# SOIL ORGANIC CARBON LEVELS IN SOILS OF CONTRASTING LAND USES IN SOUTHEASTERN NIGERIA [1]

# [NIVELES DE CÁRBONO ORGÁNICO EN SUELOS CON USO DE TIERRA CONTRASTANTES EN EL SUR DE NIGERIA]

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## SUMMARY

Land use change affects soil organic carbon (SOC) storage in tropical soils, but information on the influence of land use change on segmental topsoil organic carbon stock is lacking. The study investigated SOC levels in Awgu (L), Okigwe (CL), Nsukka I (SL), and Nsukka II (SCL) locations in southeastern Nigeria. Land uses considered in each location were the cultivated (manually-tilled) and the adjacent uncultivated (4-5 year bush-fallow) soils from which samples at 0-10, 10-20, and 20-30 cm topsoil depth were assessed. The SOC level decreased with topsoil depth in both land uses. Overall, the SOC level at 0-30 cm was between 285.44 and 805.05 Mg ha$^{-1}$ amongst the soils. The uncultivated sites stored more SOC than its adjacent cultivated counterpart at 0-10 and 10-20 cm depth, except in Nsukka II soils, which had significantly higher SOC levels in the cultivated than the uncultivated site. Nonetheless, at 20-30 cm depth, the SOC pool across the fallowed soils was statistically similar when parts of the same soil utilization type were tilled and cultivated. Therefore, while 4 to 5 years fallow may be a useful strategy for SOC stabilization within 20-30 cm topsoil depth in the geographical domain, segmental computation of topsoil organic carbon pool is critical.

**Key words:** Soil organic carbon; topsoil; land use; bush-fallow; cultivated soil.

## RESUMEN

El cambio en el uso del suelo afecta el almacenamiento de carbono orgánico del suelo (SOC) en suelos tropicales; pero falta información sobre la influencia del cambio de uso de la tierra en la reserva de carbono orgánico superficial del suelo. El estudio investigó los niveles de SOC en Awgu (L), Okigwe (CL), Nsukka I (SL) y Nsukka II (SCL) en el sureste de Nigeria. Los usos del suelo considerados en cada ubicación fueron los suelos cultivados (de labranza manual) y los adyacentes no cultivados (4-5 años de arbusto de barbecho) a partir de los cuales se evaluaron las muestras a 0-10, 10-20 y 20-30 cm de profundidad del suelo. El nivel de SOC disminuyó con la profundidad de la capa superficial del suelo en ambos usos de la tierra. En general, el nivel de SOC a 0-30 cm fue entre 285.44 y 805.05 Mg ha-1 entre los suelos. Los sitios no cultivados almacenaron más SOC que su contraparte cultivada adyacente a 0-10 y 10-20 cm de profundidad, excepto en los suelos Nsukka II que tenían niveles de SOC significativamente más altos en el sitio cultivado que en el no cultivado. No obstante, a 20-30 cm de profundidad, la cantidad de SOC a través de los suelos en barbecho fue estadísticamente similar cuando se cultivaron y cultivaron partes del mismo tipo de utilización del suelo. Por lo tanto, mientras que de 4 a 5 años el barbecho puede ser una estrategia útil para la estabilización de SOC dentro de la profundidad de la capa superficial de 20-30 cm en el dominio geográfico, el cálculo segmentario de la cantidad de carbono orgánico de la capa superior es crítico.

**Palabras clave:** carbono orgánico; suelo superficial; uso del suelo; arbustos; barbecho; cultivos.

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## INTRODUCTION

The importance of organic carbon (C) in soils abounds in literature and cannot be overemphasized. Soil organic carbon (SOC) influences soil physical fertility (Blair *et al*., 2006), soil chemical properties (Carter, 2002), and soil biological properties (Bauer and Black, 1994). It also improves soil quality (Lal, 2006), and crop productivity as well as improvement in sustainable use of agricultural soils (Nwite and Okolo, 2017). The presence of SOC and its related nutrients contribute positively and effectively to soil resilience**.** Most recently in a systematic review, Obalum *et al.* (2017) highlighted the importance of soil organic matter as the sole indicator of soil degradation thus stressing the need for preserving the SOC pool. Nevertheless, owing to the disastrous environmental consequences of global climate change, recent concern have shifted from importance of C in food production to more concerted studies on the quantities, distribution, kinds, and dynamics of C in different ecosystems (Onweremadu *et al*., 2007; Lal *et al*., 2007; Anikwe, 2010; Gelaw *et al.*, 2014; Nwite and Okolo, 2017). More importantly, the rising atmospheric levels of $CO_2$ have stimulated interest in C flow in terrestrial ecosystems, which have great potential for increased soil C sequestration (Huggins *et al*., 1998).

