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RESEARCH ARTICLE

TROPICAL SOIL CARBON STOCKS IN RELATION TO FALLOW AGE AND SOIL DEPTH

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ABSTRACT

The interest in Soil carbon has risen significantly in the science community due to the potential of climate change mitigation through soil carbon sequestration. Changes in fallow periods influence how much and at what rate carbon is sequestered in or released from the soil. Carbon sequestration in soils under three different fallow ages (7, 14 and 21) at varying sampling depths (0-20, 20-40, 40-60, 60-80, 80-100 cm) was investigated using the method of Batjes and data obtained were subjected to analysis of variance. Organic carbon content was generally low ranging from 3.99 – 5.67g kg^{-1}. Soil carbon sequestered under the three varying fallow ages ranged from 1295 – 1611g cm^{-2}. Though no significant variation was observed in the amount of C sequestered by the varying ages of vegetation, results showed that 14 years fallow sequestered the highest quantity of carbon (1611g cm^{-2}) while the least (1295 g cm^{-2}) was obtained in 7 year fallow. On the other hand, sampling depth had a significant influence on soil carbon content. In 7 years fallow period, 0-20, 20-40 and 40-60 cm sampling depths contained significantly highest carbon stock values. In 14 and 21 years fallow ages, 0-20 cm sampling depth sequestered significantly highest carbon (3147.04 g cm^{-2}, 2247 g cm^{-2}) compared to other sampling depths. Conclusively, more carbon is sequestered at the soil surface than in the sub-soil and prolonged fallow age up to 21 years may not be beneficial to soil carbon sequestration.

KEYWORDS

Carbon Sequestration, Fallow Period, Tropical Soil, Sampling Depth.

1. INTRODUCTION

Quantification of the impacts of fallow periods on carbon stocks in Sub-Sahara Africa is challenging because of the spatial and vertical heterogeneity of soil, climate, management conditions and due to lack of data on carbon pools of most common agro-ecosystems. Soil is important reservoir of active organic carbon and is major player in the global cycle of this element. The soil serves as a source or sink of atmospheric carbon dioxide (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%) (Alexander et al. 2015). 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 and carbon, thereby increasing the carbon dioxide (CO_2) level in the atmosphere (Ahukaemere 2015).

Carbon sequestration involves the process of transferring atmospheric CO2 into the soil through crop residues and other organic solids and storing it securely so it is not immediately re-emitted into the atmosphere (Lal 2004). Thus, soil carbon sequestration means increasing soil organic carbon (SOC) and soil inorganic carbon (SIC) stocks through judicious land use, adequate fallow period and other management practices (Akamigbo 2010). This transfer or "sequestering" of carbon helps off-set emission from fossil fuel combustion and other carbon-emitting activities while enhancing soil quality and productivity. Globally, scientists and policymakers are facing challenges on how to increase the amount of carbon sequestered in the soil in order to mitigate climate change. Understanding how fallow period affects carbon stored in the ecosystems and how canopy cover influence atmospheric concentrations of CO_2 will be important in understanding the long-term sequestration capacity of the plants. In general, the amount of carbon in soil is determined by the balance between carbon input from vegetation cover, in the form of dead plant litter (roots and shoots) and root exudates, and output via decomposition processes, burning and soil erosion. Another possible way to enhance soil carbon sequestration involves the manipulation of plant-soil feedbacks, especially in grassland. For example, recent studies showed that increase in plant diversity and the introduction of certain plant species such as legumes into mixed grasslands can reap benefits for soil carbon sequestration (Anikwe 2010; Ahukaemere et al. 2016). Generally, a research effort aiming at the influence of soil depth, fallow duration and type, offers a potential way forward for understanding how vegetation-soil interactions might be manipulated to enhance soil carbon storage. Therefore, a good knowledge of carbon sequestration and storage in soils

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is important for the development of healthy soil and reducing its adverse effects.

