Journal of Agriculture and Environment for International Development - JAEID 2018, 112 (1): 109-119
DOI: 10.12895/jaeid.20181.702

Smallholder agriculture land use impact on soil organic carbon stock in Federal Capital Territory of Nigeria

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Submitted on 2017, 26 October; accepted on 2018, 20 March. Section: Research Paper

Abstract: Smallholder agriculture land use systems have profoundly influenced soil organic carbon stock. The study was conducted in Abuja, the Federal Capital Territory (FCT) of Nigeria, located in the Southern Guinea Savanna zone. The aim was to determine the effect of smallholder agriculture land use on soil organic carbon stock. Cashew plantation, sole maize farm and maize-cowpea mixed cropping farm were studied. The soil samples were collected randomly using an auger at 0 to 20 cm depth from the farms in all the six Area Councils (Abuja Municipal, Kuje, Bwari, Kwali, Gwagwalada and Abaji) of Federal Capital Territory (FCT). Composite samples of 48 in number were taken to represent each land use type, making it a total of 144 composite soil samples. The soil samples were taken to the laboratory for analysis and computations. Results were subjected to statistical analysis. Cashew plantation significantly had the highest soil organic carbon stock (24.84±0.225 t ha-1) followed by maize-cowpea mixed cropping farm (21.98±0.283 t ha-1) and sole maize farm recorded the lowest (13.87±0.089 t ha-1). The significant difference in soil carbon stock among cashew plantation, maize-cowpea and maize farm may be due to the differences in overall soil management practice and cropping system. Residue removal, soil erosion, intensive tillage, low rate of biomass production, low carbon input and high rate of mineralization are the factors that contributed to lower soil organic carbon stock in maize farms compared to cashew plantation. In the savanna zone of Nigeria, maize farms are subjected to continuous and intensified cultivation, coupled with no return of crop residues. The decline in soil organic carbon stock under sole maize cultivation compared to maize-cowpea suggests degradation of the soils for sustainable crop production exacerbated by climate change in the savanna. However, the maintenance of soil carbon stock and soil productivity in maize farms under continuous cultivation and changing climate could be possible by combining maize with legume plus adequate soil management practices.

Keywords: Soil organic carbon stock, climate change, smallholder agriculture land use, Nigeria, Savanna zone

Introduction

Smallholder Agricultural land use practices have significantly contributed to increase atmospheric CO2 concentration through organic carbon losses from the soil. Inter-Government Panel on Climate Change (IPCC) reported that agricultural activities are responsible for about one third of the world's greenhouse gas emissions and this share is projected to grow, especially in developing countries (IPCC, 2007). Smallholder agricultural systems in particular, are highly dynamic and heterogeneous that may have significantly contributed to greenhouse gas emissions over the past decades (Berry, 2011). It is known that soil carbon sequestration is affected by interconnected natural and anthropogenic factors, such as land use (Lal, 2003), climate (Jobbágy and Jackson, 2000) and soil structure (Lal, 2010). In the Nigerian Southern Guinea Savanna, the soils are continuously and intensively cultivated for maize, sorghum, rice, yam, cassava, cowpea, groundnut and soybean resulting in the depletion of soil carbon stock and poor fertility status (Odunze, 2006).

Smallholder agricultural management practices in the Savanna zone of Nigeria are inadequate and have led to decrease in soil organic carbon stock. Hedlund, (2015) reported that management practices influence soil organic carbon stock. The FCT has two distinct seasons: the rainy season (April to October) with mean rainfall - 305 to 762 mm. The dry season that lasts (November to March) is marked with dry winds and lowering the temperature to as low as 12o C. Meanwhile, the air temperature rises up to 40o C in May (Abubakar, 2014). This high rainfall and temperature encourage erosion and high rates of residue decomposition in the savanna zone. Erosion, decomposition and leaching are important soil processes for decline in carbon concentrations in the soil (Lal 2003). Surface disturbance from cultivated systems decreases soil carbon content due to reduction in tree cover and faster rate of mineralisation (Bationo 2007). Appropriate land-use management practices could increase the soil organic carbon pool, providing a series of benefits not only on climate change mitigation, but also on desertification and erosion control, water quality, food security and soil fertility (Lal, 2004; Lipper et al., 2011). Organic Carbon (OC) plays a key role in preventing and mitigating soil degradation - the loss of actual or potential productivity and decline in soil quality.

