Journal of Agripreneurship and Sustainable Development (JASD)
www.jasd.daee.atbu.edu.ng; Volume 3, Number 1, 2020
ISSN (Print): 2651-6144; ISSN (Online): 2651-6365

INFLUENCE OF LAND USE SYSTEMS ON CARBON STOCK AND STRUCTURAL STABILITY OF A TROPICAL ALFISOL

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ABSTRACT

The study was conducted to investigate the influence of four adjacent land use systems (Arable [A], Pasture [PL], Fallow [FL] and orchard [OL]) on carbon stock and structural stability of a tropical Alfisol in Sudan Savannan agro-ecological zone of Nigeria. The result reveals that carbon stock was statistically higher ($P = 0.03$) in OL and FL than the other two land use systems. Carbon stock in the soil increased by 5.67t ha^{-1} in OL relative to FL for over 10 years. But in contrary, a decline in carbon stock of 6.4 t ha^{-1} and 4.9 t ha^{-1} was observed relative to FL in AL and PL, respectively. This indicates soil carbon stock in the study area lost rapidly under continuous arable cropping than any other land use systems. Correlation analysis showed that soil carbon stock in the study area was significantly explained by clay ($r = 0.71^{**}$), silt ($r = 0.54^{*}$) and sand ($r = -0.70^{**}$) contents. The structural stability index (SI) did not significantly vary ($P = 0.195$) among the land use systems were all values fell below less than 5% that indicates structurally degraded condition of the soil due to generally small organic carbon content. The structural stability index was significantly related to pH in KCl_2, available phosphorus and carbon stock with correlation coefficients (r) of 0.45*, 0.62** and 0.72**, respectively. Therefore, there is a need to adopt proven management practices that enhance and maintain organic carbon content especially in the AL in order to improve productivity and structural stability of the soil vis-à-vis environmental resilience.

Keywords: Land use systems, carbon stock, structural stability and Alfisol.

INTRODUCTION

Ensuring food security under changing climate conditions and growing population is the major challenge that received critical attention worldwide in recent years by the policy makers. Food security is of interest because the current human population of 7 billion will increase to more than 9 billion people by 2050, creating an eminent demand for food, fuel, and fiber (Burney *et al.*, 2010; and Worldbank, 2012). Agriculture and land-use change are responsible for about one-third of total emissions of greenhouse gases in the world and even if emissions in all other sectors were eliminated by 2050, growth in agricultural emissions would perpetuate climate change (IPCC, 2007; Smith *et al.,* 2008; and Worldbank, 2012). Recently, there has been an increased interest in understanding the effect of land use changes and agriculture on the global emission of greenhouse gases from the soil to the atmosphere. This is due to the fact that soil is the largest pool of organic carbon in the terrestrial biosphere, and minor changes in soil organic carbon storage can impact atmospheric carbon dioxide concentrations (Don *et al.,* 2011).

The soil organic carbon pool represents a dynamic balance between gains and losses and it changes over time depending on photosynthetic carbon added and the rate of its decomposition. A considerable amount of literature has been published on the effect of land use changes on carbon stock. Those studies have reported that soil organic carbon can be loss through changes of land use system mainly conversion of natural land to agricultural land with an estimate of 0.2 $GtCyr^{-1}$ in tropical soil (Achard *et al.,* 2004; and Houghton, 2003). In contrast, recent work by many researchers has established that land use changes may lead to an increased in soil organic carbon stock as reported from conversion of cropland to grassland or afforested land (Guo and Gifford, 2002; Paul *et al.,* 2002).

Moreover, the estimates of soil organic carbon losses and gains as a result of land use changes have been subject of interests within scientific community especially in tropical soil of Nigeria where there is dearth of such information i (Goidts *et al.,* 2009). Hence, the research was aimed to bridge the gap by evaluating the influence of four adjacent land use systems on soil organic carbon stock and structural stability in a tropical Alfisols of Sudan savannah agro-ecological zone of Nigeria. The findings of this research would help to design land use practices that reduces emission of CO_2 from soil and biomass pools which environmentally and economically increases agricultural productivity and its resilience to climate change in the tropics.

MATERIALS AND METHODS

Experimental Site Description

The study was conducted at the Faculty of Agriculture Research Farm, Bayero University Kano, located in the Sudan Savanna agro ecological zone of Nigeria (Figure 1). The research farm is located in the Northern part of Kano at latitude of $11^{o}58^{I}$ N and longitude of $8^{o}25^{I}$ E with altitude of 458 meters above sea level. The area is characterized by mono modal rainfall pattern with mean annual rainfall of 657mm and daily range of temperature between 15^{o}C – 34^{o}C (Sowunmi and Akintola, 2010). The soil of the experimental site is very well drained sandy loam on the surface with loamy sand on the sub surface which was classified as Typic Kanhaplustalfs according to USDA soil classification (Samndi *et al.,* 2014).