Soil C sequestration (SCS), according to Macyk and Richens (2002), is one of the important mechanisms wherein C storage in soil is enhanced and its loss minimized. According to Stockmann *et al.* (2013) SCS implies an increase in soil C for a defined period against a baseline condition where the increased C is sourced from atmospheric $CO_2$. Increasing $CO_2$ sink (C sequestration) has been acknowledged as a major possible mitigation option against global warming since soil contain more C than is contained in vegetation and the atmosphere combined (Swift, 2001). However, SOC pool is the most vulnerable to disturbance (Stockmann *et al.*, 2013), especially because of the competition between various types of land use. Thus, agricultural soils can serve as either a source or a sink of atmospheric $CO_2$ depending on the type of management practice adopted and extent of human influence exerted (Chen e*t al.*, 2009). Many cultivated soils have lost 50 to 75 % of their antecedent SOC pool (Lal, 2004). Saggar *et al.* (2001) found that percentage C loss differed with soil type, with Marton silt loam (260 g $kg^{-1}$, clay) soil losing one and half times as much percentage C as Kairanga silty clay loam (420 g $kg^{-1}$, clay) soil. Similarly, Campbell and Souster (1982) reported higher C losses of about 55% on coarse textured soils.

Widespread areas of degraded farmlands with extremely low agricultural productivity abound in sub-Saharan Africa which is as a result of poor soil quality due to land misuse and soil mismanagement. Farage *et al*. (2003) found that stocks of soil C in Nigeria were 8-23 t $ha^{-1}$ before cultivation and 6-12 t $ha^{-1}$ after cultivation. In eastern Nigeria, as most part of Africa, present day economic problems and high cost of inorganic fertilizer have forced many farmers into adopting ancient practice as natural or bush-fallowing of farmlands for some years. This practice is believed to raise the humus content of the soils and hence increase its fertility status for maximum output. Nonetheless, soils respond differently to management depending on the inherent properties of the soil and the surrounding landscape (Andrews *et al*., 2006). More so, unaltered factors as landscape, texture, and clay mineralogy are among important determinants of soil and biomass C pool.

Research on soil C for the last couple of decades has focused on the change in C storage due to change in land use and management practices. With diverse climate and soil types, results of SOC storage under different land uses and soil management practices in Nigeria are often conflicting and in some cases, inconsistent with other findings. Anikwe (2010) reported highest C stocks of 7906-9510 g C $m^{-2}$ under natural forest, artificial forest and artificial grassland ecosystems while continuously cropped and conventionally tilled soils had about 70% lower C stock (1978-2822 g C $m^{-2}$). In addition, C stock of continuously cropped and conventionally tilled soils was 25% lower than the soil cultivated by use of conservation tillage. More so, Akpa *et al.* (2016) reported SOC concentration range of 4.2 and 23.7 g $kg^{-1}$ in the top 30 cm and a range of 2.6 and 9.2 g $kg^{-1}$ at the lower soil depth. However, almost half of the SOC stock was found in the topsoil (0–30 cm) layer which represents the rooting depth of many agronomic crops and is more easily affected by management practices. Since the depth of tillage and plough layer varies between 20 and 30 cm depth, what is the effect of land use change on SOC stock across segmental topsoil layers? Reports on the alteration in SOC content of the soil surface (0–10 cm) due to land-use change (Wilson *et al.*, 2010, 2011; Zinn *et al.*, 2014), and the effect of changes in land management on the SOC content close to the soil surface (0–15 cm) (Sanderman *et al.*, 2013; Wilson and Lonergan 2013; Corral-Nunez *et al.*, 2014) abound. However, information on the effect of land use change on SOC stock at 10-20 and 20-30 cm topsoil layers is lacking.

Copious literatures have provided evidence that the retention or incorporation of crop residues may increase C input while decreasing the rate of C loss from the soil (Anikwe 2010; Nwite and Alu, 2017; Mbah *et al.*, 2017). Agricultural and other land use practices have a significant influence on the amount and duration of C sequestration in the soil before it is returned to the atmosphere (Anikwe, 2010). Potentially, C stock in soil could be increased by improved soil management practices and land use change towards a system that ensures high organic matter input to soil and slow decomposition (Rabbi *et al.*, 2014), and also by the adoption of other recommended management practices (RMP's) as opined by Lal (2004). Since, land use management practices play an important role in the global C pool and fluxes, their impact demand quantification. Soil C quantification is a useful index in the determination and management of SOM which is very important in soil physical, chemical and biological fertility as well as the overall soil quality (Stockmann *et al.*, 2013; Hobley *et al.,* 2015). Such quantification can provide useful information that will necessitate farmers to adopt appropriate measures in order to minimize SOC loss from crop lands. Furthermore, improvement in the data base on SOC levels needed to be validated with ground truth measurement, as the use of reliable data is essential for developing techniques of soil management and identifying policy options needed for promoting appropriate measures. This will facilitate scientific progress in predicting the effects of land use changes, and agricultural practices on SOC in the face of climate change. Moreover, knowledge of C sequestration potential of each sub-Saharan African country would enable the region to obtain accurate estimate of the net soil C pool. This would allow the zone to participate in the trading system for $CO_2$ emissions and carbon sequestration projects in the world.

Despite several studies carried out on the quantification of C stock in different geographical regions of the world (Cruz-Rodriguez, 2004; Lal *et al*., 1998; Lal, 2001; Hobley *et al.,* 2015), comprehensive data on SOC pool in Africa, including Nigeria are rather proceeding slowly (Anikwe, 2010). The dynamics of soil C storage calls for evaluation in the context of local soil and soil spatial variability among other factors because of the differences in edaphic/climatic conditions and soil management practices which influence C level in soil. The objectives of the study were to (i) quantify SOC stocks across segmental topsoil depths, and (ii) estimate their distribution in cultivated and adjacent uncultivated soils of some locations in southeastern Nigeria.

