International Journal of Sustainable Agricultural Research
2020 Vol. 7, No. 2, pp. 84-92.
ISSN(e): 2312-6477
ISSN(p): 2313-0393
DOI: 10.18488/journal.70.2020.72.84.92

PRINCIPAL COMPONENT ANALYSIS FOR THE QUANTIFICATION OF SOIL HORIZON CARBON STOCKS IN RELATION TO SOIL BULK DENSITY

Ahukaemere, C.M[1+]
Obasi, S.N[2]
Egbuche, C.T[3]
Aririguzu, B.N.[4]

[1,4]*Department of Soil Science and Technology, Federal University of Technology Owerri, Owerri, Imo State, Nigeria.*
[1]*Email: mildredshine@yahoo.com Tel: +2348036598383*
[4]*Email: bernadine.ndukwu@futo.edu.ng Tel: +2348038787468*
[2]*Department of Crop and Soil Science, Faculty of Agricultural Sciences, National Open University of Nigeria, Kaduna Campus, Nigeria.*
[2]*Email: nobasi@noun.edu.ng Tel: +2348034499155*
[3]*Department of Forestry and Wildlife Technology, Federal University of Technology Owerri, Nigeria.*
[3]*Email: christian.egbuche@futo.edu.ng Tel: +2348068093593*

(+ Corresponding author)

Article History
Received: 6 December 2019
Revised: 9 January 2020
Accepted: 14 February 2020
Published: 12 March 2020

Keywords
Carbon stock
Horizon
Bulk density
Organic carbon
Climate change.

ABSTRACT

Accurate quantification of the changes in carbon stocks of different horizons of the soil profile pit in relation to soil bulk density is a prerequisite to understand the role of soil in the global carbon cycling and climate change mitigation. This paper seeks to draw attention to the carbon storage capacity of the individual soil horizon with particular emphasis on soil bulk density. Three (3) profile pits were dug at equal distance of 100 meters. These profile pits were carefully sampled and analysed in the laboratory using standard methods. Soil data were subjected to principal component analysis (PCA), regression and coefficient of variation analyses using SPSS. Results showed that A, Ap, AB and Bt were the soil horizons identified in the three different soil profiles at the time of sampling. Bulk density values ranged from 1.43 – 1.66 g cm^{-3} (mean = 1.49 g cm^{-3}) in profile pit 1, 1.43 – 1.62 g cm^{-3} (mean = 1.53 g cm^{-3}) in profile pit 2 and 1.15 – 1.64 g cm^{-3} (mean = 1.40 g cm^{-3}) in profile pit 3 respectively. In profile 1, 2 and 3, the average carbon stock ranged from 4500.6, 3791.67 and 3689.2 g C m^{-2} respectively. From the PCA results, four variables were observed, they include organic carbon, inorganic carbon, water stable aggregate and carbon stock. The first PC (PC1 = organic carbon) had a value of 0.968, PC2 (inorganic carbon) = 0.968, PC3 (water stable aggregate) = 0.874 and PC4 (carbon stock) = 0.844, indicating positive effects. From the PC plot, the eigenvalues are 3.57, 3.08, 1.78 and 1.10. However, the first PC explains 32.47 % of total variation whiles the second, third and fourth PCs explain 60.47, 76.67 and 86.72 % respectively.

Contribution/Originality: This study contributed substantially to the effective understanding of carbon accumulation in soil in relation to soil compaction; hence, for the comprehension of the exact quantity of carbon accumulated in the soil, accurate measurement of the amount of carbon sequestered by individual natural horizon of the soil profile is imperative.

1. INTRODUCTION

Accurate and effective determination of bulk density is indispensable in monitoring soil carbon stocks and soil carbon stock variations in the soil profile pit. The result of soil carbon stock is conventionally expressed in units such as percentage (%), milligram of carbon per kilogram of soil (mg C kg^{-1}) or microgram of carbon per kilogram of soil (μg C kg^{-1}) (Powlson, Whitmore, & Goulding, 2011). These are units of concentration, though they are often incorrectly referred to as C contents. To express C as a quantity or content rather than concentration, concentration has to be multiplied by the mass of soil to a given depth, often determined from measurement of bulk density (Powlson et al., 2011). Soil carbon stock can then be expressed in units such as milligram of carbon per hectare (mg C ha^{-1}) or gram of carbon per meter square (g C m^{-2}) to the defined depth.

