

## EFFECT OF LAND USE IN RELATION TO SLOPE POSITION ON SOIL PROPERTIES IN A SEMI-HUMID NSUKKA AREA, SOUTHEASTERN NIGERIA

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### ABSTRACT

A study was carried out during 2011-12 in Department of Soil Science, University of Nsukka, Nigeria. The study assessed the influence of different land uses and slope positions on variability of some selected soil properties. Correlation between clay, dry bulk density, soil organic carbon (SOC) with slope and land use was highly significant ( $P < 0.001$ ). Clay content decreased downslope, increased in forest soil and with depth but silt-sand increased upslope. Soil bulk density increased with depth, upslope and cropped soil. Soil saturated hydraulic conductivity (Ks) was 48.4% less under footslope, decreased with depth and increased (42.9%) in fallow/grassland soil. Volumetric soil moisture under cultivated and fallow soils was significant ( $P < 0.05$ ). Soil total nitrogen, SOC and cation exchange capacity were significantly different ( $P < 0.05$ ) for different land uses. Soil available phosphorus value was statistically similar. However, all the soil property values were found statistically higher in forest soil than in soil of other land uses. Spatial analysis showed various relations between these soil properties, slope and land uses. No-till practices and ridge-furrow system were recommended to increase SOC for soil and water conservation. The study is useful for knowing the land use effect in relation to slope position on soil properties of Ukpabi-Nsukka located in semi-humid agro-ecology zone of Nigeria.

**KEYWORDS:** Land uses; soil properties; soil organic carbon; slope position; semi-humid; Nsukka; Nigeria.

### INTRODUCTION

Land degradation can largely be associated to variation in rainfall and a combination of multiple human activities like over-cultivation, deforestation, overgrazing and other land misuses (8). In Nsukka of southeastern Nigeria, the increase in population (220,411 in 1991 to 309,448 in 2006) and 2.4 percent annual increases in population density, which is approximately 639.4

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person per km<sup>2</sup> (1996 Census) (2). This increase in population is one of the acute factors exerting a profound influence on soil disturbance through uncontrolled human activities, which could cause some negative environmental changes such as rupture of lag cover, soil displacement, landscape disruption, vegetation deterioration, soil compaction (Al-Awadhi, 2001). Soil fertility is lost due to over-cultivation of land for increased production of food, fibre, fuel wood and feeds for the growing population (8). The fore-going raises concern about the human impact on productivity and deteriorating soil quality.

Soil properties vary in fields and the study, both vertically and horizontally (33). The variations in soil properties influences soil productivity. For instance soil bulk density, which is a reflection of amount of pore spaces in the soil, influences soil productivity through favorable physical conditions such as optimal aeration, permeability and water-holding capacity (3). Similarly, soil hydraulic conductivity is arguably one of the most important hydrologic properties of soils that influence soil productivity.

Soil organic carbon (SOC) is a key indicator of soil quality and overall soil productivity (10). It increases cation exchange capacity (CEC), aggregation, water retention and overall soil health (14). Cation exchange capacity (CEC) enhances the buffering capacity of soil, and improves biological activities, while soil total nitrogen (STN) and soil available phosphorus (SAP) are closely related to soil productivity (32).

Parent material, climate and geological history are major factors affecting the distribution of soil properties at continental scale (18), whereas land use, land use history and topography are the dominant controls at smaller scale such as catchment scale (9). In field experiments, Jimenez *et al.* (12) reported that bulk density and saturated soil hydraulic conductivity of soils are influenced by land use type, vegetation (including plant and litter cover and type), topographic and climatic conditions.

In a related study (34) on land use conversions, found that converting grassland to cropland resulted in significant soil degradation through loss of fine soil particles, moisture status, SOC and nutrients. In addition, Wang *et al.* (32) reported that SOC, STN and soil phosphorus varied with topography in terms of slope and elevation. According to Mulla and McBratney (20), variability in soil properties at series level is often caused by changes in topography that affect the transport and storage of water across and within the soil depth.