## MATERIALS AND METHODS

### Site Description

Southeastern Nigeria, which stretches from 04° 75'N to 07° 00'N and between 05° 34' E and 09° 24' E, has a total area of approximately 78, 612 km (Unama *et al.,* 2000). The zone is characterized by a sub humid, tropical climate with bimodal pattern of rainfall usually spread from April - July and September - November with dry spell in August. With a bimodal distribution, the average annual rainfall is 1700 mm; while the mean annual temperature ranges between 27 - 32 °C. The soils of the zone have isohypethermic temperature regime (Unama *et al.,* 2000) with a bimodal distribution.

Soils from four different locations within two agro-ecological zones (derived savanna and secondary forest), in southeastern Nigeria, were considered. Differences in soil texture and land management practices guided the choice of the different locations. The study locations included two soil series in the University of Nigeria Nsukka Research Farm. The flat land is designated as Nsukka I (Nkpologu series), while the hilly-terrain area (Uvuru series) is designated as Nsukka II. Others were Awgu in Enugu state, and Okigwe in Imo state; both are of hilly terrain. The details of the individual site description, soil classification and land use history are presented in Table 1.

Top soil, which makes up the largest C reservoir in earth's ecosystem, was sampled at 0–10, 10–20, and 20–30 cm, from both manually-tilled (tillage operation in this area does not exceed 30 cm soil depth) cultivated plots, and the adjacent 4-5 yrs bush-fallowed uncultivated sites of the four locations listed above. Bulk and undisturbed soils were sampled in triplicate at each depth. Undisturbed core samples were used for the determination of bulk density (BD), which was used to compute SOC pool on an area basis. The bulk samples were air dried, sieved (using 2 mm mesh) and were used for the determination of particle size distribution, soil pH, SOC, and total nitrogen (N). Composite sample were used for particle size analysis. Laboratory analysis was conducted using standard analytical procedures described below.

### Laboratory methods

All laboratory analysis was conducted at the Soil Science Research Laboratory, University of Nigeria Nsukka. Particle size distribution of < 2 mm size fractions were measured by the hydrometer method as described by Gee and Bauder (1986), using sodium hexametaphosphate as the dispersing agent. Bulk density was obtained by the cylindrical core method (Blake and Hartge, 1986). Soil pH was determined in potassium chloride (KCl) solution using pH meter (McLean, 1982). Total nitrogen content was quantified by the macro-Kjeldahl digestion method using $CuSO_4$ and $Na_2SO_4$ catalyst mixture (Bremner and Mulvaney, 1982), while SOC content was obtained by the Walkley and Black method (Nelson and Sommers, 1982). The SOM was computed by multiplying the % OC with the conventional Van Bernmeller factor of 1.724 while SOC pool (stock) content was calculated using the following equation (Lal *et al*., 1998):

Carbon stock ($Mg\ C\ ha^{-1}$) = [% C/100] x $\rho_b$ x d x A

Where;

$Mg\ C\ ha^{-1}$ = mega gram carbon per hectare (1 Mg = $10^6$g)

%C = Percentage of soil content of organic carbon
$\rho_b$ (Mg $m^{-3}$) = soil bulk density
d (m) = soil depth
A (ha) = area (1 ha or $10^4$ $m^2$)

**Data analysis**

The data obtained from the physicochemical measurements were analyzed using SPSS version 16.0 computer package to determine the mean and coefficient of variation (CV %). The ANOVA was performed on SOC pool values to determine the differences in means by the F-LSD procedure. Carbon stock and selected soil properties of the soils were subjected to simple linear regressions to evaluate the relationship between the SOC and selected soil properties.

## RESULTS

**Soils characteristics**

The particle size distribution of the soils as shown in Table 2 indicates predominance of sand fraction in almost all the locations. The clay content was between 200 and 390 g/kg, with a mean of 268 g/kg and 23% CV. Results also showed great differences in silt content of the different soils, which ranged from 60 to 370 g/kg and a high CV of 69%. Although the silt content of the soils averaged 170 g/kg, the silt content of soil No 1 (370 g/kg) and soil No 5 (310 g/kg) are comparatively high. These soils correspond to continuously cultivated plot and agricultural abandoned plot. The textural classes were mainly loam (L), clay loam (CL), sandy loam (SL) and sandy clay loam (SCL).

Table 1: Location, soil classification and land use of the study sites in southeastern Nigeria