Carbon sequestered in soils, was not given enough attention due to unavailability of data to demonstrate any major changes in soil carbon stock resulting from variation in fallow periods. As a result, the dynamics of soil carbon stock under the fallow lands has not been adequately evaluated, particularly in relation to the Carbon status of soils under different ages of fallow. Therefore, the objective of the study was to assess the effects of fallow periods and soil sampling depths on soil carbon sequestration.

2. Materials and Methods

2.1 Description of the Study Area

The study sites are located at Ezinihitte Mbaise, in Owerri, South-eastern region of Nigeria. The geology of the study area is characterized mainly by coastal plain sands. The area lies between latitudes 5°28' and 5°41'N and longitudes 7°20' and 7°48'E with elevation ranging from 120 to 143 m above sea level. The climate is a humid tropic with annual rainfall average of 2500 mm. Mean annual temperature varies between 27 – 30°C with a relative humidity of 75-80% (NIMET 2016). The vegetation is rainforest characterized by a variety of plant species. Low technology agriculture is common, and farmers concentrate their activities on an arable form of farming and small ruminant animals. Land preparation is by slashing, followed by burning and packing un-burnt debris. Short duration following has resulted to use of inorganic fertilizers in the area.

2.2 Soil Sampling and Laboratory Analyses

Three representative sampling sites were chosen based on the fallow duration using the random survey approach. The fallow lands comprised of mixed vegetation involving different plant species. Information on land use history and fallow duration was obtained from the farmers and landowners through an oral interview. One profile pit was dug at each site. With a measuring tape, in order to obtain a uniform depth, each profile pit was demarcated into 5 layers namely 0-20, 20-40, 40-60, 60-80, 80-100 cm respectively. These uniform sampling depths were carefully selected to eliminate error caused by inherent horizon thickness. Four representative soil samples were collected from each layer of the pits. Core samples were collected using open-faced coring tube for bulk density determination. Soil samples were air dried and subsequently ground and sieved with 2 mm sieve. Soil samples were subjected to routine analyses. Particle size distribution was determined by hydrometer method, bulk density was by core sampler method [10], moisture content was by gravimetric method, soil pH was determined using pH meter and organic carbon was by chromic wet oxidation method (Gee and Or, 2002; Grossman and Reinch 2002; Obi 1992; Thomas 1982; Nelson and Sommers 1996). Total Nitrogen was estimated by micro-Kjeldahl method while available phosphorus was determined using Bray II solution (Bremner and Mulvaney 1982; Olsen and Sommers 1982).

Carbon sequestration (g cm^{-2}) was evaluated using the equation of Batjes (Batjes 1996). The equation is outlined as follows;

Amount of carbon sequestered= $C_i \times B_i \times D_i \times 10$

Where B_i is the bulk density of individual layer (g cm^{-3}); C_i is organic carbon content of the layer (g kg^{-1}); D_i is the thickness of the layer (cm).

2.3 Data analysis

Analysis of variance (ANOVA) was used to evaluate the differences in soil physicochemical properties and soil carbon sequestration across soils of different fallow ages. For statistically different parameters ($p<0.05$), means were separated using Least Significant Difference (LSD). Correlation analysis was conducted to detect the functional relationship between soil variables while the vertical variations of soil properties were evaluated using coefficient of variation analysis and ranking done using the procedure of Wilding where CV < 15% = low variation, CV >15 < 35% = moderate variation, CV > 35 % = high variation (Wilding 1985). GenStat statistical software was used for statistical analyses (Payne et al. 2007).

