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Research Paper

CARBON AND NITROGEN FORMS AND SEQUESTRATION IN RELATION TO AGRICULTURAL LAND USE TYPES IN A HUMID AGRO-ECOSYSTEM

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Abstract

Changes in agricultural land use patterns influence how much and at what rate carbon and nitrogen is sequestered in or released from soil. Carbon and nitrogen forms and sequestration were investigated in three different agricultural land use types (7 year old-fallow, 23 year old-secondary forest and cultivated land). The results showed that fallow soils sequester higher quantity of carbon (4222 gCm^{-2}) than forest (3586 gCm^{-2}) and cultivated soils (2844 gCm^{-2}). Carbon and nitrogen sequestration increase with increased horizon thickness, organic carbon and bulk density. Forest soils contained higher quantity of organic carbon (24.60 gkg^{-1}) and available nitrogen than other land use types studied. From the results also, Land use practices that involve soil disturbances and removal of vegetation cause losses of soil organic carbon to the atmosphere and prolonged fallow period may not encourage carbon and nitrogen sequestration.

Key words: Carbon, Land use, Nitrogen, Sequestration.

INTRODUCTION

Carbon and nitrogen in agricultural soils contribute positively to soil fertility, crop production and overall soil sustainability (Lal, 1999). Soils are important reservoirs of active organic components (such as carbon, nitrogen) and play a major role in the global cycle of these elements. As such, soil can be either a source or sink for atmospheric CO_2 depending on land use and management of soil and vegetation (Lal, 2005). Over 60% of the world's carbon is held in both soils (more than 40%) and the atmosphere (as carbon dioxide; 20%) (Stevenson, 1994).The conversion of native ecosystems such as forests, grasslands and wetlands to agricultural uses, and the continuous harvesting of plant materials, have led to significant losses of plant biomass (Davidson and Ackerman, 1993), thereby increasing the carbon and nitrous oxides levels in the atmosphere. However, soil disturbance is redistributing the carbon and nitrogen, augmenting the atmospheric carbon and nitrogen pools. Changes in agricultural land use practices influence how much and at what rate carbon and nitrogen is stored in or released from soils. Quantification of the impact of land use on carbon and nitrogen sequestration in tropical agro-ecosystems is challenging because of the heterogeneity of soil, climate, management conditions and due to lack of data on soil carbon and nitrogen pools of most common agro-ecosystems.

Carbon and nitrogen sequestration is the facilitated redistribution of carbon and nitrogen from the air to other pools, thereby reducing the rate of atmospheric carbon and nitrogen increase and mitigating global warming (Anikwe, 2011, Tieszen, 2000). The amount of carbon and nitrogen sequestered at a site reflects the long-term balance between influx and efflux of carbon and nitrogen. Recent concerns with rising atmospheric levels CO_2 have stimulated interest in carbon flow in terrestrial ecosystems (Huggins *et al*., 1998). Since soils differ in their responses to different land use practices and management systems, it is important to investigate more closely the influence of agricultural land use practices on carbon and nitrogen sequestration. Similarly, researches of quantification of carbon and nitrogen forms in soils in most African countries including Nigeria is proceeding slow. This study therefore investigated carbon and nitrogen forms and sequestration in three different land use types in south-eastern Nigeria.

MATERIALS AND METHODS

Study Area

The study area is located between latitudes 5^0 53'N and longitudes 7^0 54'E. The geology of the study area is Coastal plain sands. Umuagwo-Ohaji is a humid tropical climate with a mean annual rainfall of 1700-2250 mm distributed to about 139 days of the year. It is double maxima, with an August break occurring in July or August and high relative humidity (above 80%) during the rainy season; mean annual temperature ranges from 24 – 30^0C (NIMET, 2008). As agriculture is the major socio-economic activity of the area, about 70% of the total areas is used for crop production.

Filed Study

Three different land use types (secondary forest, fallow and cultivated lands) were randomly selected for the study. Complete randomized design was used for the experiment. Three profile pits were dug in each land use type giving total of nine profile pits. These profile pits were examined according to FAO (2006) guidelines. Bulk soil samples were collected from various identified genetic horizons of the profiles and analyzed in the laboratory.