| Location/ Coordinates | Soil classification | Land use history |
|---|---|---|
| 1. Awgu cultivated 5° 43' N, 7° 21' E | Typic Paleudult Unclassified - Shale | Farmers plot manually tilled with traditional hoes and sole planted with cassava (*Manihot esculenta)* after 5 years of natural fallow. No addition of soil amendment. |
| 2. Okigwe cultivated 5° 28'N, 7° 32' E | Typic Hapludult Unclassified - Shale | Farmers plot manually-tilled with traditional hoes with continuous cultivation of cassava (*Manihot esculenta*), yam (*Dioscorea rotundata* and maize (*Zea mays*) intercrop after 5 years bush fallow. Harvested maize stover and weeded residues used as mulch. No fertilizer application. |
| 3. Nsukka I cultivated 6° 52' N, 7° 24' E | Typic Kandiustult Nkpologu series - weathered Sandstone | University Research plot under 4 year fallow. Continuously tilled conventionally, previously under 4 year fallow and planted with sorghum (*Sorghum bicolor*)/soybean (*Glycine max L. Merrill*) intercrop. Application of swine and poultry droppings (15 Mg $ha^{-1}$) and NPK 15:15:15 fertilization (90 kg $ha^{-1}$) for 3 years |
| 4. Nsukka II cultivated 6° 41' N, 7° 17' E | Typic Paleustult Uvuru series | Farmers plot conventionally-ridged across the slope and planted to cassava (*Manihot esculenta*), maize (*Zea mays*), yam (*Dioscorea rotundata)* and fluted pumpkin (*Telferia occidentalis*). Soil amended with poultry manure. |
| 5. Awgu uncultivated 5° 43' N, 7° 21' E | Typic Paleudult Unclassified - Shale | Five years agricultural abandoned land, plants and twigs formed canopy with decayed and dead leaves scattered on the soil surface. Common trees found include plantain (*Musa paradisiaca*), banana (*Musa sapientum*), mango (*Mangifera indica*), and oil palm (*Elaeis guineensis*). |
| 6. Okigwe uncultivated 5° 28'N, 7° 32' E | Typic Hapludult Unclassified - Shale | Five years bush-fallowed agricultural plot, predominated by oil palm (*Elaeis guineensis*), sweet orange (*Citrus sinensis*), and oil bean (*Pentaclethra macrophllum*) trees, including *Mimosa pudica*, *Panicum maximum*, and *Pennisetum purpureum* grasses. |
| 7. Nsukka I uncultivated 6° 52' N, 7° 24' E | Typic Kandiustult Weathered Sandstone | Plot formally cropped with *Telfairia spp,* and subsequently was left to naturally regenerate since four years. Vegetation made up of scattered gmelina trees, twigs and shrubs, *Panicum maximum, Cyperus esculentus, Spermacoce verticillata, Cynodon nlemfuensis,* and *Oldenlandia corymbosa.* |
| 8. Nsukka II uncultivated 6° 41' N, 7° 17' E | Typic Paleustult Uvuru series | Four years natural-fallowed agricultural land with scattered plantain (*Musa paradisiaca*), oil palm (*Elaeis guineensis*), gmelina and avagado pear trees, common grasses include *Mimosa pudica, Andropogon gayanus, Oldenlandia corymbosa, Guterbergia spp, Ageratum conyzoides,* and *Pennisetum polystachion.* |

Table 3 presents some selected properties of the soils. Generally, the pH values of the soils in KCl indicated that they were acidic. The values ranged from 3.80 (conventionally cultivated plot of Nsukka I) to 5.30 (agricultural abandoned plot of Awgu). The soils pH decreased slightly with increase in soil depth. At increasing soil depth, the mean values of soil pH are 4.33, 4.15 and 4.08 with CV of 10%, 6% and 4%, respectively. The SOC value at 0-10, 10-20, and 20-30 cm depth among the locations varied with depth and ranged from 8.30 to 18.00 g/kg, 5.40 to 16.90 g/kg, and 3.90 to 10.7 g/kg, respectively. The SOC concentrated mostly at 0-10 cm depth. With the exception of soils No. 2 and 6 (corresponding to continuously cultivated plot and bush-fallowed Okigwe plots) which had moderate to adequate SOC following Landon's (1991) rating, the SOC content of the other soils was generally low. At 0-30 cm soil depth, the highest SOC content (44.00 g/kg and 52.00 g/kg) was found in soil Nos. 2 and 6 (corresponding to clay textured continuously cultivated and bush-fallowed Okigwe soil) while soil Nos. 3 and 7 (corresponding to sandy loam textured conventionally cultivated plot and natural fallowed plot) had the least SOC content (19.50 g/kg and 19.00 g/kg). On the other hand, the SOC content of the cultivated sites were slightly lower than their uncultivated counterparts, except for soil No 4 (Nsukka I continuously cultivated plot) that had organic soil amendment.

In contrast to SOC content, total N content of the soils followed no definite trend with depth. Although the N concentration was generally low at the various sampling depths, the pooled N content at 0-30 cm depth in all the locations was moderate with mean range of 3.40 to 5.00 g/kg. The C/N mean value decreased with soil depth and ranged from 7.47 (6% CV) to 10.13 (35% CV). Pooled among the soil depths, the highest C/N range of 27.55 to 32.97 were obtained in soil Nos 2, 4, 5, 6, and 8. These plots correspond to manually tilled plot, manually tilled and conventionally ridged plot, abandoned agricultural plot, bush-fallowed plot, and natural fallowed plot, respectively. Bulk density of the soils also varied with depth with no clear definite trend. The mean ranged from 1.39 to 1.50 Mg $m^{-3}$ with low CV of 6 to 11 % in the 0-30 cm soil layer.

