SOIL CARBON SEQUESTRATION CAPACITY MEASUREMENT PER CENTIMETRIC DEPTH UNIT: A RATIONAL APPROACH

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ABSTRACT

This study was conducted to investigate soil carbon sequestration measurement with calibration per centimeter (cm) rise in depth of soils derived from the Ajali sandstone. It was designed to determine and whether more carbon are sequestered at the epipedon or soil sub-surface horizons. The field design involves the use of transect survey technique, three profile pits were dug in 100 meters apart and evaluation of all underlain by identified false bedded sandstone (that formed Ajali formation) lithology. Standard laboratory procedures were adopted in analyzing the soils. Soil generated data were subjected to descriptive statistics and correlation analysis. Results showed that the soils were basically loamy sand and sandy loam with low pH values which ranged between 4.50 and 4.90. Soil Organic Carbon (SOC) decreased down the profile pit and ranged between 9.7 and 9.10 g kg^{-1}. Carbon sequestered by the different horizons ranged from 3072.62- 3989.9 g cm^{-2}. It was also found that the thicker the soil natural horizon, the more the carbon in all the profiles. Inversely, when sequestered carbon was measured against calibrated horizons in per centimeter unit rise in soil depth, it was found that more carbon were rather stored in the upper horizons than in deeper horizons which was contrary to earlier observation. The regression analysis further portray and support this finding by giving a negative relationship between sequestered carbon per centimeter against horizon thickness, indicating decrease in carbon sequestration with increase in soil profile depth. Therefore, this study established and concluded that more carbon is sequestered in the epipedal portions of the soil profile than in the sub-surface horizons.

Keywords: Carbon sequestration, calibration, Rational approach and Soil depth.

INTRODUCTION

The ability of the soil to store carbon is referred to as carbon sequestration. Soil organic carbon (SOC) includes plant, animal and microbial residues in all stages of decomposition (Post and Kwon, 2000). The amount of carbon store therefore in soil is 3-2.5 times greater than the amount sequestered in vegetation and two times the amount that exist in atmosphere (Denmam *et al*., 2007, Eswaran *et al*., 1999 and Schlesinger, 1990). Hence this confers that soil has the ability to mitigate rapid climatic changes through carbon trapping and subsequent storage. The turnover rate of the different SOC compounds varies due to the complex interactions between pedological, biological, chemical, and physical processes in soil. Although there may be a continuum of SOC compounds in terms of their decomposability

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and turnover time, physical fractionation techniques are often used to define and delineate various relatively-discrete SOC pools. Physically defined fractions, while containing a diverse array of organic compounds, integrate structural and functional properties of SOC (Christensen, 1996). The rates of transfer and transformation are influenced by biologically important factors including soil depth, soil moisture and soil temperature (Post and Kwon, 2000). Variability in carbon distribution within the soil profile is attributed to variations in horizon depth, bulk density and organic carbon content. Ahukaemere *et al*., 2015 supported that various changes in soil horizon depth, organic carbon, bulk density and land-uses do affect soil carbon sequestration. However;it has been documented thatthe amount of carbon stored in soil varied among soil groups, agro-ecological zones and human interference (Batjes, 1999).A lot of studies have been carried out on carbon storage in soils with reference to depth. Batjes (1996), Mba and Idike, (2011), Ahukaemere (2015) and Abebayehu (2013) observed in various studies at different periods and locations that as sampling depth of soils increased, carbon storage also increased; they noted that deep soil profile allows more organic carbon accumulation than shallow depths.

Assessments of the distribution of carbon within and among soils are critical to developing an understanding of the cause and effect relationships between climate and release of carbon dioxide to the atmosphere (Schimel *et al.,* 1994). In addition to understanding the cause and effect relationships, knowledge of soil carbon distribution within the soil profile is critical when developing carbon budgets for basic ecosystem characterization (Davis *et al*., 2004). Ideally equivalent environmental condition and management practices, the distribution and sequestration of carbon in soil vary with horizon depth (Jobbagy and Johnson, 2000). In most developed countries, some regional studies on estimation of soil carbon pools using profile data have been conducted (Grossman *et al*., 1998). Such regional studies are scanty in developing countries like Nigeria and where available consider too many soil properties. It was for this reason therefore, that this study sought to find out the amount of Carbon sequestered per centimeter unit rise in soil depth vertically down the soil profiles of some soils in Okigwe, South-east Nigeria; and consequently, to also find out whether more carbon is sequestered in the epipedal horizons than in the sub-surface horizons of the profile if given the same calibration.

