ISSN: 1394-7990
Malaysian Journal of Soil Science Vol. 20: 37- 48 (2016) Malaysian Society of Soil Science

Sub-Soil Carbon and Nitrogen Sequestration: Soil Profile Measurement Approach

Ahukaemere, C.M

Department of Soil Science and Technology, Federal University of Technology, P.M.B. 1526, Owerri, Imo State, Nigeria.

ABSTRACT

Carbon sequestration is the process of transferring atmospheric carbon dioxide into the soil and storing it securely so it is not immediately re-emitted into the atmosphere. A thorough understanding of carbon and nitrogen sequestration in various horizons of the soil profile would be helpful to comprehend carbon and nitrogen cycling from a pedological perspective. The quantity of carbon and nitrogen sequestered at different horizons of the soil profile pit was investigated. Results showed that the mean organic carbon content of the soils varied from 6.81 to 37.75 g kg^{-1}. The organic carbon content of the individual horizon varied substantially within the profiles. Carbon and nitrogen sequestration capacities of the soils varied from 3142.60 – 7643.25 g C m^{-2}, 101.33 – 503.55 g N m^{-2} and increased with horizon thickness in all the soil profiles. Bulk density has significant positive relationship with the amount of carbon sequestered in the soil. The results of regression analysis showed that with the effect of horizon thickness, bulk density and organic carbon on carbon sequestration, the regression coefficient of determination (R^2) was 0.693 (p<0.001). On N sequestration versus horizon thickness, bulk density and total nitrogen, it was found that 67 % of the variation (significant at p<0.001) in soil nitrogen sequestration capacity was due to the aforementioned independent variables in soil.

Keywords: Coastal plain sand, horizon depth, soil bulk density, multiple linear regression, correlation analysis.

INTRODUCTION

Global soil nitrogen (N) and carbon (C) sequestration has been estimated since the 1970s. Early inventories of global soil carbon and nitrogen used a carbon/nitrogen (C/N) ratio conversion approach (Burns and Hardy, 1975; Stevenson, 1982). However, more recently, soil profile measurement approaches have been used to estimate soil N and C sequestration (Batjes, 1996, Lin *et al.*, 2010; Abebayehu, 2013). However, there are many methodological problems with sampling soils for C and N sequestration, including accurate measurement of bulk density, accurate measurement of horizon thickness, organic carbon and/or total nitrogen and the maximum profile depth to which soils should be sampled (Burton and Pregtizer, 2008). Assessments of the distribution of C and N within and among soils are critical to developing an understanding of the cause and effect relationships between

---

*Corresponding author : E-mail: *mildredshine@yahoo.com* climate or land use change and release of carbon dioxide and nitrous oxide to the atmosphere (Schimel *et al*., 1994). In addition to understanding the cause and effect relationships, knowledge of soil C and N distribution within the soil profile is critical when developing C budgets for basic ecosystem characterisation (Davis *et al*., 2004). Under ideally equivalent environmental condition and management practices, the distribution and sequestration of carbon and nitrogen in soil varies with horizon depth (Jobbagy and Johnson, 2000). Variability in C distribution within the soil profile is attributed to variations in horizon depth, bulk density and organic carbon content.

In most developed countries, some regional studies on estimation of soil C pools using profile data have been conducted (Grossman *et al*., 1998). Eswaran *et al*., (1993) reported the contributions of O horizon and sub-soils of forest soils to the carbon pool. Such regional studies are scanty in developing countries like Nigeria and where available, they are found to consider too many soil properties. In view of this, this study was aimed at investigating the quantity of C and N sequestered at different horizons of soil profile pits.

MATERIALS AND METHODS

Study Area

The study area (Umuagwo, Ohaji) is located between latitudes 5^{o} 19^{1} N, and longitudes 6^{o} 58^{1} E. The geology of the region is characterised by coastal plain sands, alluvium and Sombreiro-Warri deltaic plains (Atlas of Imo State Geology, 1984). Coastal plain sands which underlie a major part of the region (including Umuagwo) consist of unconsolidated sand materials which are sometimes cross-bedded with clays, sandy clays and sometimes, pebbles (FDALR, 1985). The area receives an average of 2500 mm of rainfall distributed over about 139 days of the year. The daily temperature ranges from a minimum of 21^{o} C to a maximum of 30^{o} C. The relative humidity reaches a minimum of 60% in January (at the peak of the dry season) and rises to 80 - 90 % in July (at the peak of the rains) (NIMET, 2014). The original vegetation of the study area was tropical rainforest (FDALR, 1985). The rain forest has, however, been destroyed largely through human activities and supplanted with what is today referred to as the oil palm bush.

