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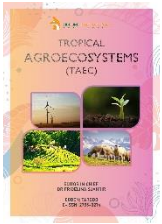

RESEARCH ARTICLE

CARBON STOCK AND FLUX UNDER THE INFLUENCE OF VARIOUS AGRICULTURAL PRACTICES IN TROPICAL SOILS OF SOUTHEASTERN NIGERIA

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ABSTRACT

This study investigated carbon stock under different agricultural practices in tropical soils of Southeastern Nigeria in two distinct seasons. Six agricultural practices {Natural undisturbed forest land (NUFL); Afforestation (AFP); Continuous cultivated land (CCL); Cattle transit (CT); Grassland (GRL) and Uncultivated land (UCL)} were identified. Carbon stock and flux were investigated at three distinct depths (0-30, 30-60 and 60-90 cm). Experimental design adopted was randomized complete block design. Results showed that under NUFL practices, highest concentrations of carbon were obtained from soil aggregates (macro-aggregates: 1.86 and 1.93 g kg^{-1}; micro-aggregates: 4.48 and 4.64 g kg^{-1}) in both raining and dry seasons. Carbon concentrations in the studied sites diminished with depth. Highest soil organic carbon stock (SOCs) contents of 85.77 and 99.86 kg C ha^{-1} were obtained from site under NUFL practices. Carbon stocks in the study soils declined with depths 99.86 to 27.31 kg C ha^{-1}; 89.49 to 48.13 kg C ha^{-1} in raining and dry seasons. High values of CO_2 (4.96 and 7.77%) were obtained from soil under intensive cultivation (CCL) in both seasons. Maximum Net carbon fluxes (-22.35 and -23.31) were recorded in soils under CCL practices in raining season and dry season. Net carbon flux was consistently negative and significantly lower in soils under NUFL (-84.68 and -97.88) in both seasons. Conclusively, NUFL and AFP practices enhanced vegetation cover which reduced carbon emissions, improved storage of carbon as well as other soil properties with lower risk of soil degradation when compared to soil under other farming practices.

KEYWORDS

Soil Carbon Pool, Carbon Emission, Carbon Sequestration, Tropical Soil, Management Practices.

1. INTRODUCTION

Since soil contains around three times as much carbon (C) as the atmosphere and about 3.8 times as much as combined nitrogen (N) biotic pool, it plays a significant role in the global carbon cycle (Zomer et al., 2002). Depending on land usage and management techniques, it can either be a source or a sink of atmospheric carbon (Lal, 2003). Agricultural management practices such as mulching, tillage operations, use of soil amendments and fertilizers impact soil qualities such as soil carbon content, organic carbon dynamics and water retention capacity (Swift, 2001; Zhang et al., 2019; Bell et al., 2020; Ibrahim et al., 2020; Jayaraman et al., 2022). Farm management methods that reduce soil disturbance and increase cultivation decrease the amount of carbon stored in soil ecosystems. This is largely due to the fact that loss of carbon due to land intensification and usage conversion from a natural ecosystem to a cultivated agricultural ecosystem affects soil production (Awoonor et al., 2022).

The potential to store carbon by improving agricultural practices or restoring degraded lands is enormous because measures that sequester carbon in soils generally boost productivity (FAO, 2010). Practices that increase the sequestration of carbon in arable soils also tend to increase resilience to climate change, which is anticipated to improve long-term adaptation to changing climatic conditions (Giri et al., 2007; FAO, 2010). As a result, managing soil organic carbon to keep the soil healthy is a significant worry and difficult work in agricultural methods as carbon plays a key role in preventing soil quality decline (Okpoho, 2018). The basis and storehouse of the majority of plant nutrients necessary for plant growth is soil and management strategies for raising and maintaining agricultural yields at a high productivity level must take this into account (Odunze et al., 2017).