METHODOLOGY

Study area

The study was located at Umulolo in Okigwe, Northern area of Imo State, South-east Nigeria. Okigwe is situated at the Northern apex area of Central South-east Nigeria with the study site lying between latitude 5º 52^1 N and longitude 7º 15^1 E.. The lithology of the studied area is made-up of False bedded Sandstone. The mean annual temperature is between 24.5 and 28.5 ºC, mean annual rainfall ranges between 1700 and 2250 mm; mean daily relative humidity of above 75 %, evaporation of above 1450 mm/y (NIMET, 2014). Vegetation of the study site comprised of mixed vegetation. Arable crop production is a major socio-economic activity of the study area.

Soil sampling

A hectare of land comprised of mixed vegetation such as Oil palm tree (*Elaeisguineensis*), Banana (*Musasapientum*), Oil been tree (*Pentaclethramacrophylla*), bush mango (*Irvingiagabonensis*), Elephant grass (*Pennisetumpurpurem*), Giant star grass (*Cynodonplectostachyus*). Fluted pumpkin (*Telfaria occidentalis*), *Albemoschusesculentum*

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(okro), *Zeamays* (maize), *Discorearotundata* (yam), and wild legumes was sampled. At the study site, guided by transect sampling technique; three pedons were dug 100 meters apart. The pits were described and sampled according to the procedure of FAO (2006). After horizon demarcation according to their natural appearance, soil samples were taken from the component horizons; air dried and ground to pass through 2 mm sieve prior to laboratory analysis.

Laboratory and data analyses

Laboratory analyses was conducted for particle size distribution by hydrometer method (Gee and Or, 2002), bulk density by core method (Grossman and Reinsch, 2002), moisture content by (Obi, 1990), soil pH using pH meter (Hendershot *et al*., 1993), organic carbon by wet digestion (Nelson and Sommers, 1982). Carbon stored (gCm^{-2}) in each horizon was determined by multiplying bulk density (gcm^{-3}) x organic carbon (gkg^{-1}) x horizon depth (cm) (Batjes, 1996). Carbon storage - horizon depth ratio was obtained by dividing carbon stored in each horizon by the corresponding horizon depth. Carbon stored per centimetric unit of each horizon was obtained by dividing sequestered carbon in a horizon against its horizon thickness. After this calibration, a regression analysis was carried in order to know how sequestered carbon per cm depth unit would relate with horizon depth.Generated soil data were subjected to mean and standard deviation analyses from which coefficient of variation (in percentage) was computed. Variability among selected soil properties of the different horizons of each profile pit was ranked using Wilding, (1985).

RESULTS AND DISCUSSION
Selected soil properties of the three pedons

Considering the three pedons investigated, the average sand content ranged from 750.7-796 gkg^{-1} The three pedons had silt content range of 68 and 208 g kg^{-1}; with 168 ± 31.62, 178 ± 24.49 and 128 ± 42.43 for pits 1, 2 and 3, respectively (Table 1). The clay content ranged between 68 and 88 g kg^{-1}; with pit 1 having a mean value of 72 ± 8.94, whereas pits 2 and 3 had mean values of 71.3 ± 8.16 and 76 ± 10.95, respectively (Table 1). The textural class of the soils studied comprised generally of loamy sand and sandy loam. However, the sand, silt and clay fractions of the soils and their textural class generally represent soils of the area as was shown by previous studies (Unamba-Oparah, 1985, Unamba-Oparah and Kemakolam, 1985).Bulk density and porosity of the soils are shown in Table 1. Results showed that bulk density increased down the profile pits; conversely, porosity decreased with depth in each of the three pedons. Bulk density value was between 1.9 and 1.58 gcm^{-3} while the porosity of the soils ranged between 32.8 and 53.8 %. The bulk density and total porosity values of the studied soils fall within the range that is expected of tropical soils (Landon, 1991). Soil total porosity has direct relationship with bulk density; at increasing bulk density, total porosity decreases (Iwara *etal*., 2011; Offiong*et al*., 2009). Results obtained showed that moisture content ranged between 9.5 and 11.4 %. Generally, the moisture content of the soils were low, this showed that the soils are sandy and as such are not able to retain enough moisture. The soils' pH was generally low ranging between 4.5-4.9. Soil pH of the humid tropics especially that of the area under study is known to be acidic (Unamba-Oparah and Kemakolam, 1985; Onweremadu, 2007). Landon (1991) noted that soil pH lower than 5.5 is low, and that a range of 5.5-7.0 is preferred. Therefore, the soils of the three pedons are generally acidic, which is typical of the area.