Soil Analysis

Bulked soil samples collected were air-dried, gently crushed and passed through 2 mm sieve to obtain fine earth separates. Organic carbon was measured by wet digestion method (Nelson and Sommers, 1996).Total carbon was determined by loss on ignition and wet digestion method (Veres, 2002), while Inorganic carbon was calculated thus: total carbon – organic carbon. Available nitrogen was extracted using 2 M KCl in a 1: 5 (soil: water) ratio. NH_4-N and NO_3-N was determined by steam distillation of ammonia, using heavy MgO for $NH4^+$ and Devarda's Alloy for NO_3^- (Bremner and Keeney, (1965), Keeney and Nelson, (1982). Total nitrogen was determined by Kjeldah digestion method (Bremner and Mulvaney, 1982).Carbon sequestration **(**gCm^{-2}**)** was calculated using the method of Batjes (1996) : BD (gcm^{-3}) x OC (gkg^{-1}) x thickness of horizon (cm) while Nitrogen sequestration **(**gNm^{-2}**) =** $\sum$Di x BDi x TNi (He *et al*., 2012): where D = depth, BD = bulk density , OC = organic carbon and TN = total nitrogen . This method was adopted because the study was a pedological study involving profiling and natural horizonation. The soil samples were also analyzed for some physico-chemical properties following procedures outlined by FAO (2002). Briefly, particle size analysis was determined by hydrometer method, soil pH in 1:2.5 water suspension was measured with pH meter. The available P was determined according to Bray No. 2 method, bulk density was determined by Core method, TEB was by summation of the base forming cations which were extracted by neutral ammonium acetate method and Base Saturation by calculation.

Data analysis : Soil data were subjected to analysis of variance (ANOVA) to test differences in soil properties, soil carbon and nitrogen forms and sequestration across soils of different land use types. For statistically different parameters ($p < 0.001, 0.01, 0.05$), means were separated using Least Significant Difference (LSD). Correlation analysis was also conducted to detect the functional relationships among soil variables.

RESULTS AND DISCUSSION

Physical and Chemical properties of soils

Soil texture ranged from sand, loamy sand to sandy loam in soils of the varying land use types. The soil texture reflect the nature of the parent material from which the soils where developed and the drainage pattern of the area. Sandiness of the soils suggests high infiltration rate and observable low moisture content of these soils which may result to moisture stress. In addition to the above, this scenario may encourage rapid leaching of nutrient from the soils beyond the rooting zones of the planted crops. However, the coarse nature of these soils can in turn encourage soil erodibility on exposure to high rainfall through reduced fallow period and the conversion of forest to cultivated land, leading to soil degradation. Soil degradation as a result of erosion can be checked to the barest minimal level through appropriate land use practices which are not only environmental friendly and acceptable by the land users, but which also ensure the maintenance and continuous vegetative cover over the soil surface. The proportions of sand, silt and clay varied significantly ($p < 0.01$, $p < 0.001$) and ranged from 834 – 871 gkg^{-1}, 44 – 70 gkg^{-1} and 64 – 122 gkg^{-1} across the varying land use types .The mean bulk density values varied from 1.09 in forest to 1.38 gcm^{-3} in fallow soils. From the results, forest soils had the least bulk density value compared to other soils. This finding agrees with the reports of Michel *et al*., (2010); Islam and Weil (2000); Yihenew and Getachew, (2013) who found that bulk density increased from natural forest to non forested land. Low bulk density of forest soils may be a reflection of organic matter contents of the soils. Yihenew and Getachew, (2013) further reported that in forest land, there was relatively higher organic matter making the soil loose, porous and well-aggregated thus reducing the bulk density. Significant negative correlation was obtained between bulk density and organic carbon (r = - 0.537,) ($p < 0.001$), bulk density and total nitrogen (r = - 0.332**) (Table 4).