3. Results and Discussion

3.1 Soil Physical and Chemical Properties

The average sand, silt and clay contents of the soils ranged from 835.2 – 889.2 g kg^{-1}; 18.2 – 57.2g kg^{-1} and 92.6 – 122.6 g kg^{-1} respectively The Sand content of the 7 years fallow was significantly ($p<0.05$) highest across the three fallow periods. The average silt and clay contents of the three fallow ages did not vary statistically (Table 1). Considering the sampling depth, sand content varied significantly across the soil depths under the 7 years fallow period while no significant variation was obtained among the sampling depths of the 14 years fallow period. In 21 years fallow, the sand content (775.2 g kg^{-1}) of the 60-80 cm sampling depth was significantly ($p<0.05$) lowest across the five sampling depths. The clay content of the 20-40 cm sampling depth under the 7 years fallow was significantly highest (127.6 g kg^{-1}) across the sampling depths. In 14 years fallow period, 40 -60 cm depth contained significantly highest clay fraction (142.6 g kg^{-1}) while the 80-100 cm sampling depth under the 21 years fallow period had significantly highest clay fraction (157.6 g kg^{-1}). This finding indicated the significant influence of soil depth on soil texture other than the effects of management practice.

Soil texture has earlier been defined as a near-permanent attribute of the soil and hardly does it easily change due to land use, management or conservation (Salley et al. 2017). Soil bulk density values differed significantly across the three fallow ages.14 years fallow had the least bulk density value (1.44 g cm^{-3}) while the 21 years fallow had the highest value (1.64 g cm^{-3}). Also, significant differences were found among the individual sampling depths. Bulk density influences availability and flow (lateral or vertical) of soil water and the growth of the plant roots. The results indicated that the soils had values that stood at its optimality (Powlson et al. 2011). The soil reactions were moderately acidic (mean pH values = 5.11 – 5.70) and differed significantly across the contrasting fallow periods. From the results, significantly highest pH value was obtained in 14 years fallow while the lowest was recorded in 7 years fallow respectively. The acidic condition of the soils could be attributed to the uptake of base-forming cations by plants. The uptake of nutrients by plants, differences in quantity and quality of biomass returned to the soil affect soil reaction (Ahukaemere et al. 2013).

Table 1 showed no significant differences in cation exchange capacity of the soils under the different fallow ages. However, the effective cation exchange capacity (ECEC) of soils of the study area was generally low (2.80 – 3.44 cmol+kg^{-1}). Soils of the coastal plain sands origin had earlier been reported to be made of low ECEC, base cations and base saturation (Soil Survey Staff, 2003; Offiong et al. 2009). The mean total nitrogen (TN) and available phosphorus contents ranged from 0.37-0.49 g kg^{-1} and 12.74-20.30 mg kg^{-1}. Significant differences were not found in the TN and available phosphorus contents of the soils under the three fallow ages. Sampling depths significantly ($p<0.05$) affected the TN contents of the soils. The soil TN was significantly lowest at 60-80 and 80-100 cm sampling depths due to lower organic carbon content as compared to the other sampling depths. 0-20 cm sampling depth under the 14 and 21 years fallow contained significantly highest quantity of TN (1.01, 0.62 g kg^{-1})

Table 1: Soil physical and chemical properties

DEPTH (cm)	Sand g kg^{-1}	Silt g kg^{-1}	Clay g kg^{-1}	BD gcm^{-3}	MC (%)	SCR	pH	OC g kg^{-1}	TN g kg^{-1}	AVP mg kg^{-1}	C/N	TEB	TEA cmol+kg^{-1}	ECEC cmol+kg^{-1}	BS (%)
7 years fallow period															
0-20	895.2	32.2	72.6	1.42	7.94	0.44	4.80	5.39	0.47	24.50	11.5	2.25	1.00	3.25	69.2
20-40	835.2	37.2	127.6	1.61	9.01	0.29	4.92	4.59	0.38	10.51	12.1	4.98	1.36	6.84	80.1
40-60	915.2	7.2	77.6	1.58	8.32	0.09	5.57	6.38	0.57	12.00	11.2	1.55	1.36	2.41	43.5
60-80	905.2	7.2	87.6	1.58	9.09	0.08	5.18	2.39	0.22	13.30	10.9	1.28	0.6	1.44	58.4
80-100	895.2	7.2	97.6	1.59	7.11	0.07	5.11	2.19	0.19	11.21	11.6	1.55	0.56	2.11	73.4
Mean	**889.2**	**18.2**	**92.6**	**1.56**	**8.29**	**0.19**	**5.11**	**4.19**	**0.37**	**14.30**	**11.46**	**2.32**	**0.98**	**3.21**	**64.92**