The reports from the savanna zone indicated that rising temperature (Nutsukpo, et al., 2012; Bessah et al., 2016) has led to instability in precipitation, increased food insecurity, increased decomposition rates reducing carbon stored as organic matter in the soil. It was reported from the legacy data of soil OC in Nigeria (Akpa et al., 2016) that the mean SOC concentration is 4.2 to 23.7 g kg−1 in the top 30 cm and 2.6

to 9.2 g kg−1 at the lower soil depth. Total SOC stock in the top 1 m was 6.5 Pg with an average density of 71.60 Mg C ha−1. Almost half of the SOC stock was found in the 0–30 cm layer. SOC stocks decreased from the southwest to the northeast of Nigeria, and increased from Sahel to Humid forest agro-ecological zones. Restoration of the various land use types has the potential to sequester about 0.2 to 30.8 Mg C ha−1 depending on the AEZ. The Derived Guinea Savannah presents a potential hotspot for targeted carbon sequestration projects in Nigeria. Chidowe et al. (2017) reported the effect of maize based cropping systems on soil carbon stocks in Nigeria and concluded that maize / Desmodium combination is best in improving carbon stocks. More studies that focus on soil organic carbon stock assessment are necessary for a clearer understanding of carbon stock dynamics in the savanna zone. A decline in soil organic carbon stock may indicate degradation or even loss of soil and low crop yields. Therefore, the present study was carried out with the objective of assessing impacts of these agricultural land-use practices on soil organic carbon stock in the Southern Guinea Savanna of Nigeria with special reference to smallholder agriculture.

Materials and methods

Study Area

The study was conducted in Abuja, the Federal Capital Territory (FCT) and lies between 8° 25′and 9° 25′ north and 6° 45′ and 7°45′ east. FCT is geographically located in the centre of the country with a landmass of approximately 8000 km². It has boundary with Kogi state in the south, Kaduna in the north, Nasarawa in the east and Niger state by the west. The climate is characterized by six months dry season (November to April) and six months rainy season (May to October) with mean annual rainfall of about 1400mm (Abuja master plan, 2000). During rainy, season the daytime temperature is 28° C to 30° C and 22°C to 23° C during night. In the dry season, the daytime temperature may go up to 40° C but sudden drop in night temperature to below 12° C. The undulating terrain has a moderating influence on the weather of the Territory (Oyetola and Agber, 2014). The underlying rocks are basically of Basement Complex (igneous and metamorphic rocks) and sedimentary rocks. The Basement Complex rocks cover about 48 % of the total area with hills and dissected terrain (Mabogunje, 1977). Dominant soil parent materials are the weathered remains of these rocks. The soils derived from the weathered rocks are deep, weakly to moderately structured (Lawal *et at.,* 2013). The dominant soils are broadly categorized as Ferric Luvisols, Ferric Acrisols and Ferric Cambisols (Ojanuga 2006). Soil texture is predominantly sandy loam and soil pH slightly acidic. Base saturation ranges from 66.11 to 95.60% and cation exchange capacity (CEC) is between 3.92 to 6.12 cmolkg^{-1} (Hassan *et al.,* 2007; Oyetola and Agber, 2014). The FCT come under

Southern Guinea Savanna Agroecological zone of Nigeria with deciduous trees scattered among grasses. The major occupation among the indigenous people is farming.

Soil Sampling

The major three land use types seen in FCT were selected for soil sampling during June 2016 viz cashew plantation, maize farm and maize-cowpea mixed cropping farm. The randomly surface auger samples up to a depth of 0 to 20 cm were collected in three land use systems as mentioned former in all the six Area Councils (Abuja Municipal, Kuje, Bwari, Kwali, Gwagwalada and Abaji) of FCT. A total of 144 composite samples were collected, out of 48 composite samples were taken to represent each land use type. Soil samples were air-dried and passed through 2 mm sieve for fine earth fraction to use it for laboratory analysis.

The cumulative mass soil sampling as described by Aynekulu *et al.*, (2011) was used for the measurement of bulk density. Bulk density (BD) was calculated as given under:

Bulk density = oven-dry weight of soil (Mg) / volume of soil (m^3)   (1)

Soil organic carbon content was determined by Walkley-Black method modified by Allison (1965).The remaining soil portion on the 2 mm sieve was weighed and recorded as the coarse fraction greater than 2 mm.

