N ha^{-1} application rates which are at par with 120 kg N ha^{-1} application in both seasons. Stover yield value under 120 kg N ha^{-1} was higher than other treatments plots with a difference of 9.21% for 80 kg N ha^{-1}, 40.63 % for 40 kg N ha^{-1} and 76.20 % for 0 kg N ha^{-1} in 2020, and 1.63% for 80 kg N ha^{-1}, 38.25 % for 40 kg N ha^{-1} and 80.65 % for 0 kg N ha^{-1} in 2021. Generally, the values of maize grain and stover yields recorded in 2020 were lower than those obtained in 2021 considering all the nitrogen treatment plots together. This implies that N fertilizer contributes greatly to crop production especially maize in soils of low N status. Nitrogen is typically the nutrient of most concern because it has a strong influence on crop yields (Havlin *et al*., 2005). The result is in line with that of Onasanya *et al.,* (2009) and Omeke (2016), who showed that application of 120 kg N ha-1 significantly increased the growth and yields of maize than other N treatments. The results indicated better maize production at 120 kg N ha^{-1} which was at par with 80 kg N ha^{-1} application rate under soybean -maize rotation and intercrop combination as compared with other treatments combination in 2021 as presented in Fig. 1. This could be possibly explained by residual effect of soybean in the rotation system which was enhanced by plant residues accruing from soybean in-season biomass production.

Table 3: Effect of soybean/maize cropping system and N fertilizer on grain yield

	Grain yield (kg ha^{-1})	Grain yield (kg ha^{-1})	Stover yield Kg ha-1	Stover yield (kg ha^{-1})
Treatment	2020	2021	2020	2021
Soybean-maize-based Cropping system				
Rotation	2312	5438a	3785a	6422a
Intercrop rotation	2721	3664c	3665c	4134c
Continuous soybean	2012	2199d	2498d	3233d
Continuous maize	2121	2399e	2881e	2972e
SE±	88.33	33.42	51.02	61.02
Nitrogen Rate (kg ha^{-1})				
0	608d	351d	897d	411d
40	1876c	2125c	2189c	3226c
80	2622ab	4103ab	2977b	5139b
120	27289a	4221a	3108a	5225a
SE±	113.31	131.66	98.67	105.63
SMCS*NR	NS	**	NS	NS

NS - not significant at $p < 0.05$, *significant at $p < 0.05$

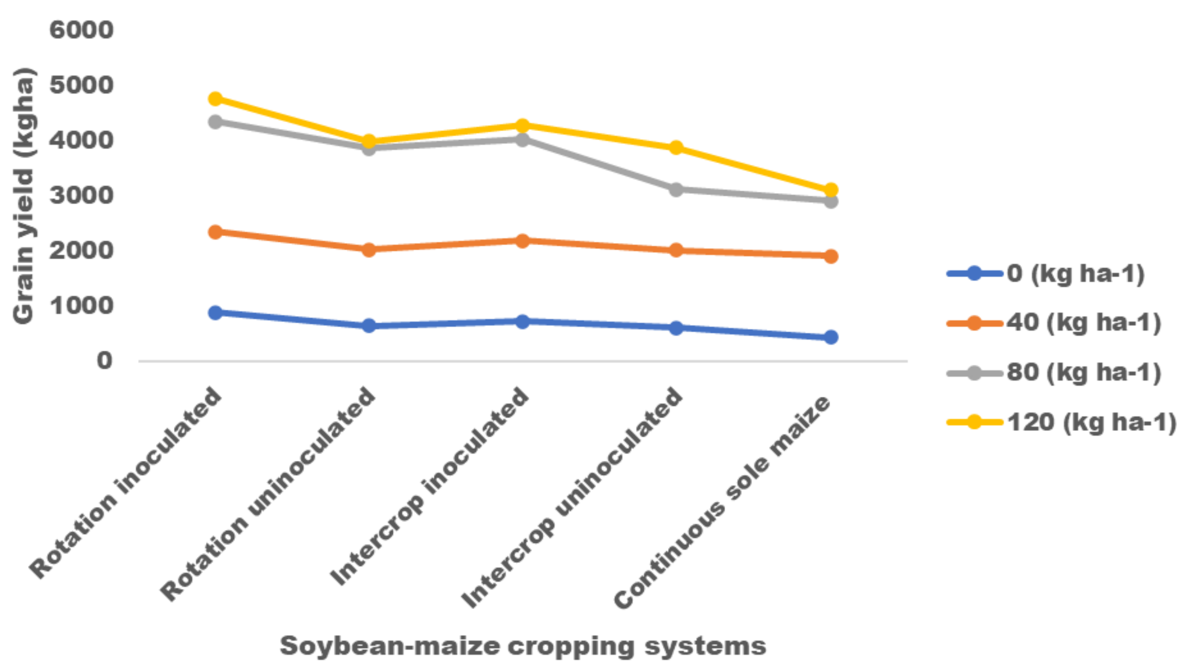

Fig. 1: Interaction between Soybean-maize-based cropping systems and Nitrogen fertilizer on grain yield for 2021

4.0 Conclusion

The study demonstrates the relevance of soybean in maize-based cropping systems which proved more productive than other sole cropping systems. Also, results show that nitrogen fertilizer application enhances soil organic carbon thereby increasing grain yield and yield stover of maize which was much better at 80 kg N ha^{-1} with no significant difference at 120 kg N ha^{-1}. This implies that the integration of soybean in maize-based cropping systems in combination with nitrogen fertilizer management would improve the fertility status of the soil and maize yield.

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