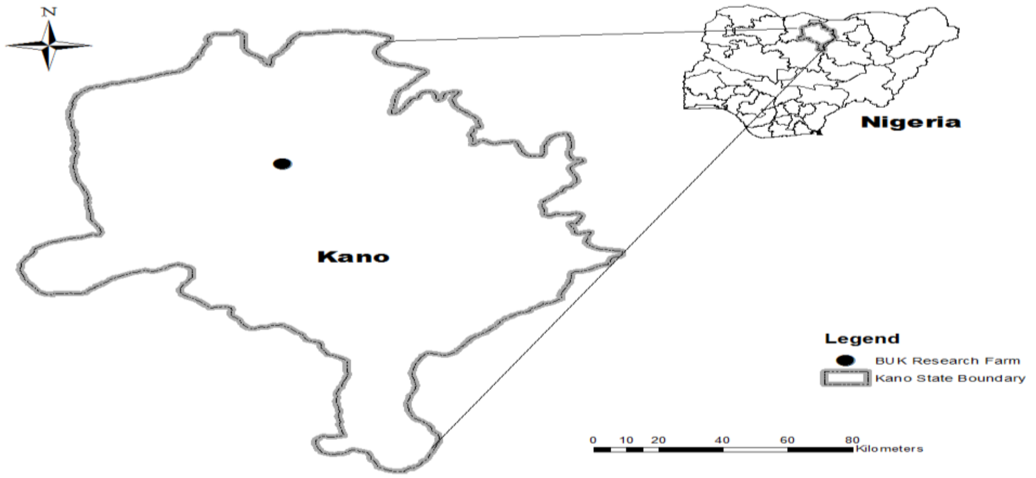

Figure 1: *Map of the experimental site*

Soil Sampling

Four (4) adjacent land use systems namely; orchard land (OL), pasture land (PL), arable land (AL) and fallow land (FL) were selected for soil sampling with over 10 years history of establishments. From each site, five (5) composite soil samples were obtained using stratified random sampling scheme at a depth of 0-20cm with the help of a soil auger. The composites samples were then air-dried, mixed well and passed through a 2 mm sieve for the analysis of selected soil physical and chemical properties. Separate undisturbed soil samples were taken from each sampling points with a sharp-edged steel core cylinder forced manually into the soil for bulk density determination.

Soil Laboratory Analysis

Standard laboratory procedures for tropical soils were followed in the analysis of the selected physical and chemical parameters considered in the study. Soil particle size distribution was determined by the Bouyoucos hydrometer method (Bouyoucos, 1962) after destroying OM using hydrogen peroxide (H_2O_2) and dispersing the soils with sodium hexameta phosphate. Soil bulk density was determined by the undisturbed core sampling method after drying the soil samples in an oven at 105°C to constant weights, while particle density was measured by the pycnometer method (Black, 1965). The pH of the soils was measured in water and potassium chloride (1M KCl) suspension in a 1:2.5 (soil: liquid ratio) potentiometrically using a glass-calomel combination electrode (Van Reeuwijk, 1992). The Walkley and Black (1934) wet digestion method was used to determine soil carbon content. Total nitrogen was determined using the Kjeldahl digestion, distillation and titration method as described by (Bremner, 1996) and available phosphorus using Bray 1 method. Exchangeable acidity was extracted with 1M KCl and titrated with NaOH as documented by (Anderson and Ingram, 1993).

Soil Organic Carbon Stock

The soil organic carbon stock was calculated using the following equation as documented by (Guo and Gifford, 2002):

$$Cs = \frac{SOC \times BD \times D}{10} \quad \ldots(1)$$

where;
Cs = soil organic carbon stocks (t ha^{-1});
SOC = soil organic carbon concentration (g kg^{-1}); BD (g cm^{-3}); and
D = soil thickness (cm).

Structural Stability Index

The structural stability index was estimated based on organic carbon levels to maintained soil structure using the equation described by (Reynolds *et al.,* 2007):

$$SI = \frac{1.72 \times SOC \times 100}{(Clay + Silt)} \quad \ldots(2)$$

where;
SI (%)= a soil structural stability index and
(Clay + Silt) = the soil's clay and silt content.