Soil organic carbon stock (SOCS) was calculated using the formula as given below:

SOCS = SOC x BD x D x (1 – Coarse fragments   (2)

Where,
SOCS = soil organic carbon stock (t C ha^{-1})
SOC = soil organic carbon (%)
BD = soil bulk density (Mgm^{-3})
D = depth of the sampled soil layer (cm)
Coarse fragments = % volume of coarse fragments (> 2 mm).

Statistical Analysis

The analysis of variance (ANOVA) and Least Significance Difference (LSD) at $P < 0.5$ were computed for comparing the results and their significant level using SAS software version 9.1 (SAS, 2003).

Results

Soil Bulk Density

The results (Table 1) show that land use significantly influenced bulk density with 1.61 Mgm^{-3} for the cashew plantation to 1.63 Mgm^{-3} for maize–cowpea farm and 1.64 Mgm^{-3} for maize farm (Table 2 and Figure 1).

Soil Organic Carbon

Soil organic carbon was significantly affected by land use type (Table 1). Organic carbon under cashew plantation was 0.81 %, 0.71 % for maize-cowpea farm and 0.45 % for maize farm (Table 2 and Figure 2).

Soil Organic Carbon Stock

There was significant difference in soil organic carbon stock among the land use types (Table 1). The carbon stock recorded for cashew plantation is 24.84±0.225 t ha^{-1} followed by maize-cowpea farm (21.98±0.283 t ha^{-1}) and maize farm (13.87±0.089 t ha^{-1}) (Table 2 and Figure 3).

Table 1 - ANOVA Results of Effects of Smallholder Agriculture Land Use on Bulk Density (Mgm-3), Soil Organic Carbon (%) and Soil Organic Carbon Stock (t ha^{-1}).

Parameters	Source	DF	F Value	Significance (P)
Bulk Density	Land Use Type	2	3.75	0.000*
Soil Organic Carbon	Land Use Type	2	35.24	0.000*
Soil Organic Carbon Stock	Land Use Type	2	36.42	0.000*

* indicates Significant at $P < 0.05$

Table 2 - Mean and Standard Error of Bulk Density (Mgm-3), Soil Organic Carbon (%) and Soil Organic Carbon Stock (t ha-1) as influenced by Smallholder Agriculture Land Use

Land Use Type	BD	SOC	SOCS
Cashew	1.61 ± 0.005	0.81 ± 0.008	24.84 ± 0.225
Maize	1.64 ± 0.004	0.45 ± 0.002	13.87 ± 0.089
Maize and Cowpea	1.63 ± 0.004	0.71± 0.009	21.98 ± 0.283
LSD (P= 0.05)	0.009	0.018	0.547

BD = bulk density, SOC = soil organic carbon, SOCS = soil organic carbon stock

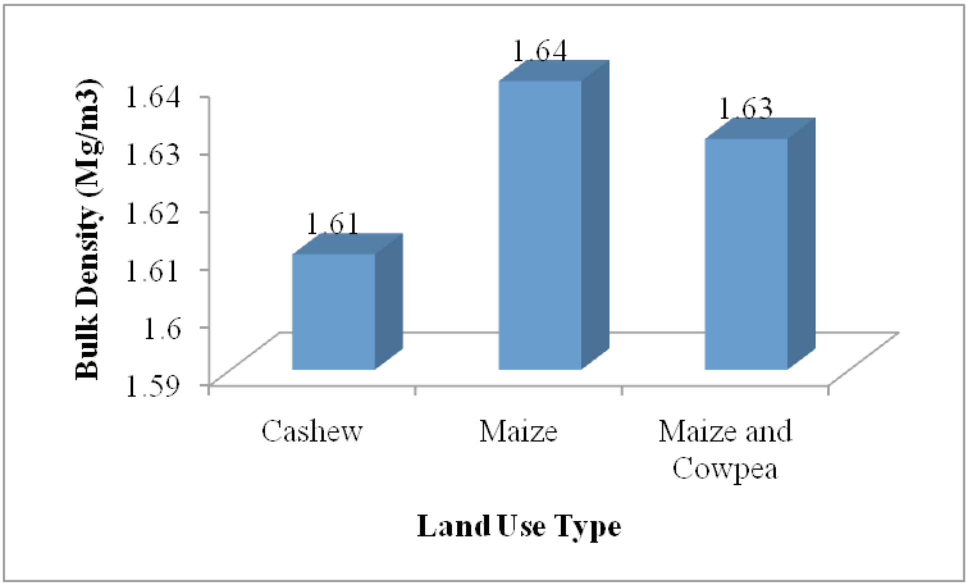

Figure 1 - Effect of Smallholder Agriculture Land Use on Soil bulk density (g cm-3).