Table 2: Particle size distribution and textural classification of the whole soils (0-30 cm) collected in southeastern Nigeria

| Location/Land use | Clay | Silt | Fine sand | Coarse sand | Total sand | Texture |
|---|---|---|---|---|---|---|
| | g/kg | | | | | |
| 1. Awgu cultivated | 250 | 370 | 190 | 190 | 380 | L |
| 2. Okigwe cultivated | 390 | 160 | 210 | 250 | 450 | CL |
| 3. Nsukka I cultivated | 200 | 80 | 260 | 470 | 730 | SL |
| 4. Nsukka II cultivated | 270 | 70 | 370 | 320 | 670 | SCL |
| 5. Awgu uncultivated | 280 | 310 | 350 | 60 | 410 | L |
| 6. Okigwe uncultivated | 300 | 210 | 230 | 260 | 490 | CL |
| 7. Nsukka I uncultivated | 200 | 100 | 260 | 450 | 710 | SL |
| 8. Nsukka II uncultivated | 250 | 60 | 300 | 400 | 700 | SCL |
| Mean | 268 | 170 | 271 | 300 | 568 | |
| CV % | 23 | 69 | 24 | 46 | 26 | |

Where, L = Loam, CL = Clay loam SL = Sandy loam, SCL = Sandy clay loam

Table 3: Selected properties of the soils in the study locations in southeastern Nigeria

| | pH (KCl) | | | SOC (g/kg) | | | Total N (g/kg) | | | C/N | | | BD (Mg $m^{-3}$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soil depth (cm) | 0-10 | 10-20 | 20-30 | 0-10 | 10-20 | 20-30 | 0-10 | 10-20 | 20-30 | 0-10 | 10-20 | 20-30 | 0-10 | 10-20 | 20-30 |
| 1. Awgu cultivated | 4.3 | 4.1 | 4.1 | 8.8 | 10.3 | 9.6 | 1.1 | 1.4 | 1.1 | 8.0 | 7.4 | 8.7 | 1.6 | 1.3 | 1.4 |
| 2. Okigwe cultivated | 4.3 | 4.2 | 4.1 | 18.0 | 15.7 | 10.3 | 1.7 | 1.5 | 1.4 | 10.6 | 10.5 | 7.4 | 1.4 | 1.6 | 1.6 |
| 3. Nsukka I cultivated | 3.8 | 3.9 | 3.9 | 8.3 | 5.4 | 5.8 | 1.4 | 1.8 | 1.3 | 5.9 | 3.0 | 4.5 | 1.4 | 1.5 | 1.6 |
| 4. Nsukka II cultivated | 4.2 | 4.1 | 4.1 | 14.1 | 14.1 | 9.3 | 1.1 | 1.3 | 1.0 | 12.8 | 10.8 | 9.3 | 1.4 | 1.3 | 1.4 |
| 5. Awgu uncultivated | 5.3 | 4.7 | 4.4 | 13.4 | 8.4 | 9.6 | 1.3 | 1.1 | 1.0 | 10.3 | 7.6 | 9.6 | 1.3 | 1.4 | 1.3 |
| 6. Okigwe uncultivated | 4.5 | 4.2 | 4.1 | 24.5 | 16.9 | 10.7 | 2.4 | 1.5 | 1.1 | 10.2 | 11.3 | 9.7 | 1.3 | 1.8 | 1.8 |
| 7. Nsukka I uncultivated | 4.2 | 4.0 | 3.9 | 9.7 | 5.4 | 3.9 | 1.5 | 0.8 | 1.4 | 6.5 | 6.7 | 2.8 | 1.4 | 1.6 | 1.6 |
| 8. Nsukka II uncultivated | 4.0 | 4.0 | 4.0 | 11.7 | 9.3 | 7.8 | 0.7 | 1.7 | 1.0 | 16.7 | 5.5 | 7.8 | 1.4 | 1.4 | 1.3 |
| Mean | 4.3 | 4.1 | 4.1 | 13.6 | 10.7 | 8.4 | 1.4 | 1.4 | 1.2 | 10.1 | 7.8 | 7.5 | 1.4 | 1.5 | 1.5 |
| CV (%) | 10 | 6 | 4 | 40 | 42 | 29 | 36 | 23 | 15 | 35 | 37 | 34 | 6 | 11 | 11 |

Where, BD =Bulk density; a, b and c represent 0-10, 10-20 and 20-30 cm depths, respectively.

**Soil organic carbon pool**

Figure 1*A-D* presents SOC pool of cultivated and uncultivated soils at the various soil depths across different locations. The mean SOC pool decreased with soil depth in both cultivated and uncultivated land uses across all the locations (Figure 1*A-D*). The SOC pool at 0-30 cm depth ranged from 130.56 to 137.28, 165.83 to 255.60, 90.48 to 112.88 and 134.85 to 198.81 Mg $ha^{-1}$ in the cultivated soils of Awgu, Okigwe, Nsukka I and Nsukka II, respectively. In the uncultivated sites, the SOC pool at 0-30 cm depth ranged from 126.72 to 176.88, 190.46 to 308.70, 63.57 to 137.74, and 129.93 to 195.90 Mg $ha^{-1}$ in Awgu, Okigwe, Nsukka I and Nsukka II soils, respectively. Amongst the locations, the total SOC pool at 0-30 cm depth ranged from 285.44 to 674.20 Mg C ha $^{-1}$, and 286.63 to 805.05 Mg C ha $^{-1}$ in cultivated and uncultivated soils, respectively. Considering only the cultivated land use, the total SOC stock at 0-30 cm depth followed this trend: Okigwe (CL) > Nsukka II (SCL) > Awgu (L) > Nsukka I (SL). For the uncultivated site, the corresponding order was Okigwe (CL) > Awgu (L) > Nsukka II (SCL) > Nsukka I (SL). On the average, whereas cultivated soils contained an average of 470.52 Mg C $ha^{-1}$, uncultivated soils had a mean of 477.96 Mg C $ha^{-1}$.