Table 1: Selected soil properties of the three (3) profile pits

Ho. deg	Hor. depth	Hor. thic.	Sand	Silt gkg^{-1}	Clay	T C	BD gcm^{-3}	MC (%)	TP (%)	pH (w)	OC gkg^{-1}	CS gCm^{-2}	CS:HT
	Pit 1												
A	0-9	9	804	128	68	LS	1.01	6.48	61.9	4.32	18.8	1708.9	189.88
AB	9-26	17	744	188	68	LS	1.12	7.05	57.7	5.23	8.9	1694.6	99.68
Bt1	26-80	54	724	208	68	LS	1.21	20.9	54.3	5.11	6.1	3985.7	73.81
Bt2	80-103	23	784	148	88	LS	1.21	9.97	46.0	5.00	6.1	1697.6	73.81
Bt3	103-180	77	764	168	68	LS	1.43	12.8	35.5	4.90	5.7	6276.3	81.51
	Mean	36	754	168	72		1.19	11.4	51.1	4.9	9.10	3072.6	103.74
	SDV		31.6	31.6	8.94		0.15	5.86	10.5	0.35	5.56	2046.1	49.30
	CV (%)		4.40	18.3	12.4		12.2	51.4	20.6	7.1	61.1	66.59	45.52
	Pit 2												
A	0-9	9	764	168	68	LS	0.9	15.3	66.0	4.43	16.8	1360.8	151.20
AB	9-29	20	764	168	68	LS	1.06	7.14	60.0	4.61	13.3	2819.6	140.98
Bt1	29-50	21	764	168	68	LS	1.20	6.45	54.7	4.92	8.8	2217.6	105.60
Bt2	50-79	29	764	148	88	LS	1.21	8.52	54.6	4.80	5.7	2000.1	69.97
Bt3	79-120	41	724	208	68	SL	1.36	9.00	48.7	4.80	6.7	3735.8	91.12
Bt4	120-180	60	724	208	68	SL	1.48	10.6	38.9	4.70	7.1	6304.8	105.08
	Mean	30	750.7	178	71.3		1.20	9.5	53.8	4.7	9.7	3073.1	110.49
	SDV		20.65	24.5	8.16		0.21	3.2	9.37	0.18	4.38	1775.5	30.79
	CV (%)		2.75	13.8	11.4		17.5	33.7	17.4	3.8	45.2	57.78	27.89
	Pit 3												
A	0-17	17	824	108	68	LS	1.12	8.20	57.7	4.00	17.0	3236.8	190.40
AB	17-29	12	804	128	68	LS	1.30	9.61	50.9	4.50	10.9	1726.6	143.88
Bt1	29-46	17	844	68	88	LS	1.15	9.07	56.6	4.60	7.7	1505.4	88.55
Bt2	46-98	52	764	168	68	LS	1.58	15.2	32.8	4.60	8.1	6654.9	127.98
Bt3	98-178	80	744	168	88	LS	1.58	14.8	32.8	4.70	5.4	6825.6	85.32
	Mean	35.6	796	128	76		1.35	11.4	46.2	4.5	9.8	3989.9	127.22
	SDV		41.47	42.2	11.0		0.22	3.36	12.5	0.28	4.46	2598.4	43.36
	CV (%)		5.20	33.2	14.4		16.3	29.5	27.0	6.22	45.6	65.12	34.08