14 years fallow period															
0-20	865.2	17.2	117.6	1.36	10.69	0.15	5.64	11.57	1.01	16.10	11.5	3.32	1.16	4.48	74.1
20-40	855.2	7.2	137.6	1.48	9.07	0.05	5.40	7.38	0.64	12.60	11.5	3.36	1.24	4.59	73
40-60	835.2	22.2	142.6	1.47	9.56	0.16	5.76	3.39	0.29	9.10	11.7	1.7	1.00	2.7	63
60-80	835.2	27.2	137.6	1.47	10.61	0.2	5.74	2.79	0.25	12.60	11.2	1.61	1.24	2.85	56.5
80-100	835.2	87.2	77.6	1.42	9.82	0.12	5.98	3.19	0.28	13.30	11.4	1.49	1.08	2.56	57.9
Mean	**845.2**	**32.2**	**122.6**	**1,44**	**9.95**	**0.14**	**5.70**	**5.66**	**0.49**	**12.74**	**11.46**	**2.30**	**2.30**	**3.44**	**64.9**
21 years fallow period															
0-20	855.2	67.2	77.6	1.61	7.36	0.87	5.52	6.98	0.62	12.60	11.3	2.46	0.44	2.9	74.1
20-40	895.2	17.2	87.6	1.82	8.34	0.2	5.18	3.79	0.34	17.50	11.2	1.97	0.2	2.17	92.1
40-60	835.2	57.2	107.6	1.69	8.35	0.53	5.86	2.39	0.21	35.00	11.4	2.52	0.56	3.08	81.8
60-80	775.2	117.2	107.6	1.61	12.43	1.09	5.11	4.59	0.41	19.60	11.2	2.42	0.8	3.22	75.2
80-100	815.2	27.2	157.6	1.49	13.07	0.17	5.51	2.19	0.2	16.80	11	1.76	0.88	2.64	66.7
Mean	835.2	57.2	107.2	1.64	9.91	0.52	5.44	3.99	0.36	20.30	11.22	2.23	0.58	2.80	77.98
LSD(0.05	**53.29**	**50.34**	**19.00**	**0.10**	**2.43**	**0.35**	**0.29**	**2.89**	**0.26**	**10.18**	**0.41**	**1.31**	**0.49**	**1.89**	**13.63**

BD = Bulk density, MC = Moisture content, SCR = Silt clay ratio, OC = Organic carbon, TN = Total nitrogen, AVP = Available phosphorus, C/N = Carbon nitrogen ratio, TEB = Total exchangeable bases, TEA = Total exchangeable acidity, ECEC = Effective cation exchange capacity

3.2 Quantity of carbon in soils under different fallow ages and soil depths

Figures 1 and 2 show the average organic carbon contents and carbon sequestration values in soils under the three fallow ages. The mean organic carbon content of the soils ranged from 3.99-5.66 g kg^{-1} while the average carbon sequestration value ranged from 1295.00-1611 g cm^{-2}. Though not statistically different, 14 years fallow had higher organic carbon (5.66 g kg^{-1}) and carbon stock (1611 g cm^{-2}) than other fallow ages (Figs.1 and 2). However, high C sequestration observed in 14 years fallow could be attributed to the plant's ability to capture and store atmospheric carbon since old plants sequester lesser carbon than young ones (Ogban and Ekerette 2001; Poulton et al. 2003). The results obtained from this study also indicated that prolonged fallow period on degraded tropical soils may not be beneficial to soil carbon sequestration.