Field Study

A transect technique was adopted in field sampling. A transect of 200 meters was drawn and four profile pits were dug at a distance of 50 m apart along the transect. These profile pits were examined according to FAO (2006) guidelines. Bulk soil samples were collected from various identified genetic horizons of the profiles. The processed soil samples were analysed for some physico-chemical properties following procedures outlined by Van Reeuwijk (2002). Particle size analysis was determined by hydrometer method, soil pH in 1:2.5 water suspension was measured with a pH meter and organic carbon by Walkley and Black method. The available P was determined according to Bray No. 2 method, total N was determined by microKjeldahl digestion method. Bulk density was determined by core method, the exchangeable bases were determined by the use of neutral ammonium acetate method and base saturation by calculation.

Carbon Sequestration (g C m^{-2}) was calculated using the method of Batjes (1996)
BD (g cm^{-3}) x OC (g kg^{-1}) x horizon thickness (depth) (cm) ≈ $\sum B_i \times C_i \times D_i$
where B_i is the bulk density of individual layer i (g cm^{-3}), C_i is organic carbon in layer i (g kg^{-1}) and D_i is the thickness of this layer (cm).

Nitrogen Sequestration (g N m^{-2}) = $\sum D_i \times B_i \times TN_i$ where D = depth, B = bulk density and TN = total nitrogen (He *et al*., 2012). The amount of C and N sequestered (gram per meter square) (g m^{-2}) in each profile was obtained by summing up the carbon stored in different horizons of the respective profiles.

Statistical Analysis
Data generated were subjected to coefficient of variation, multiple linear regression and correlation analyses using SPSS statistical software. Correlation analysis was used to detect the relationships among soil variables while the multiple linear regression model was used to determine the contribution of the independent variable to the dependent variable, described as follows: $Y = b_0 + b_{1x1} + b_{2x2} + b_{3x3}$, where Y = the dependent variable, x_1,…x_3 = independent (predictor) variables, b_1,… b_3 = coefficients that describe the effect of the independent variables on dependent variable, *b* = the value *Y* is predicted to have when all independent variables are equal to zero (0) (Shaw and Wheeler, 1996). Selection of the dependent (*Y*) and the independent (*X*) variables was done using stepwise elimination. The aim of selection is to reduce the set of predictor variables to those that are necessary and account for nearly as much of the variance as is accounted for by the total set. The coefficient of variation was ranked according to the procedure of Wilding (1985) where CV ≤ 15% = low variation, CV >15 ≤ 35% = moderate variation, CV > 35 % = high variation.

RESULTS AND DISCUSSION

The descriptions of the sites studied are presented in Table 1. The two major land use types identified were secondary forest and cultivated lands. Although both land use types contained mixed vegetation, trees dominated the secondary forest while edible crops, wild grasses and legumes dominated other plant types in the cultivated land use type. However, the nature and distribution of the vegetation types have obvious pedogenic implications on the soils of the coastal plain sand. Several bio-sequence studies show that plant species influence litter layer thickness (Johnson-Maynard *et al*., 2004), activities of soil organisms, carbon and nitrogen accumulation (Ahukaemere *et al*., 2015), and rates of decomposition (Quideau *et al*., 2001). The thickness of the soil horizons varied from 4 - 55 cm (profile 1) to 20 - 62 cm (profile 2), 5 - 71 cm (profile 3) and 28 - 65 cm (profile 4)

(Table 2). The O horizons were thin (4 - 14 cm) but with a greater likelihood that they mixed with the underlying horizons as a result of pedoturbation.