Several studies of agricultural practices have shown that adopting recommended management practices can have a significant impact on carbon fluxes in agricultural soils (Anil and Balkrishna 2017; Mangi et al., 2022). However, a search of the literature revealed insufficient information on the impact of agricultural practices on carbon fluxes in the tropical agro-ecology of southeastern Nigeria. Therefore, the aim of this study was to examine carbon inventories using pooled indices from different agricultural practices for tropical soils in southeastern Nigeria.

2. MATERIALS AND METHOD

2.1 Study Site

This study was conducted at the Forest Research Institute of Nigeria, Umuahia Station, Abia State, Nigeria. The study area is characterized by different vegetation cover. The average annual rainfall is 550 mm, with most precipitation occurring between July and September, with a bimodal pattern. Agricultural survey locations were determined using the Global Positioning System (GPS) to obtain study coordinates (Table 1).

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Table 1: Study Sites and Agricultural Practice History of the 6 Sites Used for The Study.

Site	Study sites	GPS coordinates	Agricultural practice history
1	Virgin forest or Natural undisturbed forest land (NUFL)	Longitudes 7° 31' 34.268'' N Latitudes 5° 31' 2.34'' E.	Untouched natural forest (forest reserve). It has existed for over 20 years. People are not allowed to farm, hunt animals/wildlife and cut trees/collect firewood.
2	Afforestation (AFP)	Longitudes 7° 31' 42.235'' N Latitudes 5° 31' 4.298'' E.	Secondary forest established by Forestry Research Institute. Planted with *Alanblakia floribunda* and *Tectonagrandis* (Teak).
3	Continuous Cultivated land (CCL)	Longitudes 7° 31' 34.189'' N Latitudes 5° 31' 59.963'' E.	Adjacent land near plantations. Cassava, yams, legumes, okro and vegetables are grown continuously for more than 5 years in mixed culture without fertilization or crop residue removal.
4	Cattle transit (CT)	Longitudes 7° 31' 43.406'' N Latitudes 5° 31' 18.092'' E.	Cattle walk way for over 5 years.
5	Grass land (GRL)	Longitudes 7° 31' 38.074'' N Latitudes 5° 30' 55.497'' E.	Artificial grassland established in 2018 by Forestry Research Institute, Umuahia Station. It is mainly made up of vertiver grasses such as *Chrysopogon ziziloides* mainly for erosion control.
6	Uncultivated land (UCL)	Longitudes 7° 31' 34.268'' N Latitudes 5° 31' 40.395'' E.	Land site under 3 years fallow period. However, vegetables such as cassava (*Manihot esculenta*) / amaranth (*Amaranthus hybridus*), okra (*Albemoschus esculentus*), water leaf (*Talinum triangulare*) / maize (*Zea mays*) are planted to cover the crops with a fallow period of three years.

2.2 Soil Sampling

Soil sampling was carried out in the two distinct seasons of the region (rainy and dry seasons). Using a soil auger, three disturbed surface soil samples were taken from each depth (0–30, 30–60 and 60–90 cm) respectively. This was repeated for each of the study site under the various farming techniques. The soil samples were air-dried, lightly crushed and sieved using 2- and 0.5-mm sieves.

2.3 Laboratory Analysis

2.3.1 Soil Physical Property Determination

Particle size distribution was determined using the hydrometer method described (Gee and Bauder, 1986). Soil bulk density was measured using the core method described (Grossman and Reinsch, 2002). Soil porosity was determined using the mathematical relationship between bulk density and particle density outlined (Nabayi et al., 2019).