Different researchers adopted different methods to determine soil carbon stock depending mainly on their research objectives. Abebayehu (2013) determined carbon sequestration capacity of forest soils in Kafa zone Bita District, South-western Ethiopia by multiplying the bulk density, organic carbon concentration and horizon thickness of the soil. The amount of carbon stored (ton per hectare) (t ha^{-1}) in each profile was obtained by summing up the carbon stored in different horizons of the respective profiles. He found out that carbon sequestration capacity was significantly affected by organic carbon concentration, sampling depth and bulk density. In, Nigeria, Mbah and Idike (2011) used % C /100 x bulk density x area (tha^{-1}) x soil depth (0-5, 5-20 cm) to determine carbon sequestration in tropical agricultural soils of South-eastern Nigeria under different management practices. Also, Batjes (1996); Brahim, Bernoux, Blavet, and Gallali (2010); Bernoux, Carvalho, Volkoff, and Serri (2002) and Ahukaemere (2016) used Carbon storage (g C m^{-2}) = $\sum Bi \times Ci \times Di$ where Bi = bulk density (g cm^{-3}) of layer i, Ci = proportion of organic carbon (g kg^{-1}) in layer i and Di is the thickness of this layer (cm) to determine the carbon sequestration of individual profile. Globally, there are many methodological problems with sampling soils for C, including accurate measurement of bulk density, accurate measurement of horizon thickness, organic carbon and the maximum profile depth to which soils should be sampled (Ahukaemere, 2016). Accurate and effective determination of soil bulk density is needed to monitor soil carbon stocks. Accurate bulk density measurements are often lacking in soil inventories. Mass of soils in relation to their volumes influences soil carbon content, moisture content, infiltration rate, available water capacity, total porosity, root penetration and aeration porosity. In addition, bulk densities depend on mineral composition as well as degree of compaction of soils. For instance, soils rich in organic matter have lower bulk density due to low density of organic materials. Soil bulk density values can therefore be a guide to quantifying emission of greenhouse gases (Barros & Fearnside, 2015) as well as a good measure of soil quality (Arshad, Lowery, & Grossman, 1996). However, since carbon accumulation in soil is influenced by soil bulk density and natural horizon thickness, accuracy in the quantification of these crucial soil attributes is very necessary in deepening our understanding about carbon sequestration, storage and climate change mitigation for making an informed decision to harnessing our soil resource and ecosystem. Therefore, this study investigated the quantity of carbon stored in each natural horizon of the soil profile in relation to soil bulk density.

2. MATERIALS AND METHODS

2.1. Study Area

The study was located at Ohaji-egbema in Imo State, South-east Nigeria. The study site lies between latitude 5^{o} 19^{1} N and longitude 6^{o} 58^{1} E. The lithology of the area is made-up of the coastal plain sands. The area receives an average of 2500 mm of rainfall distributed to about 139 days of the year. The daily temperature ranges from a minimum of 21°C to a maximum of 30°C. The average daily relative humidity is above 75 % and evaporation of about 1450 mm/y (NIMET, 2017). Vegetation of the study site comprised of mixed vegetation. Arable crop production is a major socio-economic activity of the study area.

2.2. Soil Sampling

An hectare of land comprised of mixed vegetation such as wild groundnut (*Calapogonium mucunoides*), butterfly pea (*Centrosema pubescens*), Elephant grass (*Pennisetum purpurem*), *Zea mays* (maize), *Discorea rotundata* (yam), Giant star grass (*Cynodon plectostachyus*), fluted pumpkin (*Telfaria occidentalis*), *Albemoschus esculentum* (okro) 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, undisturbed core samples were collected from the varying horizons for bulk density determination. Soil samples for the determination of other soil properties were taken from the component horizons; air dried and ground to pass through 2 mm sieve prior to laboratory analysis.

2.3. Laboratory Analyses

Laboratory analyses were conducted for particle size distribution by hydrometer method (Gee & Or, 2002) bulk density by core method (Grossman & Reinch, 2002) moisture content by Obi (1990) soil pH using pH meter (Thomas, 1996) organic carbon by wet digestion (Nelson & Sommers, 1996). Total carbon was determined by loss on ignition and wet digestion method (Vereş, 2002). Inorganic carbon was calculated thus: total carbon – organic carbon. Carbon stock (g C m^{-2}) in every soil genetic horizon was determined by: bulk density (gcm^{-3}) x organic carbon (g kg^{-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 while carbon stock in each profile was calculated by summing stock of carbon in individual horizon of the profile.

2.4. Data Analysis

Generated soil data were subjected to principal component (PCA), correlation and multiple regression analyses. Also, mean and standard deviation analyses from which coefficient of variation (in percentage) was computed were carried out. Variability among selected soil properties of the different horizons of each profile pit was ranked using Wilding, Wilding (1985).