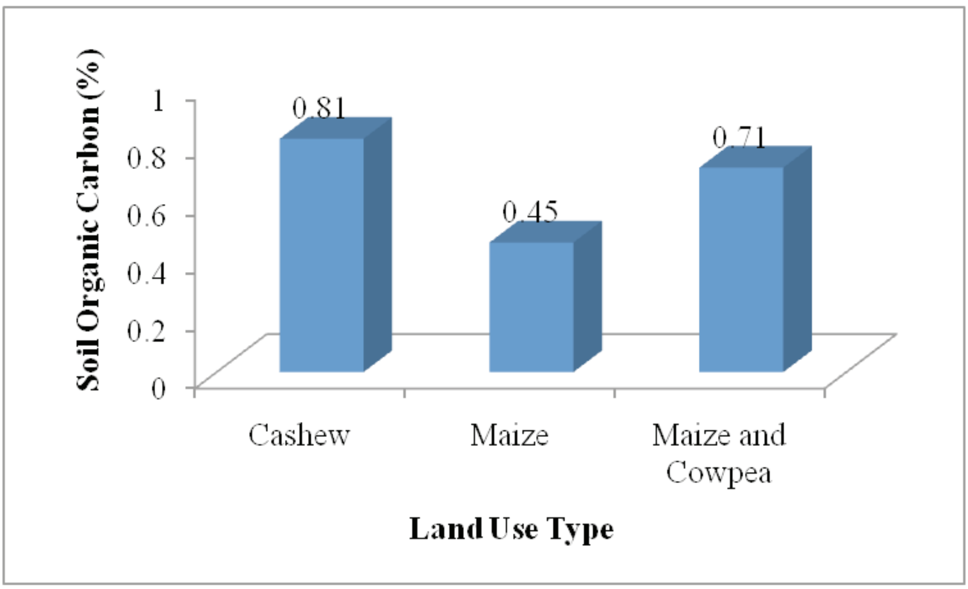

Figure 2 - Effect of Smallholder Agriculture Land Use on Soil Organic Carbon (%).

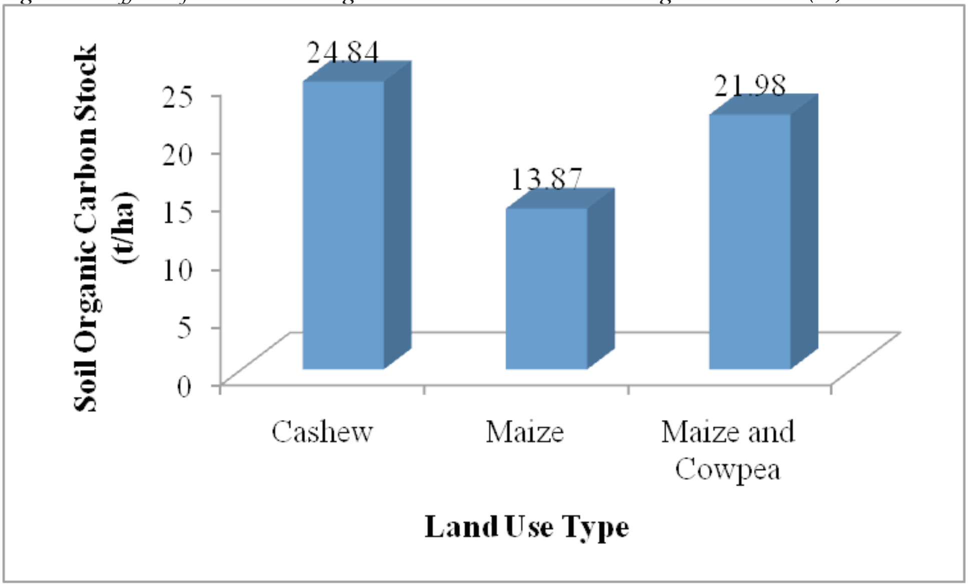

Figure 3 - Effect of Smallholder Agriculture Land Use on Soil Organic Carbon Stock (t ha^{-1}).