In soils of the varying land use types studied, the mean pH (H_2O) values ranged from 4.72 – 5.66 (Table 2). Soils of the forest had significantly higher ($p < 0.05$) pH values than those of cultivated and fallow lands This finding is in agreement with that of Michel *et al*., (2010) who reported higher pH values in secondary forest than the cultivated soils. Concisely, the result clearly showed that soil reaction differed significantly across the land use types which could be attributed to land use practices and topography of the studied sites. Soils of the cultivated land were more acidic, owing to the application of acidic fertilizers and other chemicals to these soils. According to Offiong *et al*., (2009), differences in quantity and quality of biomass and agro-chemicals returned to the soil affect soil properties. Soil pH had significant positive relationship ($r = 0.638$,) ($p < 0.001$) with organic carbon (Table 4). Increase in soil pH increases soil biodiversity and mineralization of organic matter with anticipated increase in soil carbon stock due to improved soil water infiltration and aeration. According to the ratings of Esu (1991), Effective cation exchange capacities (ECEC) of the soils were moderate ranging from 7.06 to 8.35 $cmolkg^{-1}$ while average base saturation values were high. High base saturation and moderate ECEC reported in this study contradict the assertion by Osuji *et al.* (2002) that soils formed on Coastal Plain Sands have low ECEC, low base saturation and low fertility levels. ECEC of the soils were dominated mainly by the exchangeable bases and fluctuated irregularly with depth in all the pedons. However, ECEC determines the soils capacity to hold and exchange natural and artificial sources of cationic plant nutrients (Raji, 2011).

Carbon Forms and Sequestration

In soils of the different land use types, the organic carbon content of the soils varied from 8.32 to 24.60 gkg^{-1}. From the results, forest soils contained significantly higher proportion of organic carbon than other land use types whereas no significant difference was observed in those of fallow and cultivated lands. The differences in organic carbon content of the soils of the three land use types are appreciable and may be linked to the heterogeneity of land use pattern, rainfall and temperature regimes. The low organic carbon content of the cultivated land could be a consequence of agricultural practices and soil conditions that favour rapid decomposition. Conversion of natural forest to cultivated land profoundly modified the microclimate with different vegetation canopy and litter. Degraded soils of the tropics are subjected to rapid mineralization of soil organic carbon and subsequently loss of soil organic carbon and CO_2 emission to the atmosphere especially in cultivation practices such as tillage and continuous cropping (Six *et al*., 2004). Land use practices that involve soil disturbances and removal of vegetation have been reported to cause losses of soil organic carbon to the atmosphere (Grant *et al*., 2001; Six *et al*., 2004). The amount of organic carbon in soil represent a balance between primary productivity, as influenced by environmental condition and biologically-mediated decomposition processes (Bulluck *et al*., 2002, Schroth *et al*., 2002). Organic carbon decreased down the profile in all the pedons across the soils studied (figs. 1 and 2). The higher proportion of organic carbon in the epipedons in all the soils of the different land use types is understandable and could be due to the fact that most of the organic residues in both cultivated and virgin soils are incorporated or deposited on the soil surface. Across the different land use types, inorganic and total carbon contents differed significantly and varied from 36.90 – 82.10 gkg^{-1} ($p < 0.001$), 57.10 – 93.40 gkg^{-1} ($p < 0.05$) respectively with soils under fallow containing significantly higher quantities.

Soil carbon sequestration are functions of horizon thickness, bulk density , soil organic carbon content of soils (Batjes, 1996). Under different land use types, the mean carbon sequestration in soils ranged from 2844 to 4222 gCm^{-2} and varied significantly ($p < 0.05$) with Fallow soils sequestering higher carbon (4222 gCm^{-2}) while the least value (2844 gCm^{-2}) was obtained in soils of the cultivated land (Table 3). The trend of C sequestration in the three varying land use types was fallow land > forest land > cultivated land . The higher carbon sequestration capacity of fallow soils may be attributed to the horizons thickness and bulk density resulting to greater soil mass. From the results, carbon sequestration increased with increased horizon thickness in all the profiles across the soils studied (Figs. 1, 2 and 3). The subsurface horizons contained the highest quantity of stored carbon compared to surface horizons revealing the inherent capacity of these horizons to store more C. This finding is consistent with Batjes, (1996), Eswaran *et al.,* (1995), Mba and Idike, (2011) and Abebayelin (2013) who reported high carbon storage in the deeper horizons. According to Mba and Idike (2011), carbon has higher density near the surface but soil organic carbon decomposes rapidly releasing CO_2 to the atmosphere, thus some carbon become stabilized especially in the lower part of the profile. However, carbon stored in the subsurface horizons occurs in more stable forms and therefore will not contribute much to current gaseous emission. In addition, effect of agricultural activities (conversion of forest to arable land) on carbon was largely restricted on the top soil thus causing carbon stored below this depth to be more stable under all vegetation type. Carbon sequestration correlated positively with horizon thickness, bulk density , soil available moisture and organic carbon (Table 4), respectively. These relationships indicate the potential influence of these soil parameters on carbon sequestration. The effect of horizon thickness on carbon sequestration, bulk density and organic carbon are presented in Figs 1 and 2**.** More so, soil moisture retention influences the level of carbon dioxide fluxes in the soil which may in one way or the other affect soil microbial biomass and potential mineralization of carbon (Haynes *et al*., 2004).