3. RESULTS AND DISCUSSION

3.1. Soil Physical Properties

The average sand content ranged from 814 - 851.3 g kg^{-1} in profile pits 1, 2 and 3. The three soil profiles had mean silt contents of 56, 60.67 and 32 g kg^{-1} for pits 1, 2 and 3, respectively Table 1. The mean clay content ranged between 88 and 154 g kg^{-1}; with pit 1 having a mean value of 118 g kg^{-1}, whereas pits 2 and 3 had mean values of 88 and 154 g kg^{-1}, respectively Table 1. The textural class of the soils comprised generally of loamy sand and sandy loam. The surface horizons of profile pit 1 had loamy sand texture while the subsurface horizons had sandy loam. In profile pit 2, the surface horizon had textural class ranging from sand to sandy loam while the subsurface horizon had loamy sand textural class. Also, pedon 3 had sandy top soil and sandy loam subsoil. However, the particle fractions of the soils and their textural class generally represent soils derived from coastal plain sand. According to FDALR (1985) coastal plain sands consist of unconsolidated sand materials which are sometimes cross-bedded with clays, sandy clays and sometimes, pebbles. Soils on coastal plain sands are deep, coarse-textured (loamy sand to sandy loam), easily eroded and generally of low inherent fertility (Ogban & Ekerette, 2001). Bulk density values ranged from 1.43 – 1.66 g cm^{-3} (mean = 1.49 g cm^{-3}) in profile pit 1, 1.43 – 1.62 g cm^{-3} (mean = 1.53 g cm^{-3}) in profile pit 2 and 1.15 – 1.64 g cm^{-3} (mean = 1.40 g cm^{-3}) in profile pit 3 respectively. The bulk density (BD) increased down the natural horizons and was at values (mean ≥ 1.40 g cm^{-3} ≤ 1.53 g cm^{-3}) that will allow vigorous growth of plant roots and soil organisms. The variation in bulk density of the soils was low (CV <14 %). 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. In Profile 1, the Bt3 horizon with the highest BD value (1.66 g cm^{-3}) had the least organic carbon (4.80 g kg^{-1}) and the least carbon stock (4064 g C m^{-2}). Similar trend was observed in profile 3. However, significant negative correlation was recorded between soil bulk density and organic carbon ($r = -.529^*$) Table 3**.** Also, the result of correlation analysis showed significant positive correlation between bulk density and moisture content ($r = 0.728^{**}$).

Table-1. Physical and chemical properties of soils.

Hor/Depth (cm)	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	BD (g cm^{-3}	MC (%)	WSA (%)	TC	pH (H_2O)	Av.P mg kg^{-1}	Ca	Mg	K cmol+kg^{-1})	Na	EA	ECEC
Profile 1															
A (14)	878	74	48	1.44	13.42	15.15	LS	5.47	20.4	4.6	2.8	0.11	0.06	1.55	9.12
AB (42)	878	54	68	1.43	12.44	14.02	LS	5.42	20.9	4.0	2.8	0.14	0.13	0.51	9.04
Bt1 (41)	848	64	98	1.43	11.32	12.28	LS	4.89	19.3	2.4	2.0	0.12	0.1	1.04	5.65
Bt2 (52)	798	24	178	1.50	11.94	12.55	SL	4.95	22.9	3.6	2.0	0.13	0.11	1.92	7.76
Bt3 (51)	738	64	198	1.66	15.67	26.67	SL	5.88	21.9	3.6	2.4	0.12	0.06	1.84	8.02
Mean	828	56	118	1.49	12.96	16.13		5.32	21.08	3.64	2.40	0.12	0.09	1.37	7.92
SDV	60.00	19.24	66.71	0.098	1.70	6.00		0.41	1.383	0.80	0.41	0.01	0.03	0.59	1.40
CV (%)	7.24	29.12	17.69	6.5	13.12	37.20		7.69	6.56	22.1	16.67	9.19	34.44	43.07	17.67
Profile 2															
A (11)	878	64	58	1.44	12.71	22.81	LS	4.17	18.1	3.6	2.0	0.13	0.11	1.92	7.76
AB (20)	898	54	48	1.43	10.45	14.68	S	4.45	17.8	3.6	2.4	0.10	0.07	1.79	7.96
Bt1 (55)	858	94	48	1.44	11.20	19.33	LS	6.03	16.1	4.0	2.8	0.14	0.13	0.51	9.04
Bt2 (35)	838	64	98	1.61	12.31	12.99	LS	5.30	17.1	2.4	2.0	0.12	0.01	1.04	5.65
Bt3 (33)	818	54	128	1.61	12.55	8.41	LS	5.02	17.5	3.6	2.4	0.12	0.06	1.84	8.02
Bt4 (46)	818	34	148	1.62	13.36	11.08	LS	5.11	18.34	4.6	2.8	0.11	0.06	1.55	9.12
Mean	851.3	60.67	88	1.53	12.10	14.88		5.01	17.49	3.63	2.40	0.12	0.07	1.44	7.93
SDV	32.66	19.66	43.36	0.10	1.071	5.34		0.66	0.81	0.72	0.36	0.014	0.04	0.56	1.26
CV (%)	3.84	32.41	49.27	6.35	8.85	35.88		13.17	4.63	20.0	15.00	11.67	57.14	38.89	15.89
Profile 3															
AP (12)	898	24	78	1.15	9.71	13.89	S	5.51	27.45	3.20	2.00	0.11	0.06	1.04	6.4
AB (40)	858	24	118	1.33	10.1	1.00	LS	5.23	17.1	4.20	1.20	0.09	0.19	1.36	6.84
Bt1 (65)	778	34	188	1.39	9.87	6.36	SL	5.67	16.46	4.10	2.40	0.09	0.13	1.2	7.82
Bt2 (41)	778	34	188	1.49	10.55	4.57	SL	4.56	17.5	2.80	1.60	0.14	0.09	1.84	6.47
Bt3 (42)	758	44	198	1.64	12.48	13.20	SL	4.74	21.22	2.80	1.20	0.11	0.06	1.9	6.07
Mean	814	32	154	1.40	10.54	7.80		5.14	19.95	3.42	1.68	0.108	0.11	1.47	6.72
SDV	60.66	8.37	53.19	0.18	1.13	5.59		0.48	4.58	0.69	0.52	0.02	0.06	0.39	0.67
CV (%)	8.00	34	34.0	13.07	11.0	72.0		9.34	22.96	20.2	18.42	18.52	54.6	26.5	10.00

