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# Impact of toposequence on soil properties and classification in Zaria, Kaduna State, northern Guinea Savanna, Nigeria

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## Abstract

Topography plays a major role in the variation of soil properties and nutrient distribution along a non-uniform agricultural landscape. As a result of this, there is a need for sound soil variability knowledge for sustainable agricultural production especially in farmlands with different slope classes. This study aim at assessing the influence of topography on soil properties and classification on a toposequence in Gabari, Zaria. Four pedons were dug across the physiographic positions (crest, upper, middle and valley bottom), soil samples collected from the genetic horizon of the pedons were analyzed using standard procedures. The soil colour varies from dark yellowish-brown, strong brown to yellowish-brown. Sand-dominated the mineral fraction with valley bottom recording the highest value (61%). Clay content increases with depth except in the valley bottom. The soils were slightly acidic to neutral in reaction (6.5–6.9), organic carbon (3.1-4.4 g kg-1), total nitrogen (0.1-0.2 g $kg^{-1}$) and available phosphorus (1.9 - 4.14 mg $kg^{-1}$) were rated low. The soils have moderately inherent natural fertility with moderately exchangeable basic cations (Ca, Mg, K, and Na). Cation exchange capacity (7.3–9.7 cmol (+) $kg^{-1}$) was moderate while the base saturation (55-79%) suggests the soil to be fertile being >50%. Among all the soil properties, sand, silt, available phosphorus and exchangeable acidity were significantly ($P<0.05$) different across the toposequence. Toposequence also influences the soil types (Alfisols, Inceptisols and Entisols) with their classification varying from Typic Plinthustalf/Eutric Lixisols on the crest to Fluvaquentic Epiaquepts/Endoeutric Fluvisol on the valley bottom based on USDA Soil Taxonomy and World Reference Base 2014.

**Keywords**
*Soil Properties, Toposequence, Classification, Northern Guinea savanna*

## Introduction

African soils are characterized by rolling topography and soil properties changes due to the factor of slope which plays a vital role in influencing soil properties as one moves from crest position down to the valley bottom (Egbuchua, 2014). Apart from parent material and climate, topography is another important factor that plays important roles in the distribution of soil minerals. Topography/relief determines the drainage and depth of a soil profile; for instance, soils on higher elevation are usually well-drained whereas soil on the lower slope is usually poorly drained and of fined texture (Atofarati *et al.*, 2012). Further, topography influences drainage, soil erosion, textural composition and other soil properties that affect crop development and productivity (Atofarati *et al.*, 2012). Soils on a hill or steep slope are usually very shallow and gravelly due to minimal rate of weathering and removal of soil by erosion while soil on a gentle slope allows ample infiltration of water and develops into deep profile (Esu, 2010).

Topography of a landscape can influence soil physicochemical properties, biomass production, incoming solar radiation, precipitation and affect crop

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production. As topography gradually increases down the slope, there is a significant increase in soil moisture, soil organic carbon while bulk density, pH and soil temperature would be significantly lower at the higher elevations (Nahusenay and Kibebew, 2016). Glassman *et al*. (1980), as cited in Lawal *et al.* (2014) states that water velocity on a slope affect the deposition of materials in suspension, sand drops out of suspension first, while clay size particles can be carried further away from the upland before they are deposited on the floodplains. This process of geological sorting of suspended soil materials as they travel along a slope brings about variations in soil texture as we move from upland to lowland. Normally, topography influences morphological, chemical and physical properties of soil. In essence, topography affects the pattern of soil distribution over landscape even when the soils are derived from the same parent material (Esu *et al.,* 2008). This gives rise to a succession of soil types, known as a catena from the hilltop to the valley bottom (Milne, 1935 cited in Ewato and Enaruvbe, 2010).

The catenary differentiation of soils is of pivotal importance to the management of soils in different topographic positions in the landscape. Consequently, understanding the roles of topography in a landscape will help in assessing productive values of soils and most importantly, in developing strategies for its conservation and reducing uniform soil management which could result to uneven distribution of input in an agricultural field situated on a topography (Oku *et al.,* 2010).