TABLE 1
Description of the sites

Location	Parent material, profile No.	Land use history
Umuagwo,Ohaji (5^{0} 19^{1} 29.4^{11} N, 6^{0} 58^{1} 32.6^{11} E)	Coastal plain sand; Profile 1	Secondary forest, contained mainly wild perennial plants (trees) such as *Tectona grandis (*Teak*),*
Umuagwo,Ohaji (5^{0} 29^{1} 40.4^{11} N, 6^{0} 34^{1} 32.6^{11} E)	Coastal plain sand; Profile 2	Cultivated land, contained mainly *capsicum* spp (green and hot pepper) and *Albemoschus esculentum* (okra) as intercrop, fertilized with NPK fertilizer and single phosphate fertilizer.
Umuagwo,Ohaji (5^{0} 36^{1} 29.4^{11} N, 6^{0} 32^{1} 41.6^{11} E)	Coastal plain sand; Profile 3	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} 47^{1} 29.4^{11} N, 6^{0} 32^{1} 41.6^{11} E)	Coastal plain sand; Profile 4	Cultivated land, conventionally tilled with traditional hoe, un-mulched, burning of plant debris, mixed cropping containing fluted pumpkin (*Telfaria occidentalis*), *Albemoschus esculentum* (okro), *Zea mays* (maize), *Discorea rotundata* (yam), also contained wild grasses and legumes.

Source: Field Survey (2014).

The mean bulk density of the soils ranged from 1.09 to 1.34 g cm^{-3} and increased regularly with depth in all the profile pits possibly due to changes in organic matter distribution as well as land use pattern. Least bulk density values were recorded in the surface horizons with corresponding high organic matter revealing the influence of organic matter on soil compaction. Several authors have reported significant influence of organic matter on soil bulk density (Ahukaemere *et al.,* 2015). Results of bulk density were less than the critical limits for root restriction (1.75 – 1.85 g cm^{-3}) (Soil Survey Staff, 2003). The average moisture content of the soils ranged from 9.29 – 10.48 %. Generally, the deepest horizons were more moist compared to the surface horizons. The surface horizons were better drained with the horizons being generally low in moisture content and drying out quickly due to the quick passage of water movement. Adzmi *et al*., (2010) and Marryanna *et al.* (2012) have reported on the effect of soil depth and canopy cover on soil moisture. Soil pH ranged from 4.48 – 5.04 and fluctuated irregularly with depth in all the profiles (Table 2). Strongly acidic soil reaction is characteristic of soils of South-east Nigeria and it is the consequence of the acidic nature of the parent rocks, coupled with the influence of the leached profile under high annual rainfall condition (Eshett *et al*., 1990).

TABLE 2

Physical and chemical properties of soils

Hor. des.	HT. (cm)	Sand →	Silt (g kg^{-1})	← Clay	BD (g cm^{-3})	MC (%)	pH (H_2O)	AV.P (mg kg^{-1})	TEB (cmol$_+$ kg^{-1})
Profile 1									
Oe	4	858	94	48	1.10	10.26	5.01	28.13	9.03
Oa	14	858	64	78	1.06	8.03	4.78	26.8	7.63
A	30	818	74	108	1.36	10.83	4.35	20.00	4.55
AB	51	778	54	168	1.38	9.34	4.20	16.10	4.58
Bt1	55	758	54	188	1.53	10.08	4.20	20.00	4.63
Bt2	46	748	54	198	1.58	11.85	4.80	17.80	4.21
Mean		803	65	131	1.34	10.07	4.56	21.47	5.77
CV (%)		6.10	24.24	47.33	16.10	12.91	8.00	23.00	35
Profile 2									
Ap	20	858	54	88	1.14	8.56	5.52	27.7	4.59
AB	28	858	34	108	1.17	7.18	5.13	17.1	4.99
Bt1	62	778	34	188	1.24	8.57	5.67	15.9	5.48
Bt2	42	778	24	198	1.48	11.26	4.46	17.5	7.08
Bt3	48	758	44	198	1.52	10.81	4.40	20.4	5.36
Mean		806	38	156	1.31	9.27	5.04	19.72	5.50
CV (%)		6.00	30.00	34.00	14.00	18.00	11.60	24.12	17.00
Profile 3									
Oa	5	804.00	108.00	88.00	0.82	5.60	4.20	10.4	5.03
A	12	764.00	108.00	128.00	0.96	10.61	4.21	17.9	4.13
AB	45	724.00	128.00	148.00	1.22	12.51	4.81	22.3	2.82
Bt1	71	724.00	128.00	148.00	1.35	13.20	4.71	17.2	5.22
Mean		754.00	118.00	128.00	1.09	10.48	4.48	16.95	4.30
CV (%)		5.08	9.79	22.09	21.94	32.75	8.73	29.00	25.47
Profile 4									
Ap	28	818	94	88	0.96	7.69	4.91	41.6	6.84
AB	21	838	34	128	1.15	8.86	4.64	20.0	4.63
Bt1	65	818	64	118	1.21	13.11	4.18	18.7	9.01
Bt2	36	778	74	148	1.31	9.49	4.90	19.3	6.62
Bt3	50	738	94	168	1.54	11.19	4.50	19.5	6.26
Mean		798	72	130	1.23	10.08	4.63	23.82	6.67
CV (%)		5.00	35.00	23.00	17.00	21.00	6.58	42.00	24.00