Hor. deg. = Horizon designation, Hor, thic. = Horizon thickness (cm), TC=Textural class; LS=Loamy sand; SL=Sandy loam; BD=Bulk density; TP=Total porosity; MC=Moisture content; OC=Organic carbon; CS=carbon storage; CS:HT=carbon storage: horizon thickness; SDV=Standard deviation; CV=Coefficient of variation: Cv ≤ 15% = Low variation, Cv > 15 ≤ 35% = Moderate variation, Cv >35 = High variation

Soil organic carbon and carbon sequestration

The soil organic carbon of the three pedons is presented in Table 1. Results indicated that epipedal portions of the soils had more soil carbon content in all the pits. The soil carbon generally decreased with increase in profile depths with the mean values of 9.1 ± 5.56, 9.7 ± 4.38 and 9.8 ± 4.46 g kg^{-1} for pits 1, 2 and 3, respectively. Horizontally, results as shown in Table 1 showed that more carbon was sequestered in horizon with greater depths. Therefore, as the profile depths increased with increase in horizon thickness down the profiles, carbon storage equally increased. The mean values obtained were 3072.6 ± 2046.1, 3073.1 ± 1775.5 and 3989.9 ± 2598.4, respectively.

Carbon sequestration per cm increase in soil depth

Carbon stored for every one centimeter as shown in Table 1 indicated a steady decline intrepidly and intrepidly in all the studied pedons. Results showed that 103.74 ± 49.3, 110.49 ± 30.79 and 127 ± 43.36 were obtained for pits 1, 2 and 3, respectively. The results of the coefficient of variation (% CV) showed that carbon sequestered per cm varied between moderated variation (MV) and high variation (HV) (Tables 1). Using the regression equation model derived from the regression line graph for the three pedons (Figure 1), Table 2 showed that for every 10 cm increase in depth there was a corresponding steady decline of carbon sequestered down the pit.

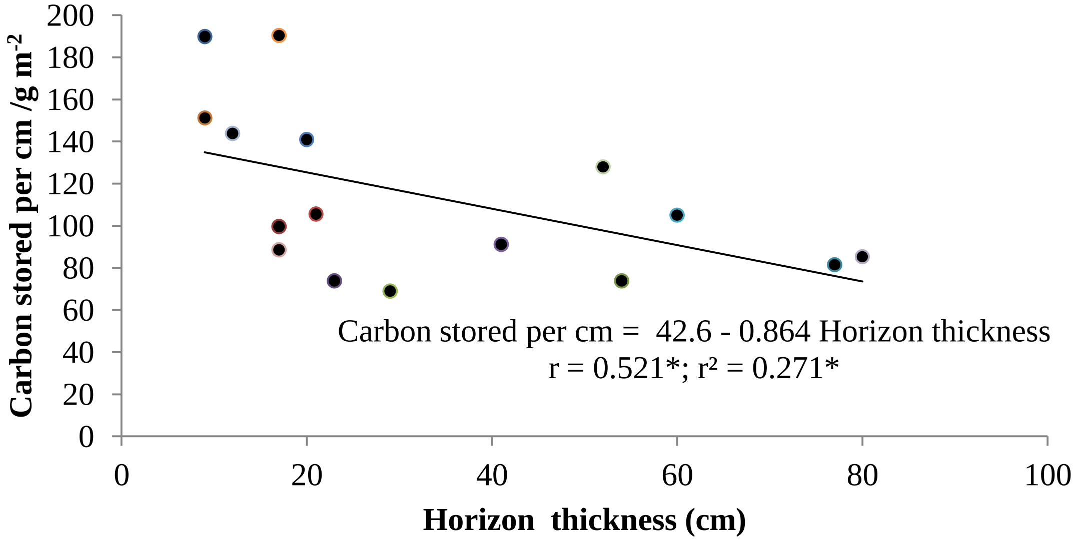


Figure 1: Carbon stored per centimeter versus horizon thickness

Table 2: Soil carbon sequestered declining by every 10 cm rise in soil depth

Soil depth (cm)	Carbon storage: horizon depth
10	134.04
20	125.39
30	116.75
40	108.10
50	99.46
60	90.81
70	82.16
80	73.51
90	64.87
100	56.22