Between the two different land uses, results showed that there were variations in total C stock along the 0-30 cm soil depth (Figure 1*A-D*). Uncultivated plots tend to sequester more carbon than the cultivated plots with the exception of Nsukka II site. The highest SOC level was recorded in soil Nos. 6 and 2, with 805.05 and 674.2 Mg C $ha^{-1}$, respectively. These sites correspond to the uncultivated and cultivated clay textured Okigwe location, respectively. The lowest C stocks were found in soil Nos. 3 (285.44 Mg C $ha^{-1}$) and 7 (286.63 Mg C $ha^{-1}$), which correspond to the cultivated and uncultivated plots of Nsukka I location, respectively (Figure 1*C)*. The SOC sequestered in soil No. 5 (Awgu uncultivated plot) amounted to 422.04 Mg C $ha^{-1}$. This quantity was significantly ($P$ = 0.05) higher than the C stock found in the adjacent cultivated (130.56 Mg C $ha^{-1}$) plot (manually-tilled soil No. 1). Hence, 29% C stock depletion was recorded in Awgu cultivated soil. Contrastingly, the results also indicated that soil No. 4 (manually tilled cultivated land with poultry manure application) had 30% higher SOC pool (515.55 Mg C $ha^{-1}$) than soil No 8 (the adjacent 4-year fallowed Nsukka II uncultivated plot) (Figure 1*D*).

**Relationship between SOC and Soil Properties**

Correlation coefficients (*r*) among some selected properties of the soils are presented in Table 4. In cultivated land uses, the properties that significantly correlated positively with SOC included the % clay content, soil pH (KCl), and C:N ratio of the soils. Similarly, pH (KCl), and C/N ratio showed positive significant correlation with SOC content of the uncultivated soils. Also, SOC pool negatively correlated significantly (P = 0.01) with % coarse sand but showed positive significant correlation with % clay, and C/N ratio.

## DISCUSSION

The clay content of the soils is moderately low when compared with the total sand fraction. Among the particle size classes, sand fraction dominates with silt being the least, which is more evident in soils of southeastern Nigeria. Akamigbo (1984) attributed this to the nature of the parent material and mineralogy of the soils in studies of accuracy of field textures in the humid tropics. Thus, the predominance of sand fraction in different land uses could be attributed to parent material rather than influence of land uses. Similarly, dominance of sand fraction in soil particle size distribution under different land uses in southeastern Nigeria has been reported (Udom and Ogunwole, 2015; Nwite and Alu, 2017). However, silt content of Awgu soil is relatively high when compared with similar soil (Okigwe) of similar parent material. This could have resulted from flow of silt materials from the adjacent river because of its proximity to the sites where the soil was sampled. Igwe *et al.* (1995) showed that pedologically, high silt content may be related to mud flow and silt materials from river deposits and the underlying geological materials.

Bulk density is an important factor for root growth and development, and the lower bulk densities in cultivated plots could be due to the effect of animal droppings and leaf litter, as well as recycling of nutrients to upper horizons of soil owing to pedoturbation. The highest bulk density obtained in the bush-fallowed agricultural sites may be due to long term impact of land degradation and compaction (Igwe, 2001; Anikwe, 2006). Even though, soil bulk density is not directly vital to mineralization and stabilization of SOC however, it can define the amount of mineral materials and/or surfaces that can interact with SOC, in addition to the aeration status of the soil which influences rate of C mineralization (Hoyle *et al.*, 2011).