Nitrogen Forms and Sequestration:

In soils of the different land use types, forest soils accumulated significantly ($p < 0.001$) higher proportion of available nitrogen (0.12 $mgkg^{-1}$ (NH_4^+ - N), 0.32 $mgkg^{-1}$ (NO_3^- -N)) compared to other land use types. High proportion of available N in soils of the forest is a reflection of their total nitrogen concentration and could be attributed to high litter production by nitrogen fixing plants, mineralization of plant litter, high organic matter content, minimized runoff and less leaching losses. Though no statistical variation was recorded in the total nitrogen contents of the soils, fallow and forest soils contained higher proportion of total nitrogen (8.87, 8.56 $mgkg^{-1}$) than the cultivated soils. Total nitrogen across the studied soils irrespective of land use types were rated low when compared with the critical value of 0.15% reported by Agboola and Corey, (1975) and could be a consequence of soil reaction, temperature and rainfall pattern of the area. The low nitrogen concentration is a common phenomenon in the soils of South-eastern Nigeria and is as a result of the high nitrogen losses sustained in these soils through the leaching of nitrates, as well as the rapid mineralization of organic matter under the isohyperthermic soil temperature regime (Eshett, 1987; Eshett *et al*., 1990). Landon (1991) reported the range of 0.1 – 0.2% of total N to be low in soils of the tropics. This finding confirms that of Haung and Schoenau, (1996) who reported higher nitrogen level in soil surface than in the deeper horizons. There were strong positive relationships between soil total nitrogen and available phosphorus (Table 4).

Nitrogen sequestration ranged from 103 to 330 gNm^{-2}. Interestingly, cultivated land sequester significantly higher quantity of nitrogen (330 gNm^{-2}) than the forest land (103 gNm^{-2}). However, no significant variation was observed in the quantity of N sequestered in Fallow and cultivated soils. The trend of N sequestration in the three varying land use types was cultivated land $\geq$ fallow land > forest land. Like carbon, nitrogen sequestration increased with increased horizon thickness in all the profiles across the soils studied. The subsurface horizons contained the highest quantity of stored nitrogen compared to surface horizons.

Table 1. : Location, parent material and Land use history of the different sites used for the study

Location	Land use	Land use history
Umuagwo,Ohaji (5^0 19^1 29.4^{11} N, 6^0 58^1 32.6^{11} E)	Forest	23 years secondary forest, contained mainly wild perennial plants and grasses such as Oil palm (*Elaeis guineensis*), Banana (*Musa sapientum*), Oil been tree (*Pentaclethra macrophylla*), bush mango (*Irvingia gabonensis*), Elephant grass (*Pennisetum purpurem*), Giant star grass (*Cynodon plectostachyus*) .
Umuagwo,Ohaji (5^0 29^1 40.4^{11} N, 6^0 34^1 32.6^{11} E)	Fallow	Imo State Polytechnic Research plot, practiced conventional tillage continuously for 5 years, allowed to grow fallow for 7 years. Contained different plant species including wild legumes such as *calapogonum mucunoid*, *centrosema pubiscense*. Goat-weed (*Sida acuta*), *Chromolaeana odorata.*
Umuagwo,Ohaji (5^0 21^1 29.4^{11} N, 6^0 32^1 41.6^{11} E)	Cultivated land	Imo State Polytechnic Research plot, Conventionally tilled with farm machines, continuously-cropped with *capsicum* spp (green and hot pepper) and *Albemoschus esculentum* (okro) as intercrop, fertilized with NPK fertilizer and single phosphate fertilizer.