According to Mbagwu (17), the toposequences are heterogeneous in morphology (physiography), soil type, vegetation, hydrology and agronomic practices.

Soil landscape relationships due to anthropogenic and natural activities can influence the properties of soils through the summits to the foot slopes, and in most cases soil organic matter (SOM) and nutrient reserves are affected. Thus, soil properties (morphological, physical and chemical) and potentials for crop production often vary among landscape position and with depth which potentially limit crop production.

Evaluation report of changes in soil properties and productivity along a toposequence has been made elsewhere (19), but the effects of slope position on soil fertility variables under different land use types in Ukpabi-Nsukka, Nigeria have not received the desired research attention. Since soil varies considerably from place to place and its characterization is fundamental to the understanding of soil-landscape processes, a study to detect changes in soil fertility parameters as influenced by the land uses and slope position in the area becomes quite important as it can serve as a basis for planning management strategies to achieve higher agricultural productivity and better environmental quality. The importance of topographic consideration in land evaluation as the process of prediction of land performances has been emphasized by Rossiten (27). The objective of the present study was to assess variations in some soil properties of Ukpabi-Nsukka located in semi-humid savanna agro-ecology of Nigeria as affected by slope position and land uses.

## **MATERIALS AND METHODS**

**Study site:** The study site was in Ukpabi-Nsukka a major farming community located 06°52'N, 07°24'E on an elevation of 400 m above sea level in southeastern Nigeria. The area is characterized by a semi-humid tropical climate with wet (April- October) and having dry (November-March) seasons, and a mean annual rainfall of 1750 mm bimodally distributed with peaks in July and September; mean annual maximum (day) and minimum (night) temperatures of 31°C and 21°C, respectively (23). The relative humidity ranges between 70 and 80% during the short harmattan period (between December and January) when temperature falls below 22°C (23).

The soils are mixtures of soil types ranging from ferrallitic soils, also called red earth or acid sands, found on the toeslope and plateau to the hydromorphic soils on the floodplains (3). Ultisols, Alfisols and Entisols make

up the total area of Nsukka soils and are located at the crest (summit), toe slope and valley bottoms of a toposequence (17).

Dominant vegetation is derived savanna, mixtures of shrubs and grass species such as African star grass (*Cynodon nlemfluensis* and *C. plectostachyus*), Bahia grass (*Paspalum notatum*), Green couch (*Cynodon dactylon*), Elephant grass (*Pennisetum purpureum*), Gamba grass (*Andropogon gayanus*), Guinea grass (*Panicum maximum*), Para grass (*Brachiaria mutica*), Setaria (*Setaria sphacelata*) and Bunge needlegrass (*Stipa bungeana*) are the main species under fallow.

**Soil sampling and measurements:** Soil variability was estimated employing discrete sampling during 2011 and 2012 crop years. A total of 200 topsoil samples were collected. The soil samples were stratified by soil types, land use, as well as a thorough coverage of study site. The study area was firstly divided into sub-regions according to soil types along the toposequence: upper slope (crest), middle slope (hillslope) and valley floor (flood plain) (20). Soil samples were randomly collected in each crop year, with a core at predetermined depths (0-20 and 20-40 cm) along the toposequence, and the chosen land uses (cropland, grassland/fallow and forest). The choice of location and depth was based on assumption that soil properties vary among landscape position and with depth which could potentially limit crop production. Soil core samples collected were analysed for particle size distribution, other physical and chemical analyses for each crop year. Average soil data for two crop years was used for interpretation.

The soil samples were air dried and passed through 2 mm sieve. Particle size distribution was determined by hydrometer method (18), bulk density as described by Blake and Hartge (5). Volumetric soil moisture contents were calculated from the ratio of gravimetric moisture content (%) and dry bulk density to the density of water. Soil saturated hydraulic conductivity ( $K_s$ ) determination was based on method by Klute and Dirksen (13) and was calculated as:

$$K_s = (Q/At) (L/DH);$$

Where,  $K_s$  = saturated hydraulic conductivity (cm/hr),  $Q$  = steady state volume of outflow from the entire soil column ( $\text{cm}^3$ ),  $A$  = cross-sectional area ( $\text{cm}^2$ ),  $t$  = time interval (hr),  $L$  = length of sample (cm), and  $DH$  = change in the hydraulic head (cm).

