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Influence of Slope Position on Soil Carbon Stock and Selected Soil Fertility Indices in Lowland Rain-Fed Rice Field

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Abstract:
Most farmlands in Southeastern Nigeria are associated with low organic matter content and are prone to soil erosion and nutrient loses due to runoffs from undulating soil surfaces. This consequently limits the capacity of these farmlands to produce abundant food. The present study investigated the effect of slope position on soil organic carbon (SOC), carbon stock and selected fertility indices of lowland rice fields in Ebonyi State, Nigeria. This study was conducted in four lowland-rice fields/location in Ishiagu, Ebonyi State, Nigeria. In each location, three slope positions (upper slope, middle slope, and lower slope) were identified. Topsoil samples (0-15 cm) were collected in quadruplicates from each slope position for soil chemical analyses. Results showed significant differences in the soil physicochemical properties across slope positions and locations. The middle slopes had higher ($p < 0.05$) pH, cation exchange capacity (CEC), and total nitrogen than the upper and lower slopes. Carbon stock varied from 4.22-13.0 t C/ha across slope position but was insignificant across locations. Upper slopes had higher (11.4 g/kg) SOC than lower slopes (9.68 g/kg). The study locations had low SOC, CEC and soil nutrients; an indication of soil erosion impact in that area. The results of study reveal that organic amendment application is needed to build-up the SOC, which is crucial to preventing soil erosion, nutrient losses, as well as enhancing crop productivity and improving the overall soil health.

Keywords: Carbon sequestration, Farming systems, Food security, Landscapes, Soil erosion

INTRODUCTION

Ebonyi state, Nigeria, is renowned for its rice farming. Rice production in Ebonyi State depends on rain-fed conditions, which is susceptible to climate variabilities that affect yield performance. About 93% of cultivated land in sub-Saharan Africa depends on rain-fed agriculture (FAO (2002). This suggests that rain-fed agriculture plays a crucial role in food security and water availability. Kadigi et al. (2004); Wani et al. (2009); Nwite et al. (2015) opined that rain-fed agricultural lands vary on the amount and distribution of rainfall in an area. Rain-fed lowlands are typically faced with poor soil quality, drought/flood conditions, and as well as unsustainable management practices that negatively affect yields (Meertens et al., 1999; Devendra, 2016). Most farmlands in Ebonyi state are prone to soil erosion, which results to nutrient loses due to runoffs from the undulating soil surface. This has serious negative impact on rice growth and yield performance. Further, most farmers often cultivate without applying adequate agricultural inputs (such as NPK fertilizers, manures or composts) to enhance soil nutrient or at least to restore soil nutrients lost to plant nutrient uptake and soil erosion. Such land use management practices negatively affect soil organic carbon, accelerate soil degradation, erosion of steep slopes (Gabiri et al., 2018) and have negative environmental effects (Wezel et al., 2007). This is because water movements erode unprotected slope surfaces and wash away soil nutrients, which are reallocated in the watershed (Dung et al., 2008; Pansak et al., 2008; Aung et al., 2013).

Soil erosion is the single largest threat that has serious negative effect on the productivity and sustainability of inland valleys/lowland rice fields in southeastern Nigeria (Sullivan, 2004). Most rice fields in Ebonyi state are located on sloppy lands with varying degrees of elevation. Hence, sediment rich water flows into the paddy fields from upper paddy side and flow out through the lower paddy. The differences in slope position cause differential influence on soil properties and hydrological conditions (Hseu and Chen, 2000); Tsubo et al., 2006; Gabiri et al., 2018). This consequently affects crop yield and productivity due to uneven sediments distribution and spatial variability in soil fertility of downstream watershed (Gao et al., 2007; Mingzhou et al., 2007; Gabiri et al., 2018). Soil varies considerably from place to place, across landscapes, both vertically and horizontally (Wilding, 1985; Ezeaku and Eze, 2014). Bockheim (2005) opined those soils formed on the same parent material within an ecological zone are intricately linked and can exhibit considerable variations in soil properties. Mojiri et al. (2018) reported changes in soil properties and productivity along a toposequence. Slope positions vary heterogeneously in morphology (physiography), soil type, vegetation, and hydrology (Mbagwu, 1995; Teka et al., 2015). Variations in soil properties across landscapes affect crop productivity and yield due to anthropogenic and natural activities (Xiao et al., 2016), which affect soil organic matter and nutrient reserves (Ezeaku and Eze, 2014; Rallos et al., 2017; Gabiri et al., 2018). Rossiter (1994) emphasized the importance of topographic position in land evaluation in predicting land performances. However, the effect of slope position on carbon stock and soil fertility attributes under intensive rice cropping in Ebonyi state have not received much research attention. This study aimed at evaluating changes in soil carbon stock and some soil physicochemical properties of a derived savanna as affected by slope position in lowland rice fields of Ebonyi state.