Traditionally, workers all over the world have studied carbon sequestered in the soil profile from the approach of carbon stored per horizon depth. Using this approach, they have concluded that carbon sequestered in the soil profile increases with increase in soil depth. For instance, Batjes (1996), Mba and Idike, (2011), Aticho (2013) and Ahukaemere (2015) observed that as sampling depth of soils increased, organic carbon storage also increased; they noted that deep soil profile allows more carbon accumulation than shallow depths. This observation was based on the horizon depth (thickness). In as much as horizon depth is high, carbon sequestered will definitely be high since horizon depth is one of the functions of carbon sequestration calculation. In calculating carbon storage in soil, organic carbon is multiplied by bulk density and horizon depth. If carbon sequestration is therefore based on this, one is bound to have more carbon stored in the deeper horizons since as depth of soil increases, horizon thickness also increases. The argument here is that higher horizon thickness will definitely yield higher carbon sequestration. This is the reason why carbon appeared to be increasing with a rise in horizon depth. In contrast to the above observation, this study found that more carbon is actually sequestered in the upper horizons than in the deeper horizons. This can be clearly seen in Tables 2, 3 and Fig. 2. This study calibrated each carbon stored in a horizon in cm by dividing sequestered carbon in a horizon against its horizon thickness. This way one can know how much carbon is stored in a horizon per cm.

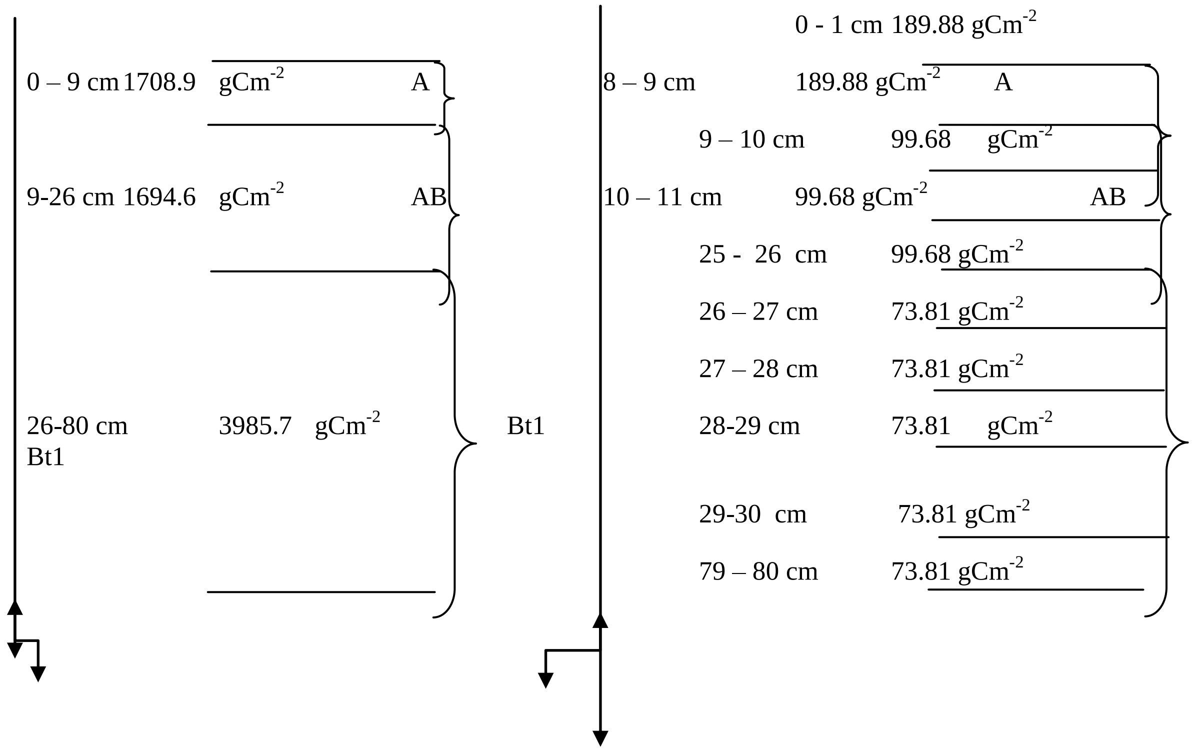
After this calibration, a regression analysis was carried in order to know how sequestered carbon per cm depth unit would relate with horizon depth. The regression line showed a negative relationship indicating that as profile depth increases, carbon sequestration decreases down the profile pits (Figs. 1 and 2).