Less than 0.25 mm fraction was used for SOC, STN, and SAP analysis. Soil organic carbon was determined by wet oxidation method (21). Soil total nitrogen (STN) was determined by using Macro Kjeldahl method (6), while soil available phosphorus (SAP) was assayed by Bray P-II method (24). SAP was determined instead of total phosphorus because of its benefit in agronomic studies. Cation exchange capacity (CEC) was determined by the procedures described by Rhoades (26).

Range and coefficient of variation (CV) were used as measures of spread about the mean. The range is difference between maximum and minimum, while CV gives a normalized measure of spread about the mean and was estimated using following equation.

$$CV = \frac{S}{Z} \times 100\%$$

Where; S = standard deviation (square root of the sample variance)  
Z = is the number of measured values

Wilding (33) described a classification scheme for identifying the extent of variability for soil properties based on their CV values, in which CV values of 0-15, 16-35 and > 36 % indicate low, moderate and high variability, respectively.

**Statistical analysis:** Two-way analysis of variance was used to determine the effect of land use on soil quality indicators and LSD test was used for multiple comparison of means. All the analyses was performed with SPSS16.0 (SPSS Inc., Chicago, USA). The least significant difference ( $LSD_{0.05}$ ) was used for mean separation when the analysis of variance showed statistically significant differences ( $P < 0.05$ ) between the investigated properties. Pearson's correlation was also employed to evaluate the relationships between dry bulk density and soil organic carbon.

## **RESULTS AND DISCUSSION**

### **Soil physical indicators in relation to land use and slope position**

The data in Tables 1 and 2 shows variability in cultivated soils and toposequence. Particle size fraction (Table 1) varied within the various land uses. Silt fraction was not significantly different in all the study land uses, whereas sand contents in forest (58.3%) and fallow/grassland (61.24%) were similar but significantly different under cultivation land use ( $P < 0.05$ ). Clay fraction in the forest was 48 % significantly higher when compared to soils

under cultivation and 13% higher than clay fraction in fallow/grassland but this was not significantly different ( $P < 0.05$ ).

**Table 1. Particle size distribution, bulk density, saturated soil hydraulic conductivity and mean volumetric soil water content at 0–20 cm for various land uses.**

Soil variables	Land use types		
	Forest	Fallow/grassland	Cultivation
Sand (%)	58.31± 1.57 a	61.24±1.38 a	63.22±1.20 b
Silt (%)	18.40±1.03a	18.42±1.07 a	24.62±1.24 a
Clay (%)	23.29± 1.04a	20.34±0.64 a	12.16±1.52 b
DBD(g cm <sup>-3</sup> )	1.19±0.06a	1.42±1.22 b	1.36±0.28 a
Ks (Cmhr <sup>-1</sup> )	2.46±0.08b	4.31±0.03 a	3.24±0.05 a
VSM(m <sup>3</sup> /m <sup>3</sup> )	26.82±1.04a	15.63±0.86 b	14.29±0.57 b

DBD = soil dry bulk density, Ks = soil saturated hydraulic conductivity, VSM = volumetric soil moisture. For each row, values followed by small letters are significantly different for  $P < 0.05$  using the LSD method.

Data in Table 2 shows that overall, clay content was significantly ( $P < 0.05$ ) less (7.4 %) in upper as compared with mid (10.2 %) and lower (24.3 %) slope positions, indicating clay increase down slope. McLauchlan (18) reported that increased clay content downslope means deposition from upland areas (upper slope position) into lower slope position is due to water erosion with precipitation event. Sand content showed opposite trend to clay, which was found higher (70%) at upland compared to footslope (52 %). Increased clay content at downslope deposited from the upland areas, culminating into enrichment of lowland slopes is an indication of influence of slope position on soil texture which may be caused by soil erosion as precipitation event.