Discussion

Soil Bulk Density

Bulk density was significantly different among the smallholder agriculture land use types. The significant difference in soil bulk density among land use type may be attributed to differences in cropping system, type of crop, soil organic matter content and land management. Oyetola and Agber (2014) reported differences in bulk density of soils due to agricultural land use in the FCT. Lemenih *et al*. (2005) attributed the significant difference in bulk density to vegetation type and land management. Sole maize cropping resulted to more soil compaction compared to maize-cowpea and cashew with lower values of soil bulk density. This is in agreement with the findings of Chidowe *et al.* (2017) in the savanna zone of Nigeria, who stated that sole maize treatment caused more compaction of the soils relative to sole soybeans, sole *Desmodium*, maize/soybeans, maize/*Desmodium* treatments, while sole *Desmodium* best improved soil bulk density.

Soil Organic Carbon

The differences in soil organic carbon among land use types may be due to the differences in farmers' soil management systems and agronomic practices that increase or decrease mineralization of organic matter. Lower values of soil organic carbon recorded for sole maize and maize-cowpea farm relative to cashew plantation might be due to continuous cultivation and cropping which had resulted to decline in organic carbon content because the amount of organic materials returned to the soil had decreased. Eludoyin and Wokocha (2011) reported that lower organic carbon content of soils under maize cultivation compared to forest observed in the study of soil dynamics under continous monocropping of maize (*Zea mays*) on a forest Alfisol in south-western Nigeria was due to site clearance before cultivation which had disrupted the rate of organic matter decomposition giving chance for erosion and leaching to degrade the soil.

Soil Organic Carbon Stock

The significant difference in soil organic carbon stock among cashew plantation, maize-cowpea and maize farm may be as a result of overall soil management, cropping system and agronomic practice. Residue removal, soil erosion, intensive tillage, low rate of biomass production, low carbon input and high rate of mineralization influence soil carbon stock (Paustian *et al*., 2000; Lal *et al*., 2007).These factors contributed to lower soil organic carbon stock recorded in maize farms compared to cashew plantation. In the savanna zone of Nigeria, maize farms are subjected to continuous and intensified cultivation, coupled with no return of crop residues. Most of the maize and cowpea farmers prefer supplying the crop stovers to livestock rather than leaving them in the field to decay and consequently increase the soil organic carbon stock (Tanimu *et al.,* 2007). Also, due to the fragile nature of the soils in the Savanna, soil organic carbon degrades rapidly under continuous and intensive cultivation (Abu and Abubakar, 2012). The decline in soil organic carbon stock under sole maize cultivation compared to maize-cowpea suggests degradation of the soils for sustainable crop production exacerbated by climate change in the savanna. The best strategies focus on the protection of soil organic carbon against further depletion and erosion, or the replenishment of depleted carbon stocks through certain management techniques (Anikwe, 2010) will involve legume/ cereal cropping systems such as maize/soybean, maize/*Desmodium* (Chidowe *et al.,* 2017)) and maize/cowpea systems.

Conclusion

Smallholder agriculture land use systems have profoundly influenced soil organic carbon stock in the FCT. Among the land use types studied cashew plantation significantly had the highest soil organic carbon stock followed by maize-cowpea mixed cropping farm and sole maize farm recorded the lowest. The significant difference in soil carbon stock among cashew plantation, maize-cowpea and maize farm may be due to the differences in overall soil management practice and cropping system. Residue removal, soil erosion, intensive tillage, low rate of biomass production, low carbon input and high rate of mineralization are the factors that contributed to lower soil organic carbon stock in maize farms compared to cashew plantation. In the savanna zone of Nigeria, maize farms are subjected to continuous and intensified cultivation, coupled with no return of crop residues. The decline in soil organic carbon stock under sole maize cultivation compared to maize-cowpea suggests degradation of the soils for sustainable crop production exacerbated by climate change in the savanna. However, the maintenance of soil carbon stock and soil productivity in maize farms under continuous cultivation and changing climate could be possible by combining maize with legume plus adequate soil management practices.

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