Table 3: Correlation and regression analysis

Model		Unstandardized coefficients		Standardized coefficients				
		B eta	Std. Error	Beta	Sig.	R	r^2	N
Cultivated	Constant	142.69	15.43					
	HT	-0.86	0.378	-0.521	0.038	0.521	0.272	16

The dependent variables for forest fallow and cultivated soils are carbon stored per cm.
HT = Horizon thickness

Traditional Approach **A Rational Approach (Calibrated to 1cm)**



The two arrows facing down show increasing soil depth

Figure 2: A sketch of traditional approach (that sequestered carbon increases with soil depth) and rational approach (that sequestered carbon decreasesdown the profile when properly calibrated).

Therefore, it is scientifically erroneous and rationally unacceptable to say, for example that a soil horizon depth of 0-9 cm (9 cm thickness) with carbon sequestration of 1708.9 gCm^2 asobserved in this study (Table 1, pit 1, fig. 2) is smaller than that in a soil horizon depth of 26-80 cm (54 cm thickness) with 3985.7 gCm^2 sequestered carbon. Rationally, for one to know which horizon depth actually has higher carbon sequestration, then it should be measured against their various horizon thicknesses, that way one can exactly say which one

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sequestered more carbon with a unit depth rise in cm. Hence, for a unit depth rise in cm, 0-9 cm of 9 cmsoil thickness sequestered 189.9 gCm^{-2} carbon as against 73.81gCm^{-2} sequestered by 26-80 cm of 54 cm soil thickness. This trend of decrease in sequestered carbon for every unit depth rise in 1 cm continues down the soil profiles (Fig. 2). This is the main thrust of this study.This observation in which higher amounts of carbon is sequestered in the upper portions of the profile pits than in the deeper layers can be empirically explained. The upper parts 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. Even though the distance travelled by the carbon down the soil profile that is normally captured by plant from the atmosphere is determined by soil type vis-à-vis the parent material from which the soil was formed, the nature of the soil separates, ambient weather conditions of the place, and the land disturbances such as cultivation, land-use changes and other soil management practices; it is worthy of note that as carbon moves down the soil, there is replacement through photosynthetic processes. The rate of movement down the soil pedons is usually slower than the rate of replacement from the atmosphere. This therefore further explains the reason why more carbon is sequestered in the epicedial layers. Although cultivation and other soil disturbances can lead to loss of carbon from the soil (Schlesinger and Litcher, 2001), findings from this study however, suggests that more carbon were sequestered in the upper layers of the soil than in the inner portions (Fig. 2). However, soil management and land-use practices that encourage the deposition of organic materials at surface of the soil should be adopted. This therefore makes it imperative that in order to continue the reduction of carbon in the atmosphere as a means of combating or mitigating global warming (Tieszer, 2000), all types of vegetative growth that ensures soil cover should be greatly advocated for. This way, the carbon sinking ability of the soil would be potentially tapped and in the process abate global warming.

CONCLUSIONS

Considering this study, soil carbon sequestration capacity measurement using a rational approach in which soil depth was calibrated in per one centimeter unit rise in depth, found that sequestered carbon in soil profile decreased with increasing soil depth. Therefore, it concluded that more carbon is sequestered in the epipedal portions of soil pedons than in deeper horizons. In order to maintain this carbon sequestration, soils are to be kept covered and with little or no tillage; and other management practices that encourage the deposition of organic residues on the soil surface should be adopted.

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