Note: MC = Moisture content, TP = Total porosity, WSA = Water stable aggregate, TC = Textural class, CV = Coefficient of variation, CV $\leq$ 15% = Low variation, CV > 15 $\leq$ 35% = Moderate variation, CV >35 = High variation (Wilding, 1985).

3.2. Soil Carbon Content

Depending on the land use and pedogenic processes, the following horizons were found to occur in the soil profile pits investigated: A, Ap, AB and Bt. In profile 1, carbon stock ranged from 3367 to 5526 g C m^{-2} with a mean value of 4500.6 g C m^{-2}. In this profile, the AB horizon contained about 25 % of the total carbon stock while the A, Bt1, Bt2 and Bt3 contributed 15 %, 21 %, 22 % and 18 % respectively. In profile 1 also, the A horizon with the least horizon thickness (14cm) had the lowest carbon stock (3367 g C m^{-2}) Figure 4. This was due to the thinness of this horizon. In profile pits 2 and 3, the A horizons had carbon stock value of 2520 and 1588 g C m^2, constituting about 8-11% of the total carbon stored in these soil profiles. In profiles 2 and 3 also, the Bt1 had the highest carbon stocks (6415, 6505 g C m^2), constituting about 28-35 % of total carbon stored in these profiles. Generally, in most soils, the sub surface horizons are two to three times thicker than the surface horizons. The stock of carbon in the soils depends on the thickness of individual horizons and the concentration of carbon in each of them. Ahukaemere (2016); Ostrowska, Porębska, and Kanafa (2010) and (Don, Schumacher, Scherer-Lorenzen, Scholten, & Schulze, 2007) investigated the amount of carbon stored in each natural horizon of soil profile and reported higher carbon stocks at the sub surface horizons. On the other hand, Ahukaemere. et al. (2017) calculated the quantity of stock of carbon per centimetric depth unit of soil and found that higher carbon were stored at the surface horizons of soil profile. In profile pit 1, total and inorganic carbon ranged from 82.5-138.90 g kg^{-1} and 76.2-122.2 g kg^{-1} respectively while organic carbon ranged from 4.80 (Bt3 horizon) – 16.70 (A horizon) Figure 1. However, the A, AB and Bt1 horizons of profile pit 1 contained higher quantities of total and inorganic carbon. While the Bt2 contained the least values of both total and inorganic carbon Figure 1. In profile pits 2 and 3, the AB horizon contained higher quantities of total and inorganic carbon (95.10 and 83.98 g kg^{-1}) than the A horizon (90.20 and 74.29 g kg^{-1}). However, among the argillic horizons, the Bt4 contained higher values of total and inorganic carbon (88.24 and 83.14 g kg^{-1}) compared to other horizons. In all the soil profile pits investigated, organic carbon decreased down the pit Figures. 1-3.