2.3.2 Aggregate Stability

Wet sieving methods outlined by was used to determine aggregate stability (Van Bavel, 1950; Kemper and Rosenau, 1986). 200 grams of bulk soil was weighed and transferred into nest of sieve consisting of the following diameters: 2, 0.5, 0.25 and < 0.05 mm. The nest of the sieves was immersed into a bowl of water 20 times to separate the soil particles into its various fractions. The retained soils in the sieves were decanted and dried in the oven for 24hrs. The oven dried soil fractions were weighed and used to calculate the aggregate fractions distribution and mean weight diameter (MWD) of the aggregates as shown in (1) as outlined (Kemper and Rosenau, 1986).

$$MWD = \sum_{n-} w_i x_i \qquad (1)$$

Where Xi = proportional by weight of sand free aggregate; Wi = mean diameter of proceeding and preceding sieve.

2.3.3 Organic Carbon Determination

Organic carbon (OC) in the study soils was determined using the Walkley-Black method as described (Nelson and Sommers, 1982). Soil organic carbon stock (SOCs**)**: a product of bulk density, OC concentration and layer thickness (soil depth) was estimated using the following equation:

$$SOCs = \Sigma Dbi\,Ci\,Di \qquad (2)$$

Where SOCs is the soil organic carbon stock (kg C ha^{-1}), *Dbi* is the bulk density (g cm^{-3}) of layer *i*, *Ci* is the proportion of organic carbon (g C g^{-1}) in layer *i*, *Di* is the thickness of this layer (depth in cm).

2.3.4 Carbon Emission Measurement

Carbon emissions in the study soils were measured by adopting the procedures outlined (Olaniyan et al., 2020). It was an in-situ procedure involving the alkali absorption method. Readings of trapped CO_2 emissions were taken at three days intervals.

2.3.5 Net C Flux Determination

Net C flux was calculated as the difference between carbon emission (CO_2) and soil organic carbon stock (SOCs). This approach as outlined by West and Marland, (2002) was used to determine the effect of different soil management practices on carbon emission and soil carbon sequestration. Within the boundary of both systems, C emissions were accounted for as emissions from agricultural practices, whereas the C sequestration was accounted for as the SOC. This is further presented as follows:

$$\text{Net C flux} = \text{C emissions} - \text{C sequestration} \qquad (3)$$

A negative value of Net C flux indicates the efficiency of the system in terms of C sequestration and CO_2 emission mitigation.

2.3.6 Statistical Analysis

Data collected was subjected to analysis of variance (ANOVA) using the mixed linear model MIXED Procedure of SAS, (Institute Inc., 2009). Duncan's multiple range test procedures was used when the F-Cal of the ANOVA for each variable was found to be significant and their interactions were compared by computing least square means and standard errors of difference (SED) at 5 % level of probability.

3. RESULTS AND DISCUSSION

3.1 Effects of Agricultural Practices and Soil Depth on Carbon Storage in Soil Aggregates

Table 2 shows the effects of agricultural practices on organic carbon (OC) content in macro aggregates (MaAg) and micro aggregates fractions (MiAg) of the study soils during the two seasons under study. The effects on the aggregate sizes show that NUFL sequestered the highest organic carbon concentrations of 4.48 and 4.64 g kg^{-1}in micro aggregates (MiAg) in both raining and dry seasons. This was followed by AFP of which organic carbon concentrations of 3.89 g kg^{-1} for raining season and 3.89 g kg^{-1} for dry season were obtained from MiAg. Least values of carbon concentrations were obtained under CT (1.45 and 1.54 g kg^{-1} for MaAg and 2.23 and 2.27 g kg^{-1} for MiAg) under raining and dry conditions respectively.

Data on the organic carbon sequestered in the macro and micro aggregate fractions were significantly affected by soil depth in both seasons as shown in Table 2. The values were consistently higher in topsoil (0-30 cm) and decreased with increase in depth. This feature was observed in both seasons. Organic carbon was more strongly bound to the micro-aggregate fraction than to the macro-aggregate fraction in the studied soils. The high presence of stored carbon observed in soil aggregates (micro and macro) of study sites under natural undisturbed forestation land (NUFL) agricultural practices for each of the two seasons (wet and dry) can further be explained by the presence of undisturbed vegetation cover. This is largely due to minimal agricultural activities and mass production of plant residues on soil surfaces which increased the amount of organic carbon sequestered in soil aggregates. Similar results of large contents of carbon being stored in micro-aggregate of undisturbed soils were obtained (He et al., 2021). A group researchers emphasized that these high concentrations of organic carbon in soil micro aggregates contributes more to soil fertility and health (Wang et al., 2020). Group research further stated that groundcover treatments sequester more carbon in surface aggregates especially in the micro-aggregate fraction, making the carbon generated from these treatments more accessible to microorganisms (Odunze et al., 2017).