MATERIALS AND METHODS

Study Location

The study was conducted in four lowland rice fields/locations (Amaeze, Ovumte, Federal College of Agriculture Ishiagu [FCAI] and Fallow, at Ishiagu) in Ebonyi atate, Southeastern Nigeria. A split-plot factorial arranged in randomized complete block design (RCBD) was used for this study. The main plots were slope positions while locations were the sub-plots. The study area, a derived savanna zone, is located between latitude 5° 55′ N and 6° 00′ N and longitude 7° 30′ E and 7° 35′ E, has a low-lying and undulating relief (Ezeh and Chukwu (2011) and a bimodal pattern of rainfall pattern. The annual rainfall ranges from 1250 mm to 1500 mm with a mean annual temperature of about 27°C to 28°C. The relative humidity is 80% during rainy season and 65% in the dry season (ODNRI, 1989). The area is characterized by rampant flooding and water logging due to poor drainage which is caused by an impervious layer, high soil bulk density and crusting (Nwite et al., 2014; FDALR, 1985). Flooding occurs at the peak of rainy season (July and October) and it covers the basins and floodplains around the middle and lower river and stream courses (Nwite et al., 2014). The major land uses include rice farming mainly during the raining season, citrus and oil palm plantations, multiple (annual) cropping of other arable crops and vegetables during the off-peak rainy reasons.

Soil Sample Collection
In each study location, three slope positions (upper slope, middle slope, and lower slope) were identified. Topsoil samples (0-15 cm) were collected in quadruplicates from each slope position for soil chemical analyses after being were air-dried, crushed and sieved with a 2 mm sieve. Undisturbed soil samples were also collected with the aid of cylindrical (5×5 cm) cores from each slope position for soil bulk density determination.

Laboratory Methods
Particle size distribution was determined by hydrometer method as described by Gee & Bauder (1986). Soil pH in H_2O and KCl was determined using McLean (1982) method. Soil organic carbon (SOC) was determined by Walkley and Black method as described by Nelson and Sommers (1996). Total nitrogen was determined by semi-micro Kjeldahl digestion method using sulphuric acid and $CuSO_4$ and Na_2SO_4 catalyst mixture (Bremner and Mulvancy, 1982). Cation exchange capacity was determined using Rhoades (1982) method. For bulk density (BD) determination, core soil samples were collected and allowed to drain freely for 24 hours, oven dried and thereafter calculated thus: Bulk density (g/cm^3) was determined as described by Blake and Hartge (1986) method.

$$\text{Bulk density} = \frac{\text{Mass of dry soil (g)}}{\text{Volumn of soil (cm}^3\text{)}}$$

Carbon stock (t C/ha) was calculated using the equation:

$$\text{Carbon stock } = \frac{\text{Carbon x soil bulk density x area x soil depth}}{100}$$

DATA ANALYSIS
Data obtained was subjected analysis of variance (ANOVA) using GenStat 3 7.2 Edition. Treatment means were separated and compared using Least Significant Difference (LSD) and all inferences were made at 5% probability level. Slope positions and locations were subjected to simple linear regressions to investigate their relationship with SOC stock.

RESULTS AND DISCUSSION
Particle Size Distribution Across Slope Positions and Locations in Lowland Rice Fields
Results of the particle size distribution show that fine sand varied from 3% to 53%; clay content ranged from 9% to 53%, while the silt content ranged from 19% to 47% (Table 1). At the middle slope, Ovumte had the highest (47%) silt content while Fallow had the highest (53%) clay content at the upper and lower slopes.

The results show that Amaeze, Ovumte, FCAI and Fallow were composed of clay loam, loam, sandy loam and sandy clay respectively at the upper slope position. However, at the middle slope position, Amaeze and Ovumte were composed of clay loam while FCAI and Fallow were of sandy loam and clay textural classes respectively. At lower slope position, Amaeze and Fallow were of clay textural class while Ovumte and FCAI had clay loam and sandy loam textural classes, respectively. Soils of the study locations were predominantly gravelly sandy loam and clay loam texture. This is due to the sandy shales, with fine, grained micaceous sandstones and mudstones that characterized the soils of this area. Study has shown that the texture of any soil type is due to its parent material (Igwe et al., 1999).