HT = Horizon thickness, Hor. des. = Horizon designation, Oe = Hemic horizon, Oa = Sapric horizon, MC = Moisture content, BD = Bulk density, CV = Coefficient of variation, CV $\leq$ 15% = Low variation, CV > 15 $\leq$ 35% = Moderate variation, CV >35 = High variation (Wilding, 1985).

Carbon and Nitrogen Content and Sequestration

The C and N contents and sequestration are presented on Table 3. The mean organic carbon content of the soils varied from 6.81 to 37.75 g kg^{-1}. Generally, the organic carbon content of the individual horizon varied substantially within the profiles. Moderate to high variation was recorded in the organic carbon contents of the soil horizons in all the profiles. High organic carbon content at surface horizon could be due to more organic material input on the soil surface. The amount of organic carbon in the soil results from the net balance between the rate of organic material input and rate of mineralisation in soil organic carbon (Post and Kwon, 2000; Anikwe, 2010). Organic carbon content was the main factor explaining surface horizon bulk density. The deeper the profile, the stronger the mixing with mineral material in the profile and the higher the bulk density (Dale *et al*.,2011). Negative significant correlation r = -0.695* (p<0.05) was observed between soil bulk density and organic carbon content (Table 4). The mean total nitrogen content of the soil was generally low in all the profiles (3.85 – 12.76 mg kg^{-1}), and the pattern of its distribution closely followed that of organic carbon as it decreased down the profiles (Table 2). A positive significant relationship was observed between total nitrogen and organic carbon content of the soil (r = 0.865*).

The mean carbon and nitrogen sequestration capacities of the soil varied from 3124.60 – 7643.25 g C m^{-2}, 101.33 – 503.55 g N m^{-2}. Mba and Idike, (2011) reported 2435 - 6429 g C m^{-2} of carbon in soils of south-eastern Nigeria. From the results, carbon and nitrogen sequestration increased with horizon thickness in all the profiles across the soils. The effect of horizon depth on soil carbon sequestration is presented in Figure 1.

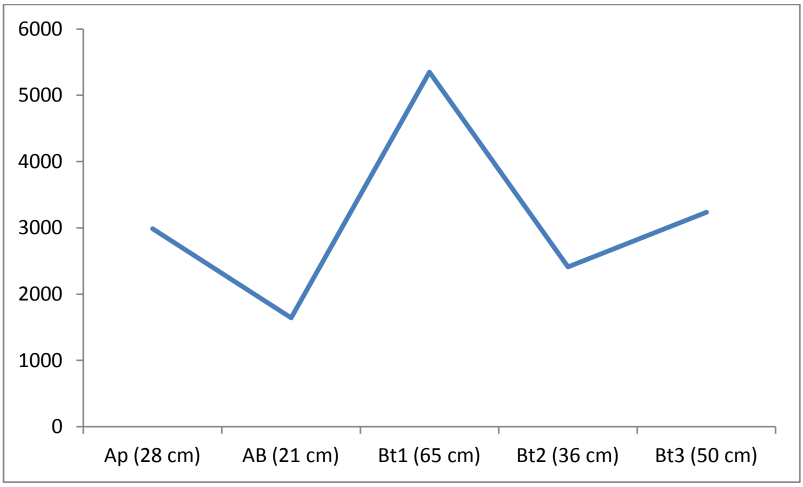

Figure 1: Profile 4 - Effect of horizon thickness (cm) on carbon sequestration (g C m^{-2})