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Table 2: Effect of Agricultural Practices and Soil Sampling Depth on Organic Carbon (g kg^{-1}) Sequestration in Large and Small Macro Aggregates

Treatment	Raining season	Dry season	Raining season	Dry season
	MaAg		MiAg	
Agricultural Practice (AP)				
CT	1.45^{d}	1.54^{de}	2.33^{f}	2.37d
CCL	1.49^{de}	1.57^{d}	2.23^{e}	2.27^{e}
NUFL	1.86^{a}	1.93^{a}	4.48^{a}	4.64^{a}
AFP	1.63^{c}	1.83^{b}	3.81^{b}	2.89^{c}
GRL	1.43^{e}	1.49^{e}	3.10^{d}	2.33^{d}
UCV	1.75^{b}	1.78^{c}	3.48^{c}	3.12^{b}
SE ±	0.01	0.016	0.021	0.019
Soil Depth (SD) cm				
0-30	1.75^{a}	1.90^{a}	3.81^{a}	3.61^{a}
30-60	1.64^{b}	1.74^{b}	2.88^{b}	2.81^{b}
60-90	1.41^{c}	1.59^{c}	2.24^{c}	2.24^{c}
SE ±	0.0047	0.008	0.0043	0.009
Interaction				
AP * SD	NS	NS	NS	NS

Means with the same letters within the same column are not statistically different at 0.05 probability level, SE = standard error, NS = not significant.

3.2 Effects of Agricultural Practices on Soil Organic Carbon Stock, Emission, and Flux

The results of the effect of agricultural practices and soil depth on soil organic carbon stock (SOCs), carbon emission (CO_2) and Net C flux in raining and dry seasons are presented in Table 3. Higher values of sequestered carbon (85.77 and 99.86 kg C ha^{-1}) were obtained from NUFL practice. The lowest carbon stocks of 31.31, 34.98 and 33.39 kg C ha^{-1} were obtained from the soil in the study sites under CCL, CT and GRL practices in both seasons respectively. Comparisons of the carbon stock values show about 50 % depletion in carbon stock in the soils under cattle transit (CT) and continuously cropped land practices. For each study site, a higher quantity of carbon was sequestered in dry season in comparison to values of stored carbon recorded in raining season as shown in Table 3.

A similar trend as observed for SOCs was obtained for carbon emission (CO_2). Carbon emission was significantly lower in natural undisturbed forest land (1.09 and 2.00 %) followed by afforested study sites (2.01 and 2.16 %) for both raining and dry seasons respectively. Highest values of CO_2 emissions were recorded in soils under continuous cultivated practices (CCL) (4.96 and 7.77%) for both rainy and dry seasons.

Table 3: Effect of Agricultural Practices and Soil Depth on Carbon Stock and Carbon Emission