Source: Field survey, 2013

Table 2: Physical Properties of Soils of the different Land Use Types

Land uses	Sand gkg^{-1}	Silt gkg^{-1}	Clay gkg^{-1}	BD gcm^{-3}	MC (%)	pH (H_2O)	Avp $mgkg^{-1}$	TEB	EA cmol/kg	ECEC	BS (%)
Cl	833.60	44.00	122.40	1.19	8.88	4.72	22.45	5.89	1.17	7.06	83.18
Forest	845.80	69.60	84.70	1.09	9.29	5.66	22.90	6.63	1.73	8.35	78.79
Fallow	871.30	66.20	63.50	1.38	11.20	4.90	18.26	6.06	1.93	8.31	73.64
LSD	19.78**	15.96**	20.26***	0.074***	1.43*	0.35*	NS	0.33*	NS	NS	5.97*

Cl = cultivated land, MC = moisture content, AvP = available phosphorus, EA = exchangeable acidity, ECEC = effective cation exchange capacity, BS = base saturation, LSD = Least significant difference, *** = ($p < 0.001$) ** = ($p < 0.01$) and * = ($p < 0.05$) probability levels, NS = Not significant.

Table 3 : Nitrogen and Carbon Forms and Sequestration in Soils of different Land Use Types

Land uses	TC	OC (gkg^{-1})	OM	Inorg. C	C stock (gCm^{-2})	TN	NH_4^+ ($mgkg^{-1}$)	NO_3^-	N Stock (gNm^{-2})
Cl	57.10	8.32	14.30	48.80	2844	7.33	0.04	0.15	330
Forest	61.70	24.60	42.40	36.90	3586	8.56	0.12	0.32	103
Fallow	93.40	11.22	19.30	82.10	4222	8.87	0.07	0.18	313
LSD	21.29*	11.15**	19.23***	21.29***	314*	NS	0.05**	0.24***	136***

Cl = Cultivated land, TC = Total carbon, OC = Organic carbon, OM = Organic matter, Inorg. C = Inorganic carbon, TN = total nitrogen,
LSD = Least significant difference, *** = ($p < 0.001$) ** = ($p < 0.01$) and * = ($p < 0.05$) probability levels, NS = Not significant.

Table 4: Correlation between Selected Soil Properties and Carbon, Nitrogen Forms and Sequestration in Soils

	TN	NO_3^-	NH_4^+	N Stock	TC	OC	Inorg.C	C Stock
Clay	-0.522***	-0.151 NS	-0.360*	0.478*	-0.10NS	0.512***	0.127NS	0.294 NS
BD	-0.332**	-0.280NS	-0.438*	0.519***	0.529***	-0.537***	0.709***	0.865*
MC	-0.044NS	-0.660**	-0.275NS	0.384***	0.617***	0.634***	0.659***	0.552*
WSA	0.200 NS	0.074NS	0.395*	-0.425***	-0.054NS	0.506***	-0.264NS	-0.003NS
pH	0.215 NS	0.004 NS	-0.178 NS	0.143 NS	0.075 NS	0.638**	0.086 NS	0.025 NS
Avp	0.329*	0.719***	0.274 NS	-0.266 NS	-0.254 NS	0.336***	-0.371*	-0.413*
ECEC	0.296 NS	0.105NS	0.210 NS	-0.121 NS	0.097 NS	0.388**	-0.078 NS	-0.017 NS
BS	0.178 NS	0.223 NS	-0.096 NS	-0.020 NS	-0.224 NS	0.800***	-0.235 NS	- 0.15 NS
HT	0.534***	-0.520***	-0.308***	0.611***	0.208	0.661***	0.454***	0.874***

BD = Bulk density, MC = Moisture content, WSA = water stable aggregate, BS= Base Saturation, ECEC= Effective Cation Exchange Capacity, TC = Total carbon, OC = Organic carbon, Inorg. C = Inorganic carbon, TN = total nitrogen, HT = Horizon thickness.

NS = Not significant, *** = significant ($p < 0.001$), ** = significant ($p < 0.01$), * = significant ($p < 0.05$).