The subsurface horizons (Bt) with horizon thickness varying from 45-71 cm contained the highest quantity of stored carbon and nitrogen compared to surface horizons with horizon thickness of about 4 - 30 cm in all the soil profiles investigated. This revealed the inherent capacity of these horizons to store more C and N. For instance, the O horizons of profiles 1 and 3 contained only about 10-24 % of the carbon stored in these profiles. Batjes (1996), Eswaran *et al*., (1995), Mba and Idike, (2011) and Abebayehu (2013) reported high carbon sequestration in the deeper horizons. According to Mbah 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 becomes stabilised especially in the lower part of the profile. Much of this deeper carbon occurs in more stable forms and therefore will not contribute much to the current gaseous emission (IPCC, 1992). In addition, effect of agricultural activities on carbon and nitrogen was largely restricted to the top soil thus causing carbon stored below this depth to be more stable in all the pits.

TABLE 3

Carbon and nitrogen content and sequestration of soil.

Horizon. Designation	Horizon thickness (cm)	Org.C ($g\ kg^{-1}$)	Total N. ($mg\ kg^{-1}$)	Carbon stock ($g\ C\ m^{-2}$)	Nitrogen stock ($g\ N\ m^{-2}$)
Profile 1					
Oe	4	42.00	12.00	1848	53
Oa	14	16.63	4.00	2468	60
A	30	8.11	1.00	3309	41
AB	51	6.90	2.00	4856	141
Bt1	55	6.10	2.00	5133	168
Bt2	46	7.21	2.10	4975	145
Mean		14.49	3.85	3764.8	101.33
CV (%)		96.76	---	37.73	55.43
Profile 2					
Ap	20	8.31	8.00	1895	182
AB	28	8.30	8.00	2719	262
Bt1	62	7.20	8.00	5535	615
Bt2	42	5.61	6.00	3487	373
Bt3	48	4.92	7.00	3590	511
Mean		6.87	7.40	3445.20	388.6
CV (%)		22.58	12.09	39.27	45.47
Profile **3**					
Oa	5	70.4	21.00	2886	861.00
A	12	49.3	16.34	5679	188.24
AB	45	19.1	8.09	10314	436.86
Bt1	71	12.2	5.52	11694	528.13
Mean		37.75	12.76	7643.25	503.55
CV (%)		71.74	56.32	53.43	55.26
Profile 4					
Ap	28	11.12	8.00	2989	215
AB	21	6.80	7.00	1642	169.
Bt1	65	6.80	7.00	5348	551
Bt2	36	5.11	7.00	2410	330
Bt3	50	4.20	6.00	3234	462
Mean		6.81	7.00	3124.60	345.4
CV (%)		39.07	10.10	44.35	47.00

Oe = Hemic horizon, Oa = Sapric horizon, CV = Coefficient of variation, CV $\leq$ 15% = Low variation, CV > 15 $\leq$ 35% = Moderate variation, CV >35 = High variation (Wilding, 1985).

TABLE 4

Correlation matrix among soil properties ($p<0.05$)

	HT	OC	TN	CS	NS	Clay	BD	MC	pH	Avp
HT	-	-	-	-	-	-	-	-	-	-
OC	-0.639*	-	-	-	-	-	-	-	-	-
TN	-0.555*	0.865*	-	-	-	-		-	-	-
CS	0.615*	0.030	-0.102	-	-	-	-	-	-	-
NS	0.337	0.250	0.480	0.324	-	-	-	-	-	-
Clay	0.720*	-0.494	-0.421	0.354	0.243	-	-	-	-	-
BD	0.683*	-0.695*	-0.738*	0.612*	-0.092	0.791*	-	-	-	-
MC	0.609*	-0.337	-0.393	0.619*	-0.006	0.424	0.584*	-	-	-
pH	-0.071	-0.218	-0.014	-0.105	-0.073	-0.179	-0.150	-0.265	-	-
Avp	-0.271	-0.163	-0.129	-0.239	-0.474	-0.461	-0.259	-0.115	0.336	-

BD = Bulk density, MC = moisture content, HT = Horizon thickness, OC = Organic carbon, TN = Total nitrogen, CS = Carbon sequestration, NS = Nitrogen sequestration.