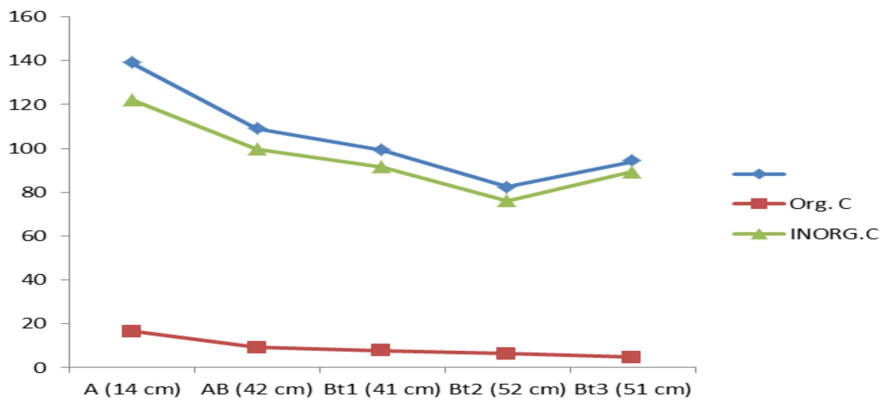

Figure-1. The distribution of total, organic and inorganic carbon (g kg^{-1}) in profile pit 1.

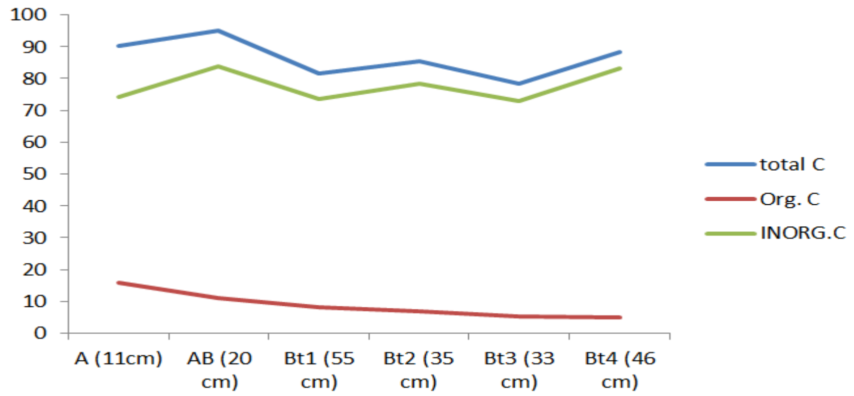

Figure-2. The distribution of total, organic and inorganic carbon (g kg^{-1}) in profile pit 2.

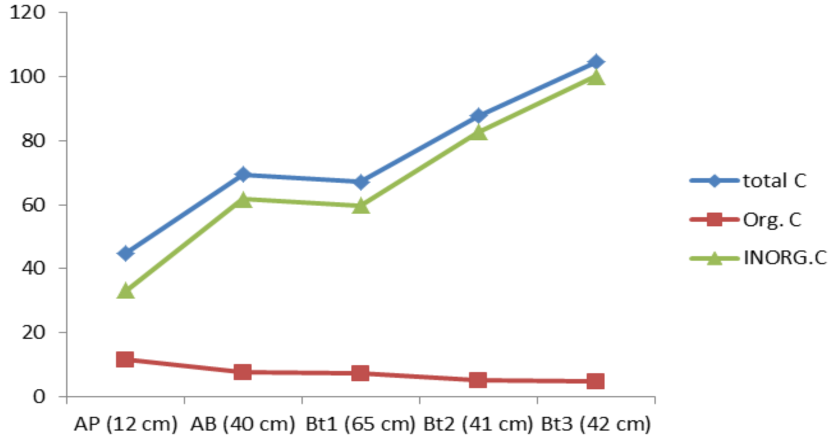

Figure-3. The distribution of total, organic and inorganic carbon (g kg^{-1}) in profile pit 3.