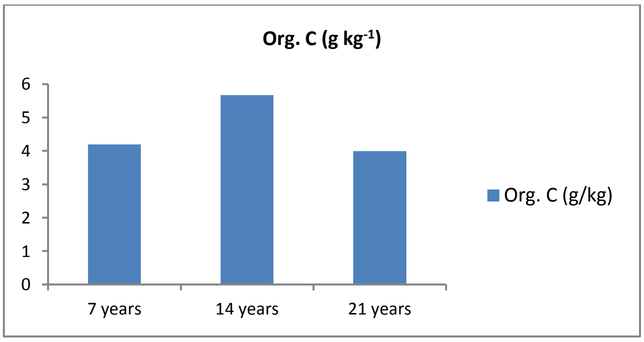

Figure 1: The average organic carbon content in soils under different fallow ages. LSD (0.05) =2.83

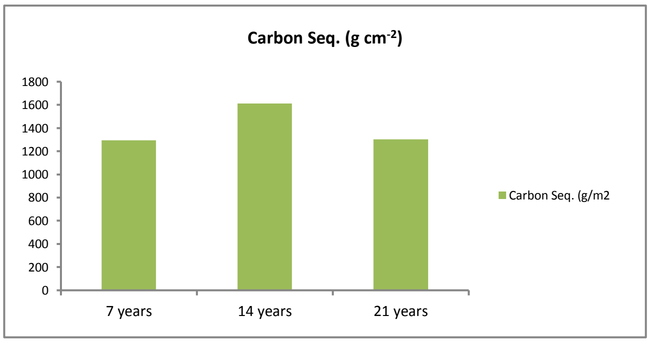

Figure 2: The average carbon stock in soils under different fallow ages. LSD (0.05) = 818.3

On the other hand, sampling depth had a significant influence on soil carbon content. In 7 years fallow period, 40-60 cm sampling depth contained significantly highest organic carbon (Table 1) while in 14 and 21 years fallow ages, 0-20 cm sampling depth contained significantly highest organic carbon content (11.57 g kg^{-1}, 6.98 g kg^{-1}). Also, 20-40 cm depth under 14 years fallow had significantly higher quantity of organic carbon than 40-60, 60-80 and 80-100 cm sampling depths. High coefficient of variation (>35%) between the SOC content of the different sampling depths confirmed these variations. Results of the study show that soil depth affected the quantity of carbon sequestered in the soil obtained similar result (Mbah and Idike 2011). Soil carbon sequestration followed a similar trend with organic carbon. Across the three fallow periods, 0-20, 20-40, 40-60, 60-80 and 80-100 cm sampling depths stored 2308.3, 1681, 1274, 998.7 and 752.7 g cm^{-2} (Table 2).

Table 2: Effect of sampling depth on soil carbon

Depth (cm)	OC (g kg^{-1})	CS (g cm^{-2})
0-20	7.98	2308.30
20-40	5.25	1681.00
40-60	4.05	1274.00
60-80	3.25	998.70
80-100	2.53	752.70
LSD (0.05)	3.73	1056.40

CS = carbon sequestration, OC = organic carbon

Generally, from the results, soil carbon reduced with sampling depth at all sites used for the study. In 7 years fallow period, 40-60 cm sampling depths contained significantly highest carbon sequestration value. In 14 and 21 years fallow ages, 0-20 cm sampling depth sequestered significantly highest carbon (3147.04 g cm^{-2}, 2247 g cm^{-2}) compared to other depths (Fig. 3). The quantity of carbon stored in the uppermost layer (0-20 cm) of soil under the different fallow ages was greater than the deepest layer by 25-28% probably because most of the litters and other plant residues are incorporated or deposited on the soil surface. Dick and Gregorich reported high carbon concentration on the soil surface. However, the upper part of the soil happened to be the first beneficiary of the photosynthetic extraction of carbon into the terrestrial environment from the atmosphere through phyto-mechanisms (Dick and Greorich 2004). The coefficient of variation results showed high variation (43, 64 and 48%) among the varying soil depths. This was further explained by the values of the standard deviation obtained from the study (Table 3).