Carbon and nitrogen sequestration is a function of horizon thickness, bulk density, organic carbon and total nitrogen. Abebayehu, (2013) found that carbon sequestration capacity was significantly affected by organic carbon concentration, horizon depth and bulk density. He also stated that a unit rise in soil organic carbon concentration, bulk density and sampling depth raises soil carbon sequestration by 5.47, 1.53 and 25.64 t ha^{-1} respectively. Linda *et al*. (2003) observed increased carbon sequestration with increased horizon thickness, bulk density and organic carbon. From the results, bulk density had positive correlation with the amount of carbon and nitrogen sequestered in the soil (Table 4).

Table 5 shows the multiple linear regression models of the soil variables. In the combined effects of horizon thickness, organic carbon and pH on carbon sequestration, the regression coefficient of determination (R^2) was 0.612 ($p<$ 0.01). This shows that about 61.2% variation in the quantity of C sequestered in soil could be due to the combined influence of horizon thickness, organic carbon and soil pH. However, about 61 % of variation in carbon sequestration is explained by these soil variables. Based on these realities, the selected model significantly fitted with the existing data meaning that the independent variables namely horizon thickness, organic carbon and pH had a strong relationship with soil carbon sequestration at $p<0.05$. This is obvious as carbon sequestration is a function of horizon thickness and organic carbon content of the soil. Similarly, for the effect of soil moisture content, bulk density and sand on soil carbon stock, the regression coefficient of determination (R^2) was 0.700 ($p<0.01$) indicating that 70% variation in soil carbon sequestration could be due to the combined influence of these independent soil variables. 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 mineralisation of carbon (Hayney *et al.*, 2004). From the regression model, it was ascertained that horizon thickness, bulk density and total nitrogen contributed 67% to the content of nitrogen stock. This indicates that these soil parameters had significant influence on nitrogen sequestration and that the selected model significantly fitted with the existing data. Abebayehu, (2013) reported similar results for carbon storage capacity of forest soil. Also, horizon thickness, organic carbon and pH contributed 51% to the content of nitrogen stock (Table 5). Organic carbon, pH and total nitrogen are essential soil variables that encourage nitrogen accumulation in soil.

TABLE 5
Multiple linear regression models for soil properties.

Multiple Linear regression	**R**	**R^2**	**P value**
HT=28.90-0.44OC-1.77TN+0.003CS +0.046NS	0.947	0.897***	P < 0.001
HT=28.899- 0.436 OC-1.768 TN+0.003 CS + 0.046 NS	0.947	0.897***	P < 0.001
OC=48.178+ 2.066 TN+0.002 CS+0.004 NS-8.649 HT-8.649 pH	0.946	0.894***	P < 0.001
CS =-5540.1+138.388HT+98.90 pH +98.90 OC	0.783	0.612**	P < 0.01
CS =2394.982 +12.263 TN +18.708 Clay -35.608 Avp	0.365	0.133ns	P > 0.05
CS =35863.691-38.990Sand-5695.801BD +651.851MC	0.837	0.700**	P < 0.01
NS= -645.323+9.972HT+10.780 OC+91.765pH	0.712	0.506**	P < 0.01
NS= -28.439+28.980TN+2.007 Clay-6.880Avp	0.705	0.498**	P < 0.01
NS= 3673.669 -3.382 Sand-358.187 BD-23.026 MC	0.552	0.305 ns	P > 0.05
NS= 327.224 +22.148 pH-3.170 TEB+22.148 TN	0.485	0.235 ns	P > 0.05
Nitrogen stock = -544.14 + 7.62HT + 286.15BD + 26.05TN	0.810	0.670***	P < 0.001
HT=34.900 -0.869 CS+0.048 NS	0.819	0.670***	P < 0.001

BD = Bulk density, MC = moisture content, HT = Horizon thickness, OC = Organic carbon, TEB = Total exchangeable bases, TN = Total nitrogen.