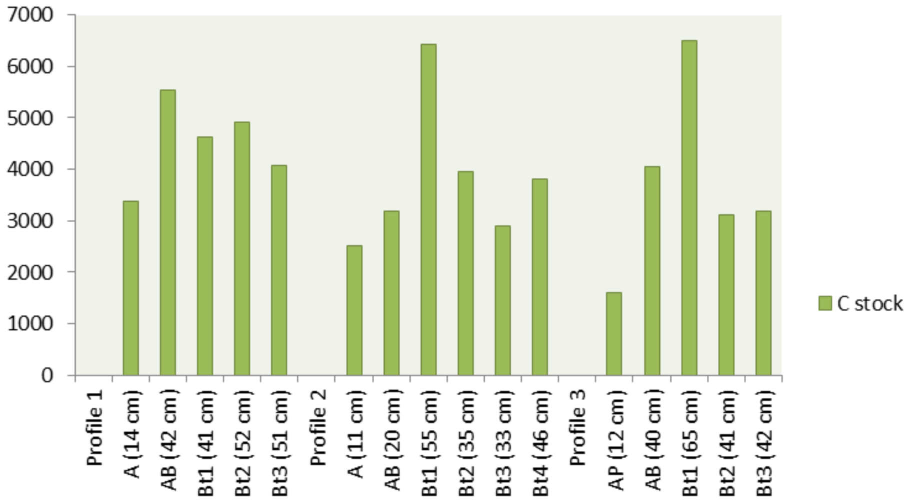

Figure-4. Carbon stock (g C m^2) in the different horizons of the three soil profile pits.

3.3. Multiple Linear Regression

Table 2 shows the multiple linear regression models of the soil variables. In the combined effects of bulk density, organic carbon, inorganic carbon and carbon stock/horizon thickness ratio on carbon stock, the regression coefficient of determination (R^2) was 0.526 ($p < 0.05$). This shows that about 53% variation in the quantity of C stock in soil could be due to combined influence of the independent variables. However, about 53 % of variation in carbon stock is explained by these soil variables (bulk density, organic carbon, inorganic carbon and carbon stock/horizon thickness ratio). Based on these realities, the selected model was significantly fitted with the existing data meaning that the independent variables had strong relationship with the ability of soil to hold carbon at $p < 0.05$. This is obvious as carbon sequestration is a function of horizon thickness, organic carbon content of the soil and bulk density. Also, considering the effect of soil moisture content, water stable aggregate, clay, soil reaction and effective cation exchange capacity on organic carbon, the regression coefficient of determination (R^2) was 0.642 ($p < 0.05$) indicating that 64% variation in soil organic carbon 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 mineralization of carbon (Haney, Franzluebbers, Porter, Hons, & Zuberer, 2004). From the regression model, it was ascertained that organic carbon, moisture content, soil structural stability and clay content of the soil contributed 77 % to the soil bulk density. This indicates that these soil parameters had significant influence on soil compaction and that the selected model was significantly fitted with the existing data.

Table-2. Multiple linear regression models for soil properties.

Multiple Linear regression	R	R^2	P value
CS = 40376.46 - 23994.04BD - 4076.59ORG + 9.42INORG + 267.44CSHT + 1087.85	0.725	0.526	P < 0.05
ORG = 19.827 – 0.279MC + 0.127WSA – 0.042Clay – 1.478pH + 0.369 ECEC + 2.7397	0.801	0.642	P < 0.05
BD = 0.870 – 0.077ORG + 0.068MC + 0.003WSA + 0.000Clay + 0.074	0.878	0.772	P < 0.05
TC = 0.002 + 0.999ORG + 1.00INORG – 1.113E.006CS +8.846E.005CSHT + 0.042	1.00	1.00	P < 0.05
INORG = -0.001 + 1.00TC -1.001ORG + 1.100E.006CS + 2.483E.006WSA + 0.014	1.00	1.00	P < 0.05

Note: Cs= Carbon stock, BD = Bulk density, TC = Total carbon, ORG = Organic carbon, INORG = Inorganic carbon, MC = Moisture content, WSA = Water stable aggregate, ECEC = Effective cation exchange capacity.

Table-3. Pearson correlation matrix of soil properties.

	CS	BD	TC	ORG	INOR	CSHT	MC	WSA	Clay	PH
CS	1.00		.		.					
BD	0.072	1.00								
TC	0.062	0.421	1.00							
ORG	-0.279	-0.529*	0.291	1.00						
INOR	0.117	0.538*	0.984**	0.114	1.00					
CSHT	-0.248	-0.364	0.424	0.981**	0.255	1.00				
MC	-0.059	0.728**	0.563*	-0.068	0.598*	0.065	1.00			
WSA	-0.054	0.220	0.290	0.318	0.241	0.373	0.635**	1.00		
Clay	0.103	0.468	-0.186	0.765**	0.048	0.745**	0.158	-0.260	1.00	
PH	0.524*	-0.096	-0.138	0.156	0.114	0.198	0.140	0.150	0.010	1

Note: *. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed). Cs= Carbon stock, BD = Bulk density, TC = Total carbon, ORG = Organic carbon, INOR = Inorganic carbon, MC = Moisture content, WSA = Water stable aggregate, CSHT = Carbon stock-horizon thickness ratio, ECEC = Effective cation exchange capacity.