Soil bulk density is an important factor for root growth, development and proliferation. Dry bulk density found under fallow/grassland soil was 16.2 % higher when compared to forest soil (Table 1). This may be associated to low root density and organic matter accumulation (15). Mean DBD values obtained from forest and cultivated soils and across the slopes (Tables 1 & 2) are below the critical minimum value (1.5Mgm<sup>-3</sup>) capable of enhancing crop root growth and development (4).

Difference in soil saturated hydraulic conductivity (Ks) obtained under fallow/grassland and forest was significant ( $P < 0.05$ ) and may be due to channeling and loosening effect of roots on Ks (Table 1). Similarly, results in Table 2 show that soil Ks was most rapid upslope (4.50 cm/hr) but fell considerably under lowslope (2.32 cm/hr) representing 48.8 % increase in the former as compared to the latter. The reduction in soil Ks may be attributed

to clay accumulation and siltation of the available pores open for Ks, hence losses in macro pore space and consequently, an increase in surface runoff (1, 30).

Table 2. Mean variation of soil properties in relation to slope position.

Soil variables	Physiographic unit		
	Upslope	Mid slope	Foot slope
Sand (%)	70.24±1.38 a	67.22±2.11 a	52.31±1.46 a
Silt (%)	23.32±1.07 a	22.62±1.24 a	23.40±1.03 a
Clay (%)	7.44±0.64 b	10.16±1.52 b	24.29±1.04 a
DBD(g cm <sup>-3</sup> )	1.44 ±1.22 b	1.30±0.28 a	1.20 ±0.06 a
Ks (Cmhr <sup>-1</sup> )	4.50±0.03 a	3.53±0.05 a	2.32±0.08 c
VSM(m <sup>3</sup> /m <sup>3</sup> )	17.93±1.29 a	18.49±1.37 a	18.32±1.33 a

Note: DBD = dry bulk density, Ks = saturated hydraulic conductivity, VSM = volumetric soil moisture. Mean values followed by the same letter (s) for each parameter within the same slope position is not statistically different at P = 0.05 level.

The soil moisture content (VSM) in the forest soil was on average twice as high as in cultivation and fallow/grassland areas (Table 1). Mean VSM under cultivated (46.7%) and fallow/grassland (41.7%) were significantly less than under forest. High VSM in forest soil is a reflection of its higher water retention capability. Reverse was the case for cultivated and fallow/grassland soils. In terms of slope position, moisture content increased downslope (Table 2).

### Soil chemical indicators in relation to land use and topography

Analysis of variance (ANOVA) showed a significant effect of land use on SOC, STN, SAP and CEC for each sampling depth for land use (Table 3). For land uses, the overall mean values of all SOC and STN tended to decrease with increasing depth. The overall mean SOC value in 20-40 cm depth was 19% lower than the value of 5.52 g/kg for 0-20 cm depth. Corresponding value for STN, SAP and CEC were 5.43, 37.0 and 27.64 g/kg with respective percent values of 31.7, 3.24 and 7.13. The results showed that overall means for SAP and CEC did not change markedly with depth.

Summation of the values of soil quality indicators (Table 3) on depth basis (0-40 cm) showed that highest SOC content (4.53 g/kg) was detected in forest soil and the lowest value (2.32 g/kg) was in cropland. Fallow/grassland showed higher SOC values than cropland but lower values than forest for different depths, which was consistent with the results of Fang *et al.* and Hertemink *et al.* (9, 11).

Table 3. Soil organic carbon, soil total nitrogen, soil available phosphorus, cation exchange capacity at 0-40 cm for various land uses.