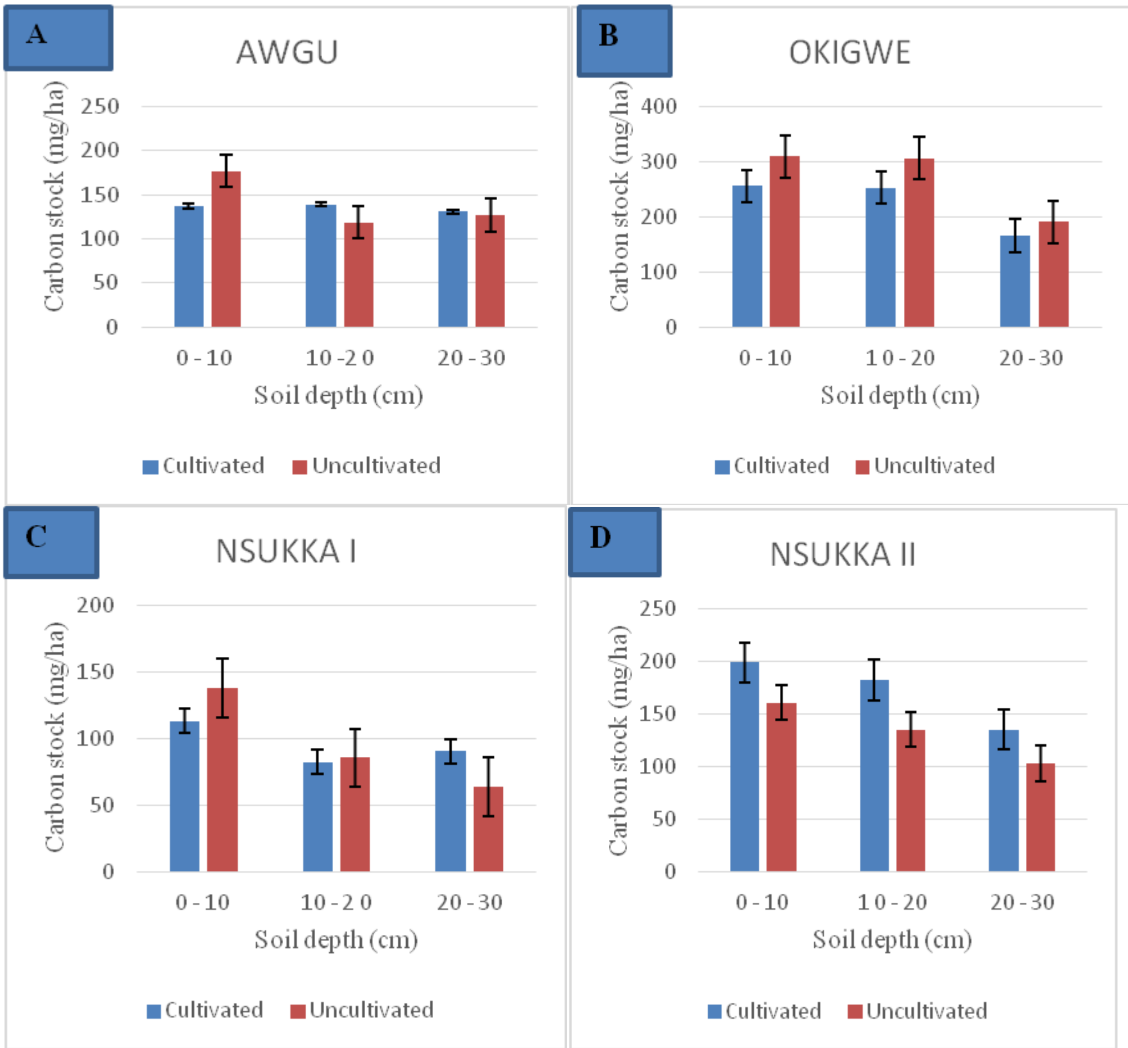


Figure 1. Distribution of soil carbon stock across varying top soil depths of the study locations in Southeastern Nigeria: Awgu (*A*), Okigwe (*B*), Nsukka I (*C*), and Nsukka II (*D*).

Table 4: Correlation coefficients (*r*) among particle sizes, and some selected properties of the soil under cultivated and uncultivated land uses in southeastern Nigeria

| | --------------Cultivated----------- | | -----------Uncultivated----------- | |
|---|---|---|---|---|
| | SOC (g/kg) | SOC pool (Mg/ha) | SOC (g/kg) | SOC pool (Mg/ha) |
| Clay (g/kg) | 0.57* | 0.39 | 0.11 | 0.57* |
| Silt (g/kg) | 0.33 | 0.27 | 0.45 | 0.38 |
| Fine sand (g/kg) | -0.11 | -0.41 | -0.08 | 0.18 |
| Coarse sand (g/kg) | -0.40 | -0.41 | -0.39 | -0.69** |
| Soil pH (KCl) | 0.70** | 0.37 | 0.58* | 0.46 |
| Total N (g/kg) | 0.13 | 0.44 | 0.36 | -0.29 |
| C:N ratio | 0.83** | -0.04 | 0.80** | 0.66** |

* = Significant 0.05 alpha level (1-tailed); ** = Significant 0.01 alpha level (1-tailed)

The pH of the soils was slightly acidic and as such, may have contributed to the low C and N contents of the soils. At pH below 5.5, bacterial activity is reduced and hence nitrification of organic matter is retarded. This is in line with Hillel's (1982) findings, which indicated that acidic condition incapacitate soil microorganisms from producing different kinds of organic matter. Considerable low soil pH values obtained under continuously cultivated soils compared to fallowed plots could be due to continuous cultivation, nutrient extraction by crops removal and application of inorganic fertilizer commonly practiced by the smallholder farmers. It could as well be attributed to increase in oxidation of SOM because of the prevailing high temperature regimes of the region, but more specifically, to reduced C input via plant biomass and increase in C losses via soil erosion and leaching as a result of high rainfall intensity (Macyk and Richens, 2002; Igwe, 2005). Our result is in line with the findings of Obalum *et al.* (2012) and Nwite and Alu (2017), who reported slight differences in the pH of soils under different land uses in southeastern Nigeria.

The N content of the soils was far much lower when compared to the C content. Low N content could be due to leaching and volatilization owning to its mobile nature (Igwe and Akamigbo, 2001). And this contributed to the narrow C:N ratios (< 20:1) of the soils which favours rapid decomposition and mineralization of SOM, suggesting that the availability of N in the top most surface layers is not a key component for reducing C losses and increasing the SOC content. Knops and Tilman (2000) observed that the rate of C accumulation in agricultural abandoned fields was controlled by the rate of N accumulation, which in turn depended on atmospheric nitrogen deposition and symbiotic nitrogen fixation by legumes.