3.4. Principal Component Analysis

Principal component analysis (PCA) is a technique used to reduce the number of variables and eliminate the relations among input variables by developing a set of new variables. These new variables are chosen to sufficiently explain the variation of data. From the results, four important variables were observed, they include organic carbon, inorganic carbon, water stable aggregate and carbon stock. Table 4 indicates the loading values of the first four principal components. These loadings explain the contribution of each variable in the principal component. The highlighted values showed the variable load on that component as presented in Table. The first PC (PC1 = organic carbon) had a value of 0.968, PC2 (inorganic carbon) = 0.968, PC3 (water stable aggregate) = 0.874 and PC4 (carbon stock) = 0.844, indicating positive effects. From the PC plot Figure 5 the eigenvalues are 3.57, 3.08, 1.78 and 1.10 respectively. However, the first PC explains 32.47 % of total variation while the second, third and fourth PCs explain 60.47, 76.67 and 86.72 % respectively.

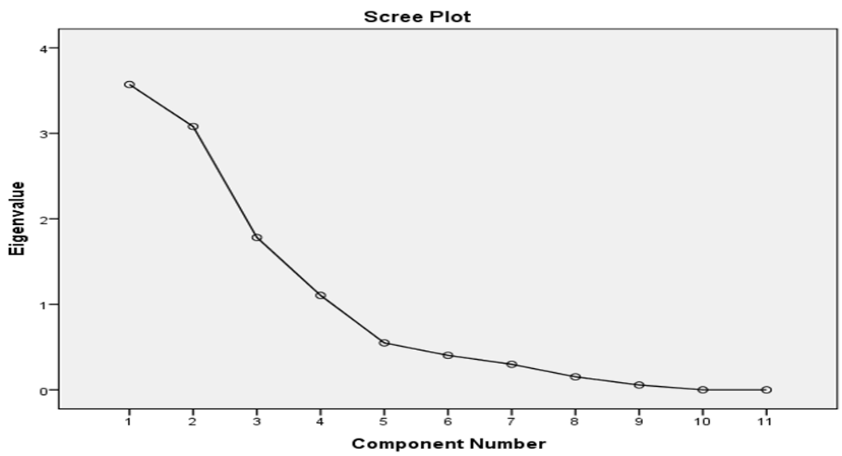

Figure-5. A screen plot for soil components.

Table-4. Loading values of the first 4 principal components from soil samples.

	Component			
	1	2	3	4
CSTOCK	-.190	.147	-.237	**.844**
BD	-.620	.567	.425	-.065
TC	.221	.944	.159	.025
ORG	**.968**	.069	.085	-.112
INORG	.046	**.968**	.149	.047
CSHT	.930	.221	.148	-.115
MC	-.184	.507	.806	.063
WSA	.269	.078	**.874**	.084
CLAY	-.878	.002	-.014	-.076
PH	-.087	-.250	.210	.821
ECEC	.305	.271	.282	.615
eigenvalue	3.57	3.08	1.78	1.10
Accumulated variance %	32.47	60.47	76.67	86.72

4. CONCLUSIONS

From the result of the PCA, the major factors identified were organic carbon, inorganic carbon, water stable aggregate, carbon stock and bulk density. Based on this, the multiple linear regression analysis was done to confirm the effects of these parameters on soil carbon stock. However, result of the multiple linear regression analysis showed that about 53% variation in the quantity of C stock in soil was due to combined influence of the independent variables (bulk density, organic carbon, inorganic carbon and carbon stock/horizon thickness ratio) indicating that about 53 % of variation in carbon stock is explained by these soil variables Also, considering the effect of soil moisture content, water stable aggregate, clay, soil reaction and effective cation exchange capacity on organic carbon, the regression coefficient of determination (R^2) was 0.642 ($p < 0.05$) indicating that 64% variation in soil organic carbon could be due to the combined influence of these independent soil variables. From the regression model, it was ascertained that organic carbon, moisture content, soil structural stability and clay content of the soil contributed 77 % to the soil bulk density.

Funding: This study received no specific financial support.
Competing Interests: The authors declare that they have no competing interests.
Acknowledgement: All authors contributed equally to the conception and design of the study.

REFERENCES

Abebayehu, A. (2013). Evaluating organic carbon storage capacity of forest soil: Case study in Kafa Zone Bita District, Southwestern Ethiopia. *American Eurasian Journal of Agriculture and Environmental Science, 13*(1), 95-100.