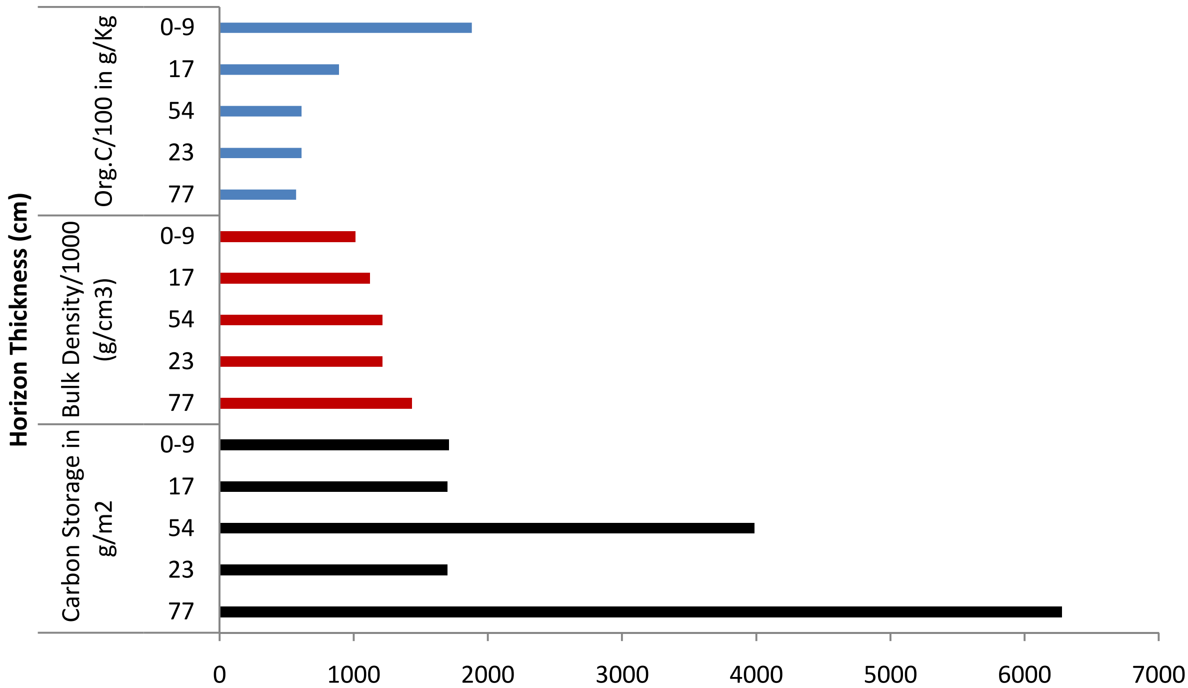

Fig. 1: Effects of horizon thickness (depth) on carbon sequestration, bulk density and Organic carbon in cultivated soils