	Raining season	Dry season	Raining season	Dry season	Raining season	Dry season
Treatment	SOCs (kg C ha^{-1})		CO_2 (%)		Net C Flux	
Agricultural Practices (AP)						
CT	34.98^{d}	43.32^{ef}	3.85^{b}	5.27^{b}	-31.13^{d}	-38.05^{e}
CCL	27.31^{e}	31.08^{e}	4.96^{a}	7.77^{a}	-22.35^{e}	-23.31^{f}
NUFL	85.77^{a}	99.86^{a}	1.09^{e}	2.00^{e}	-84.68^{a}	-97.88^{a}
AFP	60.28^{b}	63.92^{b}	1.51^{e}	2.16^{de}	-58.77^{b}	-61.76^{b}
GRL	33.89^{c}	45.26^{d}	2.89^{c}	3.08^{c}	-31.00^{d}	-42.18^{d}
UCV	57.09^{c}	57.95^{c}	2.17^{cd}	2.40^{d}	-54.92^{bc}	-55.55^{c}
SE ±	1.19	1.71	0.36	1.79	2.77	3.21
Soil Depth (SD) (cm)						
0 – 30	74.24^{a}	89.49^{a}	2.65^{b}	4.84^{a}	-71.59^{a}	-84.65^{a}
30 – 60	58.79^{b}	63.73^{b}	3.23^{a}	4.26^{a}	-55.56^{b}	-69.47^{b}
60 – 90	48.13^{c}	54.82^{c}	2.37^{b}	3.26^{b}	-45.76^{c}	-51.56^{c}
SE ±	1.74	1.63	0.21	0.27	3.11	5.01
Interaction						
AP * SD	*	*	NS	NS	NS	NS

Means with the same letters within the same column are not statistically different at 0.05 probability level, SE = standard error, NS = not significant,* = significant at $p \leq 0.05$.

Effects of agricultural practices on Net carbon flux in raining and dry seasons are presented in Table 3. Values of Net C flux were consistently negative and significantly higher in soils under CCL (-22.35 and -23.31), followed by CT (-31.13 and -38.05) in both seasons respectively. The lowest Net C flux of -84.68 (raining season) and -97.88 (dry season) was obtained from soils under NUFL practice. Results of Net C flux as influenced by soil depth was significantly ($p \leq 0.05$) higher at surface soil (0-30 cm) when compared with data obtained for other soil depths in both seasons (Table 3). The Net C flux was consistently higher in the dry season and exhibited a decreasing trend with soil depth in both seasons.

High negative Net Carbon fluxes and emissions also suggest that there is an opportunity to increase soil organic carbon in other to improve arable soil fertility and productivity, especially land under intensive agricultural

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activities (CCL). It can also be asserted that the intensive cultivation of crops resulted in lower carbon sequestration (stock) and Net Carbon flux. This confirms that intensive activities of continued cultivation leads to adverse depletion of organic carbon, depletion of carbon stores due to increased global warming, climate change and reduced soil quality for sustainable crop production (Odunze et al., 2017).

As shown in Table 3, results of Net Carbon flux and CO_2 emissions as influenced by soil depth were significantly higher in surface soil (0-30 cm) when compared with data recorded for other sampled depths for both seasons. Observations by Owoade (2020) by revealed that the high quantity and quality of litter falls and field layers under different temperature conditions with minimal soil management activities may be responsible for the decrease CO_2 emissions and low Net Carbon flux in soils under forest and plantation land uses. This also explains why lower values of CO_2 and high negative values of Net C flux found in these soils may help fight against climate change.

Owoade further confirmed that agricultural practices that truly enhance climate change cannot sequester SOC, but must at the same time limit emissions of other greenhouse gases which explained the higher negative CO_2 emissions recorded in soil under plantation and virgin forest land driven by high levels of organic carbon in the soils (Owoade, 2020).

3.3 Interaction of Agricultural Practices and Soil Depth on Carbon Stock

Interaction of agricultural practices and soil depth on carbon stock in both seasons is presented in Figures 1 and 2. Natural undisturbed forestation land (NUFL) agricultural practice in combination with 30-60 cm soil depth gave higher value of SOCs in both seasons respectively. Considering all the agricultural practices with soil depths interactions, values of SOCs were consistently higher in dry season when compared with the values obtained in raining season. Soil organic carbon content decreased with soil depths under all the agricultural practices in both seasons as shown in Figures 1 and 2 respectively.