The physical features around Zaria, Northern Nigeria, consist mainly of gently undulating high plains developed on basement complex rocks. Predominantly, soils developed on basement complex rocks of Zaria, have impervious subsurface horizons due to plinthization processes (Odunze and Kureh, 2009; Jimoh *et al.*, 2016). The plinthites do limit vertical water flow and encourage the horizontal flow of water in soils. This phenomenon may affect the distribution of soil properties in a predominantly rolling landscape of Zaria. Studies on soil-landscape relationships in the rolling terrain around Zaria, Nigeria are rare. Therefore, this study was undertaken to assess the effect of topography on soil properties, classification, and management implication of soils of a toposequence in Zaria.

## Materials and methods

### Study area

The study area was located in Zaria, Northern Nigeria, ($11^0 06'50''$N - $7^0 40'22''$E) characterize by Northern Guinea Savanna vegetation type (Figure 1). The growing periods are between 150-180 days (Abaje *et al.,* 2012). Zaria lies within a region that has a tropical Savanna climate type with distinct wet and dry seasons (Abaje *et al.,* 2012). It is characterized by a long dry season from November through March, while the wet season lasts from April to October with a mean annual rainfall of 1100mm. The temperature fluctuates within a range of $22^0$C during cold nights to over $38^0$C during the hot days. The relative humidity during the dry season is about 25 - 30 % and reaches up to 70 – 90 % during the rainy season (Abaje *et al.*, 2015). Most of the arable land consists of well-drained upland with flat or slightly undulating topography, which supports one growing season under rainfall conditions. Geologically the area lies within the high plains of Northern Nigeria characterized by landforms which consist of inselbergs and pediment landscape overlying the basement complex which are nearly level to gently undulating plains and belongs to the older granite group of proterozoic age (Bennet et al, 1977).

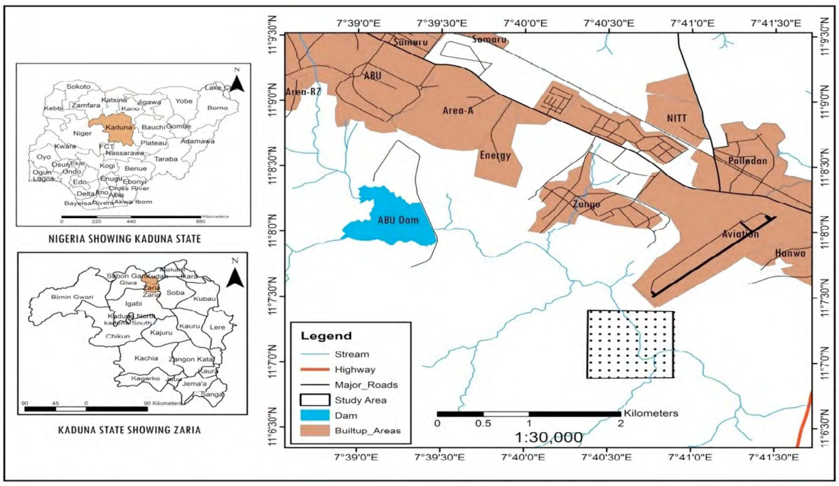


**Figure 1.** *Zaria showing the study area.*

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**Field work**

In this study, a sloping portion of an arable plantation, adjoining River Kubanni, was selected for the purpose of evaluating the impact of topography on soil morphological, physical, chemical properties and classification. Differentiation of soils along a catena is most marked along transects running from the crest of the interfluve to the valley bottom (Gerrard, 1981). Along the dominant slope, the study site was partitioned into four, designated as the crest, upper, middle slope and valley bottom. In each segment, a representative profile pit was dug and described according to Food and Agriculture Organization (FAO) guidelines for soil profile descriptions (FAO, 2014). Soil samples were collected from natural horizons for laboratory analysis. Soil samples for bulk density determination were collected using the soil core method.