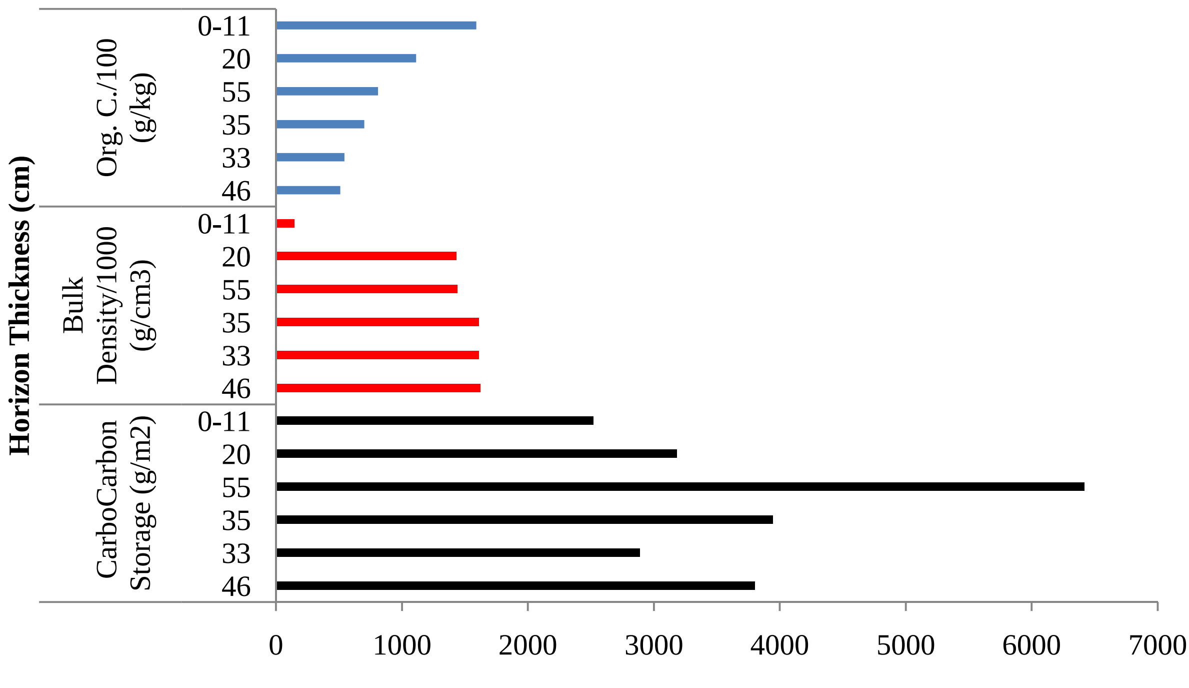

Fig 2: Effects of horizon thickness (depth) on Carbon Sequestration, bulk density and organic carbon in fallow soils.

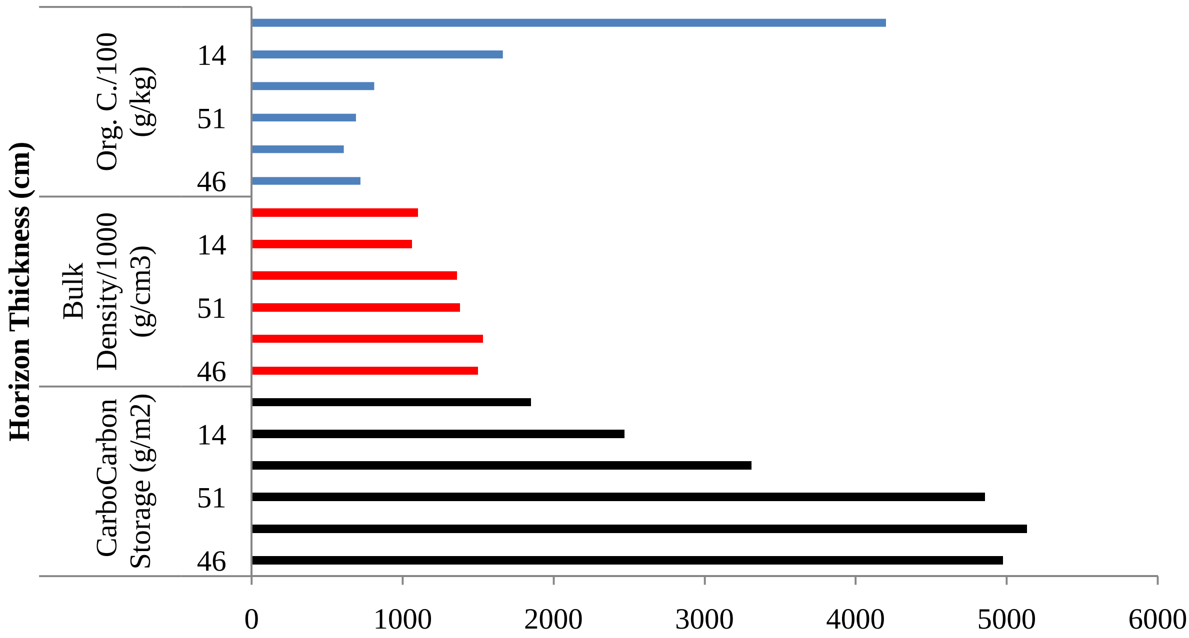

Fig 3: Effects of Depth on Carbon Sequestration, Bulk Density and Organic carbon in Forest Soils

CONCLUSION

Carbon and nitrogen sequestration in soils can be influenced by agricultural land use systems. Fallow and forest lands had higher organic and total carbon contents and sequestered higher quantities of carbon than the cultivated land. From the result, fallow and forest ecosystems appear to be most conducive environment for maximum accumulation of carbon. In other words, the large scale conversion of forest and fallow ecosystems to crop lands in southeastern Nigeria may lead to great loss in the regional carbon stock.

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