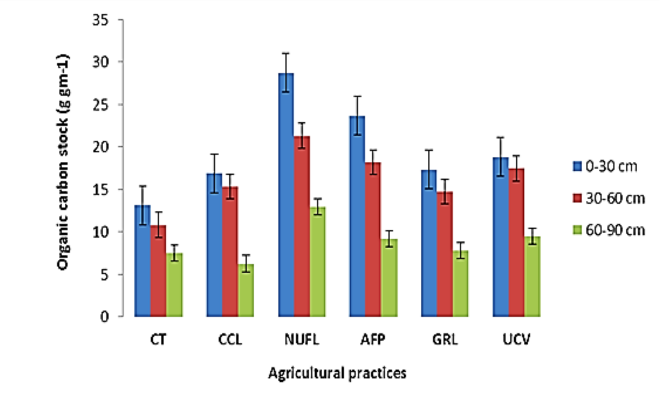

Figure 1: Interaction of agricultural practices and soil depth on soil organic carbon stock in raining season.

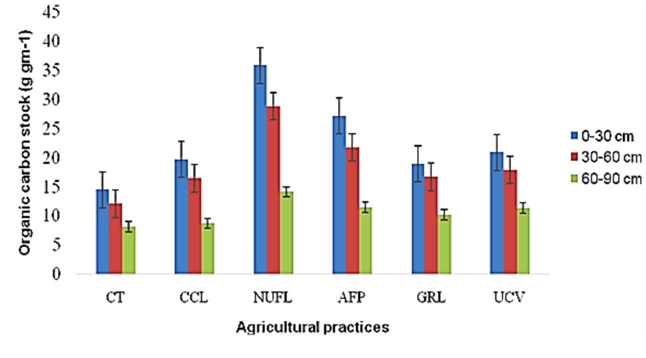

Figure 2: Interaction of agricultural practices and soil depth on soil organic carbon stock in dry season.

This study also revealed that content of sequestered carbon decreased with depth. A group researchers supported the assertion that the variation of soil properties (organic carbon, total nitrogen, available phosphorous and potassium) within the soil profiles could be attributed to amount of litters and plant residues deposited on the soil surface (Deng et al., 2022). A group researchers further corroborated this assertion by stating that the upper part of the soil horizon happened to be the first beneficiary of the photosynthetic extraction of carbon into the terrestrial environment from the atmosphere through phyto-mechanisms and buildup of organic carbon accruing decomposition of plant residues (Ahukaemere et al., 2020).

A group researcher also linked the increase in the high content of carbon stock of virgin forests to age (He et al., 2021). In other words, undisturbed and afforested soils tend to increase their carbon stock over a period of time if there are no disruptive management activities. This could explain the high level of carbon stock in the sites under the two land use types (NUFL and AFP). Low values of carbon stock obtained from sites under continuous cultivated practices (CCL) can be linked to the ongoing intensive farming activities in these sites as stated initially in Table 1. These sites are known for cultivation of cassava, cocoyam, yams and vegetables continuously for the past five years. Under this cultivation practices, residues removal, low carbon input, intensive tillage activities occur leading to low carbon stocks in the soils (Lal et al., 2007).

4. CONCLUSION

Findings from this study revealed that afforestation (AFP) and natural undisturbed forest land (NUFL) practices boost vegetation growth, which in turn enhances soil characteristics with minimal carbon flux. These particular agricultural practices also reduce the risk of soil deterioration, which helps to reduce climate change by better sequestering carbon than other agricultural methods. This investigation also showed that the carbon content in the study soils dropped with depth. In both research seasons, there was a greater accumulation of carbon in the micro-aggregates on the soils' surfaces. Intensive cultivation practices (CCL) led to high emissions of CO_2 gases, low carbon storage and high carbon fluxes. Conclusively, proper management measures should be adopted to control activities that could result in the depletion of carbon stores and consequently, the degradation of soil.

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