CONCLUSION

The average quantities of carbon and nitrogen sequestered in the soil varied from 3142.60 – 6139.74 g C m^{-2} to 101.33 – 388.6 g N m^{-2} with the thickest horizons containing the highest quantities. Carbon and nitrogen sequestration is governed by soil organic carbon, bulk density, horizon thickness and total nitrogen. Thus, organic carbon, total nitrogen and bulk density improvement are the most important management interventions to increase carbon and nitrogen sequestration capacity in soil. Therefore, farmers should focus on management activities that improve these soil characteristics to boost carbon and nitrogen sequestration capacity of the soil. Further more, it is imperative that researchers generate adequate information from other similar studies to convince farmers, policy makers and other stakeholders to protect these important soil parameters.

REFERENCES

Abebayehu, A. (2013). Evaluating organic carbon storage capacity of forest soil: case study in Kafa zone Bita District Southwest Ethiopia. American- Eurasian Journal of Agric. and Environmental Science. 13(1) 95-100.

Adzmi, Y., W.C. Suhaimi, M.S., Amir Husni, H. Mohd Ghazali, S.K, Amir and I. Baillie. (2010). Heterogeneity of soil morphology and hydrology on the 50 ha. long term ecological research plot at Pasoh, West Malaysia. *Journal of Tropical Forest Science* 22(1): 21-35.

Ahukaemere, C.M. Akamigbo, F.O.R. Onweremadu, E.U. Ndukwu, B. N., Osisi, F.A. (2015).

Carbon and Nitrogen Forms and Sequestration in Relation to Agricultural Land Use Types in a Humid Agro-ecosystem. *Journal of Global Biosciences* 4(3): 1655-1665.

Anikwe, M.A.N. (2010). Carbon storage in soils of Southeastern Nigeria under different management practices. Carbon balance and management. 5(5) 1-7.

Atlas of Imo State Geology, (1984). Geology Map of Old Imo State.

Batjes, N.H. (1996). Total carbon and nitrogen in the soils of the world. International Soil Reference and Information Center (ISRIC). *European Journal of Soil Science*. 47: 151-163.

Burton, A.J., and Pregitzer, K. (2008). Measuring forest floor mineral soil and root carbon stocks. In: field measurements for forest carbon mornitoring. Hoover, C.M (ed.). springer, SC and Business media. New York NY. PP 129-142.

Dale, W.J., James, D.M., Benjamin, M.R., and Watkins, W.M. (2011). Subsurface carbon content: Some case studies in forest soils. Forest Science 57(1).

Davis, A.A. Still, M.H and Compton, J.E. (2004). Spatial distribution of soil carbon in southern New England Hardwood forest landscapes. *Soil Sci. Soc. Am. J*. 68: 895-903.

Eshett, E.T., Omoeti, J.A.I. and Juo, A.S.R. (1990). Physico-chemical, morphological and clay mineralogical properties of soils overlying basement complex rocks in Ogoja, Northern Cross River State of Nigeria. *Soil Science and Plant Nutrition* 36(2): 203-214.

Eswaran, H., Berg, E.V.D and Reich, P. (1993). Organic carbon in soils of the world. Soil Science Society of American Journal, 57:192-194.

Eswaran, H, Berg, E.V.D., Reich, P. and Kimble J. (1995). Global soil carbon resources. In: soils and Global change. Eds. R, Lal, J. Kimble, E. Levine and B.A Stewart, CRC, Lewis publishers pp 27 – 29.

FAO (Food and Agricultural Organization) (2006). World reference base for soil resources 84 World Soil Resources Report, ISSS-AISSIBG, FAO Rome, Italy.

FDALR [Federal Department of Agricultural Land Resources] (1985). The reconnaissance soil survey of Imo State (1: 250, 000). Owerri: Federal Department of Agricultural Land Resources. 133 pp.

Field Survey (2014). Reconnaisance field survey at Umuagwo in Ohaji Egbema, Imo State, Nigeria.

Grossman, R.B., Harnes, D.S., Kuzila, M.S., Glaum, S.A., Hartung, S.L., and Portner, J.R. (1998). Organic carbon in deep alluvium in Southeast Nebraska and Northeast Kansas. In: Soil processes and the carbon cycle. Lal, R. *et al*., (Eds.). Advance Soil Science. CRC Press, Boston, M.A 45-56.