Reynolds *et al.* (2007) further stated that SI < 5% indicates structurally degraded soil due to extensive loss of organic carbon; SI = 5% - 7% indicates high risk of structural degradation due to insufficient organic carbon; SI = 7% - 9% indicates low risk of structural degradation and SI >9% indicates sufficient soil organic carbon to maintain structural stability.

Statistical Analysis

The data collected on the parameters were subjected to analysis of variance (ANOVA) and the least significance difference (LSD) test was used to separate significantly differing treatment means after effects were found significant at P < 0.05 using JMP-statistical package version 10. Moreover, simple correlation coefficients were calculated to reveal the magnitudes and directions of relationships between studied parameters.

RESULTS AND DISCUSSION

Soil Texture and Bulk Density

As shown in Table 1, the sand, silt and clay fractions were significantly ($P \leq 0.01$) affected by the land use systems. The highest average sand content (80.32%) was observed under the AL, and then followed by FL (67.92%), PL (65.92%), and OL (56.72%) that were statistically similar. Whereas the average silt fraction of the OL, PL, FL and AL were 16.48, 14.88, 11.28 and 3.68%, respectively. However, the highest mean (26.80%) value of clay fraction was recorded on the OL and the lowest mean (16.00%) value under the AL. Despite the fact that texture is an inherent soil property, management practices may contribute indirectly to the changes in particle size distribution particularly due to the impact of farming practices such as continuous tillage or cultivation and intensive grazing on the pasture land among the land use systems.

The bulk density value as also presented in Table 1 was significantly ($P < 0.01$) affected by land use with the highest mean (1.66 g/cm^3) value of bulk density was recorded on the PL which was statically similar with AL and the lowest mean (1.39 g/cm^3) value under the FL, even though there was no statistical difference relative to OL. The reason for the lowest soil bulk density in the FL as well as in the OL could be due to the highest clay content and less disturbance of the land in comparison to other land uses. The higher values of bulk density in PL and AL were slightly above the threshold level for optimal root growth and development as indicated by Hillel (1980). This might be due to compaction resulting from intensively grazing animals and continuous cropping in PL and AL, respectively.

Table 1: Effect of Land Use Changes on Physical Properties of Soil

Land Use Systems	Sand (%)	Clay (%)	Silt (%)	BD (gcm^{-3})	PD (gcm^{-3})	Textural Class
Arable Land (AL)	80.32a	16.00b	3.68c	1.65a	2.71	Sandy Loam
Fallow Land (FL)	67.92b	20.80b	11.28b	1.39b	2.65	Sandy Loam
Pasture Land (PL)	65.92b	19.20b	14.88b	1.66a	2.68	Sandy Loam
Orchard Land (OL)	56.72b	26.80a	16.48a	1.52ab	2.62	Sandy Loam
p-value	0.00**	0.01**	0.00**	0.01**	0.7244	
SE±	2.41	1.80	1.41	0.05	0.06	

BD = Bulk density, PD = Particle density and SE = Standard Error of Mean

Soil Ph and Soil Organic Carbon

The soils pH values were significantly affected by land use systems ($P \leq 0.01$) and the highest (7.10) and the lowest (6.30) soil pH values were recorded under the FL and the PL respectively (Table 2). The lowest value of pH in PL may be due to its highest microbial oxidation that produces organic acids, which provide H ions to the soil solution and thereby lowers soil pH. Generally, the pH values observed in the study are within the ranges of moderately acidic to neutral soil reactions as indicated by Foth and Ellis (1997).

The soil organic carbon content was significantly ($P \leq 0.01$) affected by land use system as further presented (Table 2). The soil organic carbon content was highest (7.24 g/kg) under the OL and lowest (3.05 g/kg) in the AL, even though PL and FL have statistically similar soil carbon content relative to OL and AL. The decline in soil organic carbon contents in the arable land might have been aggravated by the insufficient inputs of organic substances from the farming system due to crop residue removal and continuous tillage**.** Besides this, leaching problem that can be attributed to the relatively high sand content and the resultant light texture of soils also might be the root cause of soil organic carbon reduction. This is apparent because the clay particles unlike the sand particles, have substantial exchange surface areas, and therefore adsorb and stabilize organic matter and soil nutrients (Saggar *et al.,* 1996). Furthermore, the higher soil organic carbon contents in the OL might be due to the substantial amount of organic materials added from leaves and root biomass of the growing trees. According to the classification of soil organic carbon as per the ranges suggested by Landon (1991); the soils across land use systems are very low to low (0.30-0.72%) in soil organic carbon content. This indicates that the soils are severely eroded, highly degraded with very low structural stability.