Ahukaemere, C. (2016). Sub-soil carbon and nitrogen sequestration: Soil profile measurement approach. *Malaysian Journal of Soil Science, 20*, 37-48.

Ahukaemere., C. M., Onweremadu, E. U., C., C. M., Uzoho, B. U., Ndukwu, B. N., Egbuche, T. C., & Akamigbo, F. O. R. (2017). Soil carbon sequestration capacity measurement per centimetric depth unit: A rational approach. *European Journal of Physical and Agricultural Sciences, 5*(1), 40-48.

Arshad, M. A., Lowery, B., & Grossman, B. (1996). Physical tests for monitoring soil quality. In: J.W Doran and A.J.Jones (Eds.), methods for assessing soil quality (pp. 123-142). Madison, W.I: Soil Science Society of America Special Publication.

Barros, H. S., & Fearnside, P. M. (2015). Pedo-transfer functions for estimating soil bulk density in central Amazonia. *Brazilian Journal of Soil Science, 39*(2), 397-407.

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.

Bernoux, M., Carvalho, M. D. S., Volkoff, B., & Serri, C. C. (2002). Brazils soil carbon stocks. *Soil Science Society of American Journal, 66*, 888- 896.

Brahim, N., Bernoux, M., Blavet, D., & Gallali, T. (2010). Tunisian soil organic carbon stocks. *International Journal of Soil Science*, *5*(1), 34-40. Available at: https://doi.org/10.3923/ijss.2010.34.40.

Don, A., Schumacher, J., Scherer-Lorenzen, M., Scholten, T., & Schulze, E.-D. (2007). Spatial and vertical variation of soil carbon at two grassland sites—implications for measuring soil carbon stocks. *Geoderma*, *141*(3-4), 272-282. Available at: https://doi.org/10.1016/j.geoderma.2007.06.003.

FAO. (2006). *World reference base for soil resources 84 world soil resources report*. Italy: ISSS-AISSIBG, FAO Rome.

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

Gee, G. W., & Or, D. (2002). Particle size analysis. In: J.H. Dane and G.C. Topp (eds). Methods of soil analysis, part 4. physical methods. Soil Science Society of America. Book series (255-293 ed.). Madison: ASA and SSA.

Grossman, R. B., & Reinch, T. G. (2002). Bulk density and linear extensibility in: Methods of soil analysis part 4. Physical methods. Dane, J.H and G.C. Topp (Eds.), Soil Science Soc. Am. Book series No. 5 (pp. 201-228). Madison, W.I: ASA and SSA.

Haney, R., Franzluebbers, A., Porter, E., Hons, F., & Zuberer, D. (2004). Soil carbon and nitrogen mineralization. *Soil Science Society of America Journal*, *68*(2), 489-492.

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

Nelson, D. W., & Sommers, L. E. (1996). Total carbon, organic carbon and organic matter. In: Methods of Soil Analysis. Part 3. Chemical Methods (pp. 103). Nsukka: Soil Science Society of American Book Series.

NIMET. (2017). Climate weather and water information, for sustainable development and safety. Agrometeorlogical Bulletin No. 3, Dekad 3. Jan. 21 – 31.

Obi, M. E. (1990). *Soil physics: A compendium of lectures, University of Nigeria of human-induced soil degradation. An explanatory note* (2nd Revised ed.). Wageningen: International Soil Reference and Information Center.

Ogban, P., & Ekerette, I. (2001). Physical and chemical properties of the coastal plain sands soils of southeastern Nigeria. *Nigerian Journal of Soil and Environmental Research*, *2*, 6-14.

Ostrowska, A., Porębska, G., & Kanafa, M. (2010). Carbon accumulation and distribution in profiles of forest soils. *Polish Journal of Environmental Studies*, *19*(6), 1307-1315.

Powlson, D. S., Whitmore, A. P., & Goulding, K. W. (2011). Soil carbon sequestration to mitigate climate change: A critical re-examination to identify the true and the false. *European Journal of Soil Science*, *62*(1), 42-55. Available at: https://doi.org/10.1111/j.1365-2389.2010.01342.x.

Thomas, G. W. (1996). Soil pH and soil acidity. In: L.D., Sparks (Ed)., Methods of soil analysis, Part 3- chemical methods. Book Series. No 5 SSSA and ASA, Madison, WI, 475 – 489.

Vereş, D. Ş. (2002). A comparative study between loss on ignition and total carbon analysis on mineralogenic sediments. *Studia UBB Geologia*, *47*(1), 171-182. Available at: https://doi.org/10.5038/1937-8602.47.1.13.

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