Table 1: Selected physical properties of the soils of Ishiagu lowland rain-fed rice fields

Locations	Slope positions				
	Upper Slope				
	Textural class	% Clay	% Silt	% Fine sand	% Coarse sand
Amaeze	Clay	33	33	25	9.0
Ovumte	Loam	19	45	35	1.0
FCAI	Sandy Loam	9	19	35	37
Fallow	Sandy Clay	53	43	3	1.0
	Middle Slope				
Amaeze	CL	29	33	29	9.0
Ovumte	CL	29	47	23	1.0
FCAI	Sandy Clay Loam	20	23	53	4.0
Fallow	Clay	49	33	17	1.0
	Lower Slope				
Amaeze	Clay	43	33	21	3.0
Ovumte	Clay Loam	29	37	33	1.0
FCAI	Sandy Loam	11	25	32	32
Fallow	Clay	53	29	17	1.0

FCAI = Federal College of Agriculture Ishiagu

Effect of Slope Positions and Locations on Carbon Stock

There were differences in carbon stock across slope positions and locations (Table 2). The highest (9.57 t C/ha) mean carbon stock was obtained in the upper slope positions. Across upper slope, Ovumte had the highest ($p < 0.05$) carbon stock while Fallow had the least carbon stock (Table 2). Although no significant changes in carbon stock were observed across slope positions, the significant variations in carbon stock across locations, suggests that the land use types and soil management practices employed by farmers contributed to varied carbon stock obtained. Wanshnong et al. (2013) reported that alterations in land use can have negative environmental impact such as (accelerated soil degradation due to erosion) which can result organic carbon loss in steep slopes.

Table 2: Influence of slope positions and locations on the soil carbon stock

Slope positions	LOCATIONS				Mean
	Amaeze	Fallow	FCAI	Ovumte	
Carbon stock (t C/ha)					
Upper slope	11.8	6.21	7.32	13.0	9.57
Middle slope	6.50	6.94	13.5	8.43	8.83
Lower slope	4.22	12.4	7.80	6.72	7.78
Mean	7.50	8.50	9.53	9.38	8.73
LSD (0.05) slope positions				NS	
LSD (0.05) locations				2.045	
LSD (0.05) slope positions x locations				2.952	

FCAI = Federal College of Agriculture Ishiagu; LSD = Least significant difference

Irrespective of location, soil C stock correlated positively ($R^2 = 0.9901^*$, Figure 1) with slope positions. It therefore suggests that the high carbon sequestration recorded at upper slopes than lower slopes (Table 2, Figure 1) could be attributed to the improved system of rice farming, *sawah* technology, that is adopted by smallholder farmers in Amaeze and Oveumte locations. Sawah rice farming technology refers to levelled rice field enclosed by bunds having inlets and outlets for irrigation and drainage (Nwite et al., 2016) with the aim of efficient controlled water supply and its utilization within the field using bunds and structural embankments.