Decreased SOC level was generally observed in the cultivated soils of Awgu, Okigwe and Nsukka I than their adjacent uncultivated plots. This loss of C may have resulted from surface soil disturbance during tillage operations in preparation of the land for cultivation, in addition to leaching and high erodibility of the soils as a result of high rainfall intensity that prevails in the area (Igwe, 2005). Cultivation increases SOM decomposition rate because of change in aggregate structure of the soil due to cultivation and mixing effect of tillage (Gelaw *et al.,* 2013). Our inference is also supported by the report that cultivated systems have reduced C contents due to reduced tree cover and increased mineralization due to surface disturbance (Anikwe, 2010). Accordingly, cultivation effect significantly reduced the 0-10 cm depth SOC stock of Awgu cultivated site by 29%. This could be as a result of biomass activity at the soil surface and consequent fast C turnover rate in the soil. Our observation is in conformity with the findings of Six *et al.* (2002) and Lal (2004). Also, Sà (1993) observed a significant impact on SOC concentrations for 0-10 cm soil layer.

Soil depth exerted strong influence on the spatial distribution of SOC pool of Nsukka II. The SOC pool of the cultivated soil was significantly higher than the uncultivated soil by 24% and 29%, at the 0-10 and 10-20 cm top soil depths, respectively. The higher SOC level obtained in cultivated soil of Nsukka II than its uncultivated variant is ascribed to the probable positive effects of the added poultry manures. Poultry manure is known to improve the OM content of the soil (Akande and Adediran, 2004). This implies higher accumulation of OM at the topmost 0-10 cm soil layer than at 20-30 cm soil layer. More so, the conservation tillage management practice being adopted at the cultivated site could have contributed to C preservation in the soil despite its hilly topography. This is an indication of the contribution of land use management practice to SOC accumulation. On the other hand, Hall (1983) reported that steeper slopes contribute to greater runoff, as well as greater translocation of surface materials down slope through surface erosion and downhill movement of soil mass. Hence, it is possible to infer that landscape aspect (hilly-terrain) of the Nsukka II, which predisposed the fallowed land susceptible to erosion and leaching processes could have contributed to its lower SOC pool content than the bush-fallowed site.

It is generally agreed that cultivation causes a decrease in SOC content (Nwite and Alu, 2017), but the study result indicated that the SOC pool of the cultivated and uncultivated soils of Okigwe and Nsukka I locations were statistically the same across the soil depths. This could be attributed to the beneficial soil management practices adopted by the farmers (leaving crop residues in the field, mulching, and growing cover crops) which enhanced the conservation and improvement of the soil OM. Consequently, there was reduced loss of SOM due to low rate of mineralization of the organic residues while the low C conversion efficiency could be linked to the low N content of the soils as supported by Lal *et al*. (2007) and Knops and Tilman (2000). Remarkably, the SOC at 20-30 cm depth was significantly similar in the cultivated and uncultivated soils of all the locations. This implies that structural alteration of SOC due to anthropogenic disturbance during tillage operation did not exceed 20 cm depth since the C in this layer was not redistributed. Hence, the SOC at 20-30 cm depth was secluded when parts of the same soil utilization type were tilled and cultivated. Therefore, land fallow practice may be a useful strategy for stabilization of soil C below 20 cm soil depth in the geographical domain.

In considering SOC pool in relation to the textural differences of the locations, clay loam had the highest SOC stock; while the sandy clay loam had the least. The reason for this could be related to their clay content and possibly, the clay type (Lal, 2001), which was not considered in this study. Observably, clay content increased significantly with the SOC pool, where $r = 0.57^*$. The negatively charged SOM usually attaches itself to the inner positively charged clay particles hence, the higher SOC pool of soils with high clay content as observed in Okigwe and Nsukka II soils (Figures 1*B* and 1*D*). Similar results was reported by Gelaw *et al.* (2013) in a study of organic C and N associated with soil aggregates and particle sizes under different land use. Batjes (1998) showed that clay content and soil acidity, amidst others, were among the major environmental factors that controlled the behaviour of OM in the soil. Consequently, clay content, and C/N which significantly correlated positively with SOC pool appear to be the most contributing factors to the latter's improvement and stabilization in soils of this region. Hence, increased percentage of clay content, soil pH and C/N implies improved SOC storage in similar soils. The negative significant correlation between % coarse sand and SOC pool (r = –0.69**) is an indication that only 31% SOC may be associated with coarse sand dominated soils of the study area. This may have accounted to the low SOC pool of the sandy loam textured Nsukka I soils as shown in Figure 1*C*. Thus, increased percentage of coarse sand fraction of soils suggest decreased SOC stabilization of the soils.

## CONCLUSION

Organic C levels and distribution in the soils varied according to locations, topsoil depth and the land use options. In both cultivated and uncultivated soils, SOC pool decreased with topsoil depth, an indicative of the importance of specifying the topsoil layer (segment) over which soil is sampled and SOC pool calculated. Uncultivated soils stored higher SOC than the cultivated soils at 0–10 cm, and 10–20 cm depth, but C level was relatively the same at 20–30 cm depth in both land uses and across the locations. Hence, 4-5 years bush-fallow practice may be helpful in the stabilization of SOC below 20 cm topsoil depth in these and similar soils. In addition, % clay content, soil pH and C/N ratio are important determinants of SOC in these soils. Therefore, SOC pool may be a function of topsoil depth, fallow period, land use management, and soil texture.

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