Table 2: Effect of Land Use Changes on Chemical Properties of Soil

Land Use Systems	**pH (H_2O)**	**pH (KCl_2)**	**EA(Cmol kg^{-1})**	**AVP (mgkg^{-1})**	**TN (gkg^{-1})**	**SOC (gkg^{-1})**
Arable Land (AL)	6.9ab	6.5a	1.23	7.46	0.77	3.05b
Fallow Land (FL)	7.1a	6.3ab	1.03	6.81	0.98	6.00ab
Pasture Land (PL)	6.3c	5.7b	1.07	5.63	0.91	3.45ab
Orchard Land (OL)	6.5bc	5.9b	1.23	7.06	1.19	7.24a
p-value	0.04*	0.01*	0.34	0.19	0.44	0.03*
SE±	0.17	0.17	0.10	0.58	0.18	1.39

EA = exchangeable acidity, AVP = Available phosphorous, TN = Total Nitrogen and SOC = Soil organic carbon

Soil Organic Carbon Stock

The soil organic carbon stock was significantly ($P \leq 0.04$) affected by land use system as presented in Figure 2. The average values of soil organic carbon stock was highest (22.04 t/ha) in OL and lowest (9.97 t/ha) in AL which was found to be statistically similar with PL (11.41 t/ha). Soil organic carbon stock was positively and significantly correlated with clay (r = 0.71**) and silt (r = 0.54*) contents as presented in Table 3, which indicate that as clay and silt contents in the soil increases, the soil organic carbon stock increases. On the other hand, sand content is negatively and significantly correlated with soil organic carbon stock (r = -0.70**) meaning that there is inverse relationship between sand content and the soil organic carbon stock. Relatively, soil organic carbon decreased by about 6.4 t/ha after conversion of FL to AL in over 10 years. This indicates that soil organic carbon is lost rapidly under continuous arable cropping due to many factors such as erosion (the major land degradation process that emits soil carbon, tillage operations, biomass burning, fertilizer application, residue removal, and drainage of peat lands than in other land use systems. This is in line with c the findings of several past studies (Bessah *et al.*, 2016; and Ingram and Fernandes, 2001). Similarly , a decline in carbon stock of 4.9 t/ha was observed in PL relative to FL Guo and Gifford (2002) who reported that soil organic carbon can be rapidly lost up to 59% through erosion brought about by soil disturbance especially by grazing animals in pasture and crop land.

In contrary soil carbon stock had statistically increased by 5.67 t/ha in OL relative to the FL in over 10 years. This could be due to sufficient inputs of organic substances from the biomass of the trees, low bulk density, high clay and silt contents, and aeration due to high microbial activities in the soil when compared with the other land use systems. This finding is consistent with that of Ingram and Fernandes (2001) who reported that the potential carbon sequestration is controlled primarily by pedological factors mainly soil texture and clay mineralogy, depth, bulk density, aeration, and proportion of coarse fragments which set the phyico-chemical maximum limit to storage of carbon in soil. This finding was also in line with that of other studies (Don *et al.,* 2011; and Paul *et al.,* 2002).

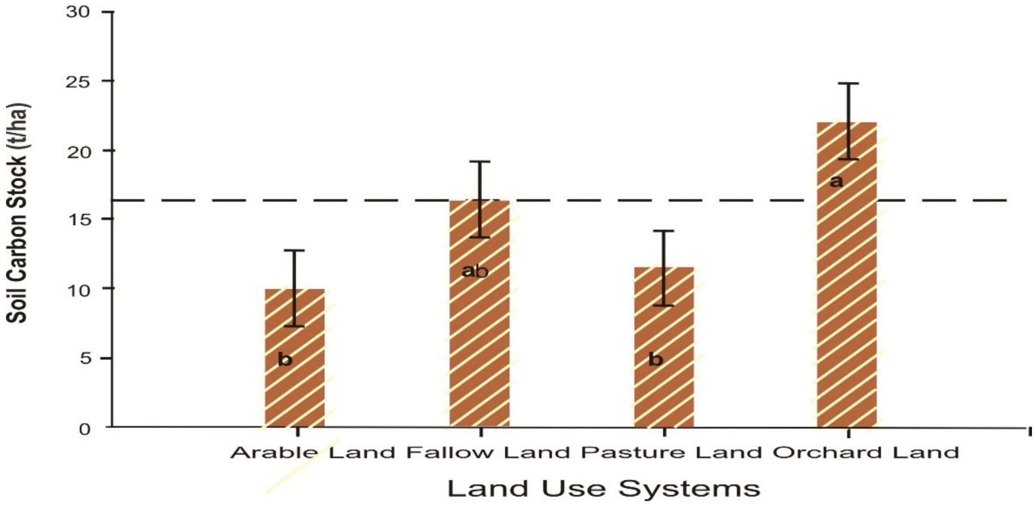

Figure 2: *Effect of land use changes on soil carbon stock*

Table 3: Pearson's Correlation Matrix among the Physical and Chemical Properties of the Soil