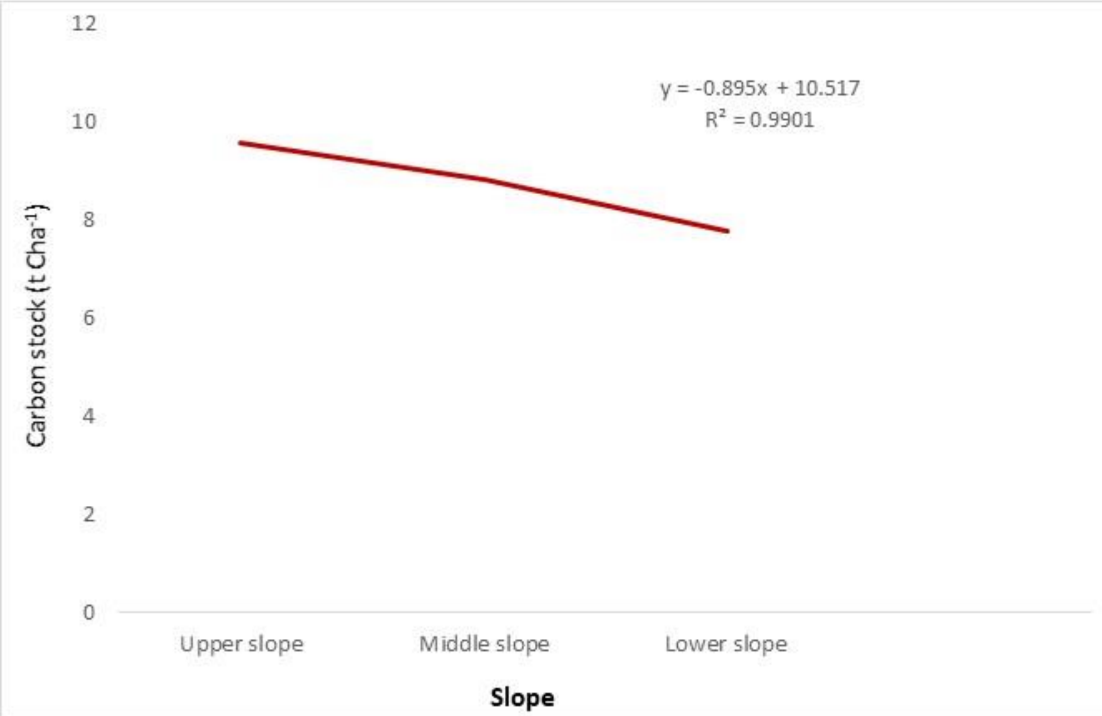

Figure 1: Relationship between slope positions and carbon stock (t C ha^{-1})

Influence of Slope Position on Soil Organic Carbon, Ph, Total Nitrogen and Cation Exchange Capacity

There are significant ($p < 0.05$) variations in the soil organic carbon (SOC) across slope positions and locations (Table 3). For Amaeze and Ovumte, upper slope position recorded higher ($p < 0.05$) SOC, while the lower slope position had the lest ($p < 0.05$) SOC. The SOC recorded for Fallow was higher ($p < 0.05$) at lower slope than at upper slope position. The high SOC associated with lower slope position for Fallow can be attributed to cumulative impact of runoff, which eroded the upper slope and deposited the eroded sediments at the valley bottoms.

This is because, the runoff process may have been ongoing at the time the location was under cultivation till time the location was fallowed. Overall, FCAI gave the highest (12.4 g/kg) mean SOC while Fallow lowland gave the lowest mean SOC (9.33 g/kg). The low mean SOC obtained from Fallow relative to those of Amaeze, Ovumte and FCAI is due to annual bush burning practice by the villagers.

Slope positions and locations interaction significantly ($p < 0.05$) influenced SOC (Table 3). This present result corroborates the study by Wanshnong et al. (2013) who found high SOC concentration at the top slope. According to Laurance et al. (1999); Porder et al. (2005); Nardoto et al. (2008), tropical lowlands display notable heterogeneity in nutrient cycling and nutrient constraints on ecosystem processes vary from local to regional scales within humid lowland forests (Kaspari et al., 2008; Townsend et al., 2011).

Table 3: Influence of slope positions and locations on the soil organic carbon, soil pH, total nitrogen and cation exchange capacity in lowland rain-fed rice fields

Slope positions	LOCATIONS				Mean
	Amaeze	Fallow	FCAI	Ovumte	
Soil organic carbon (g/kg)					
Upper slope	15.4	7.47	9.51	13.4	11.4
Middle slope	8.49	6.83	17.4	10.3	10.8
Lower slope	6.5	13.7	10.2	8.31	9.68
Mean	10.1	9.33	12.4	10.9	10.6
LSD (0.05) slope positions	0.594				
LSD (0.05) locations	0.644				
LSD (0.05) slope positions x locations	1.052				
Soil pH					
Upper slope	5.3	5.0	5.0	5.0	5.1
Middle slope	5.0	5.1	5.2	5.0	5.1
Lower slope	5.1	4.8	5.0	4.7	4.9
Mean	5.13	4.94	5.08	4.88	5.01
LSD (0.05) slope positions	0. 065				
LSD (0.05) locations	0.067				
LSD (0.05) slope positions x locations	0.110				
Total nitrogen (g/kg)					
Upper slope	1.31	0.79	1.06	0.92	1.02
Middle slope	1.87	1.1	1.57	0.93	1.37
Lower slope	1.19	1.07	1.24	2.1	1.4
Mean	1.46	0.99	1.29	1.32	1.26
LSD (0.05) slope positions	0.156				
LSD (0.05) locations	0.176				
LSD (0.05) slope positions x locations	0.285				
Cation exchange capacity (cmol/kg)					
Upper slope	22.2	10.7	14.6	19.5	17
Middle slope	25.7	9.2	23.5	14	18.1
Lower slope	12.5	14.8	20.1	11.3	14.7
Mean	20.2	11.6	19.4	15	16.5
LSD (0.05) slope positions	0.876				
LSD (0.05) locations	0.579				
LSD (0.05) slope positions x locations	1.093				