Soil quality/depth	Cropland	Fallow/grassland	Forest	CV(%)
<b>SOC (g/kg)</b>				
0-20 cm	1.20±0.11 c	1.86±0.05ab	2.46±0.02 a	28
20-40 cm	1.14 ±0.30 b	1.26 ± 0.02b	2.07 ±0.08 a	28
<b>STN (g/kg)</b>				
0-20 cm	0.92 ±0.004 b	1.24 ±0.002 ab	3.27 ±0.06a	58
20-40 cm	0.68± 0.006 b	0.84±0.004 b	2.19±0.001b	54
<b>SAP (mg/kg)</b>				
0-20 cm	7.2 ±1.2 a	12.20 ±0.35 a	17.60 ±0.40a	34
20-40 cm	7.0 ±0.30 a	11.90 ± 0.29 a	16.90 ±0.26 a	34
<b>CEC (Cmol/kg)</b>				
0-20 cm	6.11±0.36 b	8.26±0.24 a	13.27±0.17 a	32
20-40 cm	5.83±0.30 b	7.44±0.43 b	12.40±0.32 a	32
	<b>Upland</b>	<b>Midslope</b>	<b>Lowland</b>	
SOC	1.52± 0.02c	1.35±0.13 c	3.74±0.19a	49
STN	0.93± 0.18 b	0.70±0.13 c	2.20±0.18 a	51
SAP	9.51±0.07 a	6.48± 0.22 b	16.18±0.11 a	38
CEC	8.22 ±0.02b	7.12± 0.03 b	14.26±0.14 a	32

NB: SOC = soil organic carbon, STN = soil total nitrogen, SAP = soil available phosphorus, CEC = cation exchange capacity. For each row, values followed by small letters are significantly different for  $P < 0.05$

Consistently low value of SOC and STN in arable site study when compared with other land uses may be due to frequent soil erosion phenomena, and intensive human disturbance through inversion and pulverization of soil during tillage that makes for accelerated mineralization of exposed organic matter. Similar report has been made elsewhere in Nigeria (22), USA (28), Germany (29) and Argentina (31). In addition, farmers apply very little fertilizer to their crops. The relatively low vegetative cover, especially at the upper and mid-slope, may also account for low contents of SOC and STN.

On the other hand, relatively high vegetation coverage and thick litter fall and animal tissue in the forest are helpful to reduce soil erosion and accumulate SOC, STN, SAP and CEC as revealed in this study (Table 3). This is in accordance with previous findings (9, 32).

Soil CEC has been classified as low (<6 Cmol/kg), medium (6-12 Cmol/kg) and high (>12 cmol/kg) for some Nigerian soils (25). On the basis of this classification, mean CEC (0-40 cm soil depth) for cultivated and fallow/grassland soils was, respectively, low (5.97 cmol/kg) and medium (7.85 cmol/kg), while that of forest land use was high (>12 cmol/kg). Decrease in CEC suggests decrease in buffering capacity and is a cause for concern as the fallow/grassland and cultivated land use types with low to medium CEC can be catalogued as unsustainable land use due to reduction in biological activities that could adversely affect productivity of soils (14).

The results for all sampling locations along slope (Table 3) showed that SOC significantly ( $P < 0.05$ ) decreased 63.9 % under midslope and 59.4 % at the crest when compared with lowerslope. Increased SOC at lowerslope may be due to organic matter accumulation resulting from litter falls. This finding is synonymous with related studies (7, 16) that found SOC content increasing with slope because of the stronger soil erosion at higher slopes.

On the other hand, relatively higher SOC (11.2 %) at the uplands than midslope position may be due to its flatness. Li *et al.*, (15) reported that SOC may be a direct product of mineralization rates rather than being more strongly related to material deposited and eroded due to enhanced erosion process on disturbed hill slope.

The mean value of STN was significantly ( $P < 0.05$ ) lower in upland (59.4%) and midslope (57.7%) than lowerslope (Table 3). Mean SAP was 41.2 and 31.9 percent higher in lowland relative to upland and midslope, suggesting that SAP increased downslope. This finding accords earlier report (32). However, Fang *et al.* (9) found weak relations between elevation and SOC. Mean CEC increased downslope and was 42.4 percent higher in lowerslope than upslope.