	Sand	Clay	Silt	BD	PD	pH_KCl	pH_water	EA	AVP	TN	C_Stock	SI
Sand	1.00											
Clay	-0.87**	1.00										
Silt	-0.90**	0.56*	1.00									
BD	0.16	-0.29	-0.01	1.00								
PD	0.11	-0.09	-0.10	-0.02	1.00							
pH_KCl	0.39	-0.19	-0.49*	-0.16	0.09	1.00						
pH_water	0.32	-0.17	-0.39	-0.27	0.33	0.81*	1.00					
EA	-0.03	-0.03	0.07	0.23	0.11	0.02	-0.03	1.00				
AVP	0.28	-0.12	-0.37	-0.19	0.05	0.76**	0.50*	0.19	1.00			
TN	-0.56*	0.47*	0.51*	0.17	-0.28	-0.21	-0.02	0.12	-0.28	1.00		
C_Stock	-0.70**	0.71**	0.54*	-0.33	-0.01	0.04	-0.02	0.08	0.27	0.41	1.00	
SI	-0.07	0.21	-0.08	-0.54*	0.07	0.45*	0.31	-0.01	0.62**	-0.03	0.72**	1.00

Key: C_Stock = Soil organic carbon stock and SI = Structural Stability Index

Soil Structural Stability Index

The soil structural stability index was not significantly (p>0.05) affected by the land use systems as presented in Figure 3. Highest mean value of stability index was obtained in OL while lowest value recorded in PL relative to the FL. There was a significant positive correlation between stability index with soil carbon stock (r = 0.72**), available phosphorous (r = 0.62**) and pH in KCl (r = 0.45*). However, significantly (p<0.05) negative correlation was observed between stability index and soil bulk density (r = -0.54*). This indicates that soil structural stability index increases with the increases in organic carbon stocks, available phosphorous, pH in salt and decreases with increase in bulk density. This was in line with the finding of Larson and Pierce (1991) who reported soil carbon has a strong correlation with soil quality. In general, values of soil structural stability index across the land use systems were below the threshold level of 5% which indicates that all the land use systems were structurally degraded soil due to loss of organic carbon as documented by (Reynolds *et al.,* 2007).

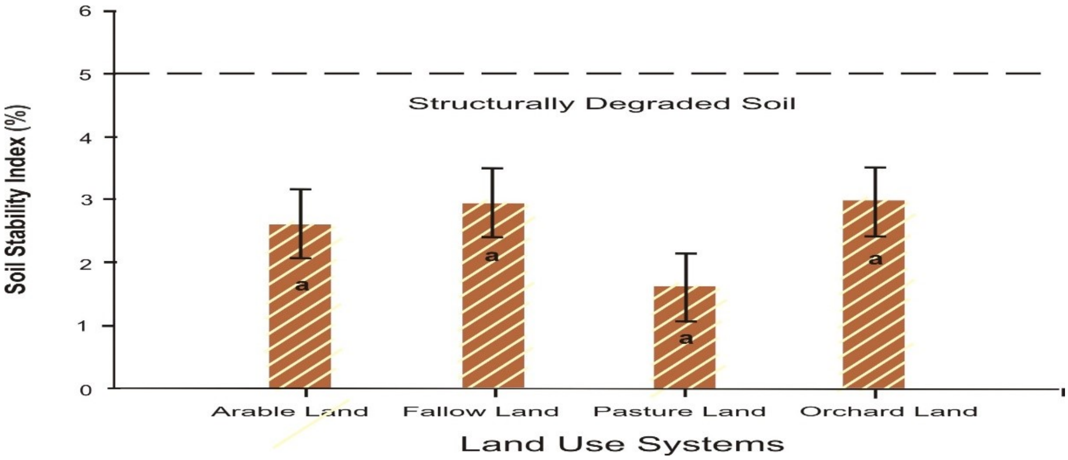

Figure 3: Effect of *land use changes on soil stability index*

CONCLUSION AND RECOMMENDATION

The soil carbon stock has been decreased in PL and AL in over 10 years when the land use was converted from FL to PL and AL, respectively. Therefore, management practices to enhance carbon storage and better structural stability are strongly recommended in the fragile soil especially in PL and AL.

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