FCAI = Federal College of Agriculture Ishiagu; LSD = Least significant difference

Locations and slope positions interactions influenced SOC significantly. Differences in soil types (Table 1) and contrasting climatic conditions might contribute to the observed differences. Salako et al. (2006) reported no significant interaction effect between locations and slope positions on SOC. The results of the present study indicate that slope positions strongly affect C stabilization (Figure 1).

Our finding corroborates the report by Hancock et al. (2010), who found a strong and significant relationship between SOC and slope position. Variations in soil properties along toposequences has been reported (Hattar et al., 2010, Umali et al., 2006; Negasa et al., 2017). Across slope positions and locations, the soil pH ranged from from 4.7 (Ovumte, lower slope) to 5.3 (Amaeze, upper slope). Overall, upper and middle slope positions had higher mean pH than lower slope position (Table 3). Across the location, Amaeze had the highest ($p < 0.05$) mean pH value (5.13) while Ovumte had the lowest mean pH value (4.88). The variations in soil pH is linked to different land use practice and land management systems undertaken in the study areas.

The result corroborates the findings of Wilding (1985) and Ezeaku and Eze (2014), who reported that soil pH varies spatially within and across agriculture fields. Soil total nitrogen (TN) differ significantly ($p < 0.05$) across slope positions and locations (Table 3).

Except for Ovumte, middle slopes were associated with higher TN concentration than lower slope and upper slope. Overall, the upper slopes had lower ($p<0.05$) TN relative to other slope positions.

The significantly low TN associated with the upper slope can be attributed to the effect of runoff due to soil erosion which wash off soil nutrients and deposit eroded nutrients at watersheds (Aung et al., 2013; Dung et al., 2008, Pansak et al., 2008). Deposited sediments create patterns of spatial variability in soil fertility of downstream watershed (Gao et al., 2007; Mingzhou et al., 2007). Across the locations, Amaeze had highest (1.46) mean TN concentration while the fallow lowland had the lowest (0.99) TN concentration (Table 3).

The low TN in fallow is due to denitrification process that resulted from frequent bush burning. This result agrees with the submission of Ayeni (2010) who reported that N volatilization and denitrification affect soil TN. The interactions of the slope positions and locations were found to significantly ($p < 0.05$) affect the soil TN concentration (Table 3). There were significantly ($p < 0.05$) variations in the cation exchange capacity (CEC) across slope positions (Table 3).

The middle slope recorded the highest (18.10 cmol/kg) mean CEC while the lower slope had the lowest (14.7 cmol/kg) CEC. Across locations, Amaeze had the highest (20.2 cmol/kg) CEC followed by FCAI (19.4 cmol/kg) while the Fallow lowland had the lowest (11. 6 cmol/kg) CEC. Generally, the CEC in all these locations is within the range of moderate to low and high to low according to Landon (1991) and FAO (2006) standards respectively. The low CEC associated with the study locations suggests that the farmers do not apply adequate amount of organic manure to restoring the productivity the soil. Gachene et al. (2004) and Obalum et al. (2012) suggested that except gully cities, where urgent intervention may be needed, a cover cropping agronomic system can go a long way to conserving the "yet-to-be-degraded" soils.

CONCLUSION

Across the study locations, slope positions significantly affected the soil carbon stock due to the farming systems practiced by farmers in those locations. Significant differences in the chemical properties along slope positions (upper, middle and lower) were also observed. Soil pH and CEC were higher at the middle slope position; TN was significantly higher at lower slope position while SOC was significantly higher at upper slope position.

Overall, the study locations were associated with low SOC, CEC and soil nutrients. This suggests that the farmers do not apply sufficient amount of organic amendment, which is crucial to preventing soil erosion and nutrient losses, as well as enhancing crop productivity and improving the overall soil health.

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