**Table 4. Two-way ANOVA results for mean soil properties in relation to slope position, land use types and soil depths.**

Source of variations	d.f.	Sand % P	Silt % P	Clay % P	DBD P	VSM P	SOC P
Block (B)	2	Ns	Ns	<0.001	<0.001	Ns	<0.001
Land use (LU)	2	0.008	Ns	<0.001	<0.001	<0.001	<0.001
Depth (D)	2	<0.001	Ns	<0.001	<0.001	0.062	<0.001
B x LU	4	<0.001	Ns	<0.001	<0.001	0.048	<0.001
B x D	4	Ns	Ns	Ns	Ns	Ns	0.052
LU x D	4	Ns	Ns	0.041	Ns	<0.001	Ns
B x LU x D	8	Ns	Ns	Ns	Ns	Ns	Ns
Error	80						

NB DBD= dry bulk density ( $\text{g.cm}^{-3}$ ), VSM= volumetric soil moisture, SOC= soil organic carbon, Ns= non significant, P= probability.

Highly significant ( $P < 0.001$ ) difference in clay content, dry bulk density and SOC with slope position, land use and soil depth was observed. The combination of land use and soil depth also had a significant interactive effect on soil moisture. Low SOC content of arable soil could partly be responsible for the larger dry bulk density observed and is evidenced by highly significant ( $r = 0.89, P < 0.001$ ) Pearson’s correlation between SOC and bulk density.

The soil properties differ in their degree of variability with land use and slope position. All the soil quality indicators (SQIs) in various land uses except STN were moderately variable but did not vary with depth (Table 3). When

compared with other soil qualities, overall value of STN was highly variable (CV>35%) following Wilding (33) classification scheme. STN varied most (CV % = 51) and CEC the least (CV% = 32) at slope positions. Moderate to high variability of SQIs obtained on slope positions may be due to random method of soil sampling employed in the study.

Land use and slope affect the relations between soil properties. Pearson coefficients of interaction between land use and slope position to soil properties (0-20 cm depth) revealed that overall degree of correlations is highly dependent on environmental variables (Table 4).

### CONCLUSION

On the basis of above results and analysis, the following are conclusions:

i) Differences in soil physical properties in relation to cultivation and fallow were mainly due to land use as the interaction resulted in a decrease in Ks by 43%. A larger proportion of precipitation may thus have formed surface runoff under cultivation and fallow, resulting in 47 and 42% lower values of soil moisture content, respectively than under forest.

ii) Soil organic carbon, STN, and CEC were significantly different ( $P<0.05$ ) for different land uses. Reverse was the case for SAP. Forest soil indicated the highest values for these soil properties, whereas cultivation-induced losses occurred in cropland reflecting relatively low values. Fallow showed lower SAP relative to forest, suggesting that vegetation restoration had little effect on SAP. Overall, this study shows that soil quality indicators can be used to monitor long-term changes effectively.

iii) Different degrees of variability of soil properties were observed. All the soil properties (SOC, STN, SAP and CEC) increased downslope. However, their relations varied with land uses and slope position. Interaction between land use types, depth and slope position showed significant effects as depicted by the correlation coefficients.

Therefore in the upland-inland continuum of Ukpabi-Nsukka location, greater land use management is required in the form of no-till or reduced tillage practices. Together with short term vegetation restoration (4-9 years after cessation of cultivation disturbances), SOC and STN contents, especially, in the soils of cropland would increase. Increase in residue return, less mixing and less soil disturbance ensures reduced soil erosion, higher moisture control and bio-activity and increased soil productivity.

Given that coefficient of variation of most of the soil quality indicators were moderate to high on the slope position, bulking of randomly sampled soil to obtain a composite sample should be avoided rather a rigid grid sampling method should be adopted. Again, uniform soil management practices should be discouraged and instead; soil management should be location specific. Practical application of ridge-furrow system is needed in the poorly drained lowland soil to increase its effective root volume, and in upland and midslope soils with nutrient deficiency for nutrient and water conservation.

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