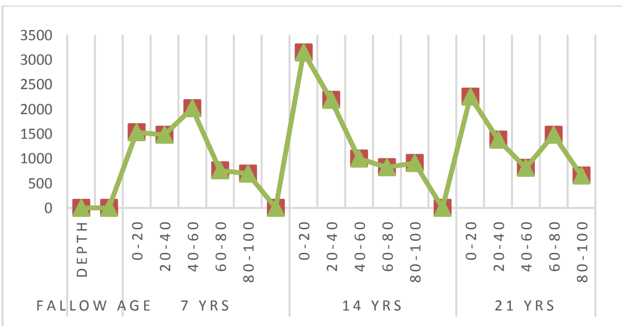

Figure 3: Carbon stocks (g C m^2) of the varying soil sampling depths (cm) under the three different fallow periods. LSD (0.05) = 818.3

Table 3: The Mean, standard deviation and coefficient of variation results of soil carbon

Fallow Age	Organic Carbon (g kg^{-1})	Carbon stock g cm^{-2}
7 years		
Mean	4.19	1295.30
SDV	1.846	560.9499
CV	44.07	43.31
14 years		
Mean	5.67	1610.88
SDV	3.787	1023.238
CV	66.91	63.52
21 years		
Mean	3.99	1313.11
SDV	1.945	631.7356
CV	48.78	48.11

SDV = Standard deviation, CV = Coefficient of variation, CV ≤ 15% = Low variation, CV > 15 ≤ 35% = Moderate variation, CV > 35 = High variation (Wilding, 1985).

Results of the correlation analysis show that carbon sequestration correlated positively with organic carbon, total nitrogen and total exchangeable bases (r = 0.988**, r = 0.999**, r = 0.502*) (Table 4). These relationships indicate the potential influence of these soil parameters on carbon sequestration. Also, soil moisture contents correlated positively with clay (r = 0.602*). Generally, clay has a high rate of adsorption and can retain water easily. Odunze reported that moisture content increased with increasing clay content as clay would cause impaired drainage, especially at the subsurface horizons (Odunze 2003). Coarse-textured soils are characterized by low moisture content and high drainage, thus resulting to moisture stress.

Table 4: Correlation matrix of soil properties

soil prop.	**CS**	**ECEC**	**MC**	**OC**	**PH**	**TEB**	**TN**	**Clay**	**Sand**	**Silt**
CS	1									
ECEC	0.453	1								
MC	-0.105	0.084	1							
OC	0.988**	0.458	-0.037	1						
Ph	-0.035	-0.23	0.1960	0.009	1					
TEB	0.502*	0.965**	-0.011	0.484	-0.311	1				
TN	0.989**	0.428	-0.032	0.999**	0.008	0.458	1			
clay	-0.140	0.369	0.603*	-0.089	0.201	0.275	-0.103	1		
sand	0.170	-0.316	-0.705	0.141	-0.258	-0.2531	0.148	-0.526*		
Silt	-0.081	0.060	0.321	-0.091	0.135	0.066	-0.088	-0.192	-0.787**	1

*and** = significant at 0.05 and 0.01 probability levels respectively, CS = Carbon sequestration, ECEC = Effective cation exchange capacity, OC = organic carbon, MC = Moisture content, TN = Total nitrogen, TEB = Total exchangeable bases.

4. Conclusions

The results of this study revealed that fallow age and soil depth influence the amount of carbon sequestered in the tropical soils. 14 years fallow sequestered the highest quantity of carbon while the least carbon stock was observed in 7 years fallow. In 7 years fallow, carbon stock was dominant at 40-60 cm depth while in 14 and 21 years fallow ages, 0-20 cm sampling depth sequestered significantly highest carbon compared to other sampling depths. Conclusively, in tropical soils, carbon is more often sequestered in the top-soil layer than in the sub-soil layer. Prolonged fallow age up to 21 years may not be beneficial to soil carbon sequestration. Soil properties such as total exchangeable bases, organic carbon and total nitrogen significantly affected soil carbon sequestration in the soils. In order to maintain this carbon sequestration, soils are to be kept covered for certain period of time; and other management practices that encourage the deposition of organic residues on the soil surface should be adopted.

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