Hayney, R.L., Franzluebbers, A.J., Porten, E.B., Hons, F.M., and Zuberer. (2004). Soil carbon and nitrogen mineralization. Influence of drying temperature. Soil Science Society of American Journal 68:489-492.

He, N., Yunhai, Z., Dai, J., Han, X., Baoyin, T and Yu, G. (2012). Land use impact on soil carbon and nitrogen sequestration in typical steppe ecosystems, Inner Mongolia. Journal of Geographical Science. 22(5): 859-873.

(IPCC) Intergovernmental Panel on Climate Change (1992). Climate change. The supplementary report to the IPCC scientific Assessment (eds. J.T. Houghton, B.A. Callander and S.K Verney). Cambridge University Press.

Jobbagy, E. G., and Jackson, R.B. (2000). The vertical distribution of soil organic carbon and its relation to climate and vegetation. Ecological application 10: 423-436.

Johnson-Magnard, J.I., P.J. Shouse, R.C. Graham, P. Costinglione and S.A. Quideau. 2004. Microclimate and Pedogenic Implications in a 50-year old chapparal and pine biosequence. SSSA Journal, 68: 876-884.

Lin, J.S., Shi, X, Z., Yu, D.S. Weindort, D.C., Wang, H.J., Zhao, Y.C., Sun, X.W., and Liu, Q.H. (2010). Nitrogen storage and variability in paddy soils of China. Biogeoscience Discuss, 7: 855-877

Linda, H., John, K., Richard, B., and Rattan, L. (2003). The potential of US forest soil to sequester carbon. Chapter 23 in Kimble, M., Health, S., Richard, B., and Rattan, L. (Eds). The potential of US forest to sequester carbon and mitigate the green house effect, CRC Press. Pp 385-394.

Marryanna, L., Rahman, A.K., S. Siti Aisha and Mohd, .M.S. (2012). Association between soil moisture gradient and tree distribution in lowland dipterocarp forest at Pasoh Malaysia. Malaysian Journal of Soil Science. 16:23-42.

Mbah, C.N. and F.I. Idike, (2011). Carbon storage in tropical agricultural soils of south eastern Nigeria under different management practices. International Research Journal of Agricultural Science vol. 1(2), 53-57.

NIMET (Nigerian Meteorological Agency), Nigeria,(2014). Climate, Weather and Water Information, for sustainable development and safety.

Post, W., and Kwon, K. (2000). Soil carbon sequestration and land use change: processes and potential. Global Change Biology. 6, 317-328.

Quideau, S.A., Anderson, M.A., Graham, R.C., Chadwick, O.A., S.E. Trumbore and Johnson, M. (2001). Vegetation control on soil organic matter dynamics. Organic Geochemistry, 32:247-252.

Burns, R.C. and R.W.F. Hardy. 1975. Nitrogen Fixation in bacteria and higher plant. Molecular Biology, Biochemistry and Biophysics, 21: 185.

Schimel, D.S., Enting, I.G., Wiegley, T.M., Raynaud, D., Alves, D and Sie,egenthaler (1994). Carbon dioxide and carbon cycle. In: Climate change. Houghton, J.T *et al*., (ed.), Cambridge University Press, New York pp: 35-77.

Shaw, G., and Wheeler, D. (1996). Statistical techniques in geographical analysis. David Fulton Publishers. London.

Soil Survey Staff (2003). Keys to soil taxonomy. 9th ed. United State Department of Agriculture.

Stevenson F.J. (1982). Humus chemistry genesis, composition, reactions. Willey Inter-science. New York.

Tijani, M.N., Nton, M.E and Kitagawa, R. (2010). Textural and geochemical characteristics of the Ajali Sandstone, Anambra Basin, Sout-eastern Nigeria. Implication for its provenance. Geosciences, 342 136 -150.

Van Reeuwijk, L.P. (2002). Procedure for soil analysis. International Soil Reference and Information Center (ISRIC) / (Food and Agricultural Organization): Wageningen. Pp 120.

Wilding, L. P. (1985). Spatial variability: Its documentation, accommodation, and implication to soil surveys. In: Soil spatial Variability. Nielsen, D. R., Bouma, J. (Eds). Pudoc. Wageningen, The Netherlands, pp. 166-194.