**Laboratory analyses**

The sampled soils were air-dried, ground and sieved through a 2mm sieve, less than 2mm fractions were used for laboratory analysis. Particle size distribution was determined by the hydrometer method (Gee and Bauder, 1979). Bulk density was determined using the core sampler (Blake and Hartge, 1986). Soil pH was measured in water (1:2.5 w/v) using a glass electrode pH meter. Organic carbon was determined by the dichromate wet oxidation method of Walkley and Black (Nelson and Sommers, 1982). The cation exchange capacity (CEC) was determined by saturating the soil with a normal neutral ammonium acetate solution (Rhodes, 1982). Base saturation was calculated as the sum of total exchangeable bases divided by cation exchange capacity. Available P was determined using Bray 1 method (IITA, 1979). Total N was determined by the kjeldahl method (Bremner and Malvaney, 1982). Exchangeable bases (calcium, magnesium, potassium, and sodium) in the soil were determined using the ammonium acetate extract from the CEC determination. Sodium and potassium in the extract were determined using flame photometer, while Ca and Mg were determined using atomic absorption spectrometer.

**Statistical Analysis**

Topographic positions and soil depths were considered as main factors. The various data on soil physical and chemical parameters were subjected to two-way analysis of variation (ANOVA) using the general linear model (GLM) procedure of statistical package for social science (SPSS) software, version 23 (SPSS, 2015) to find out whether variations in the soil properties among topographic positions and soils depth were significant or not. The mean comparison was done using Duncan multiple range tests at $P < 0.05$ significant level.

**Results and Discussion**

**Topography and soil depth effects on soil morphological properties**

Results on morphological properties of the soils are shown in Table 1. The crest was characterized by Dark yellowish brown (10YR4/4 wet) at Ap horizon which is underlain by Strong brown (7.5YR 5/6) at subsoil. The upper slope colour varied from Strong brown (10YR 5/8) at the surface to very pale brown (10YR 7/4) at the subsoil. The middle slope varied from Brown (10YR 5/3) on Ap horizon to Light gray-brown (10YR 6/2) in the subsoils. The valley bottom colour varied from yellowish-brown (10YR 5/4) on the surface to Dark yellowish brown (10YR 4/6) at subsoil. The change in colour from brown to gray colour was due to poor drainage. The Ap of all the soils horizons were mottled-free implying that the surface horizon was well-drained while the presence of mottles at Bt horizon in the crest and middle slope may be attributed to poor internal drainage condition as a result of plinthite at a lower depth. The crest, upper slope were well-drained while the middle slope and valley bottom was imperfect to poorly drain respectively. Soils in the lower topographic locations are not only characterized by lower slope angles, on account of which they hold a greater quantity of water than higher slope soil (Lopez *et al.,* 2003), they are also saturated with moisture for a much longer period than upper slope soils. The crest and middle slopes were deep and had weak subangular blocky, slightly sticky and slightly plastic consistence, on the surface to moderate angular blocky, very sticky, very plastic and structureless (massive) in the subsoil. The upper slope was moderately deep with weak subangular blocky, slightly sticky and slightly plastic which could be a result of the steep slope which experiences constant erosion. The valley bottom was also deep, structureless (single grain) with non-sticky, non-plastic consistence on the surface to structureless (massive) very sticky, very plastic and structureless (single grain) with non-sticky, non-plastic in the subsoils.

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| Horizon | Depth (cm) | Munsell colour (moist) | Structure | Consistence | Sand | Silt | Clay | Textural Class | Bulk Density (g cm$^{-3}$) | Silt/Clay ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | (g kg$^{-1}$) | | | | | |
| | | **Crest** | | | | | | | | |
| | Latitude | N11 06 57 | Longitude | E7 40.28 | Elevation 640.00m | | | | | |
| Ap | 0 – 21 | 10YR4/4 | Wfsbk | Sssp | 430 | 460 | 110 | Loam | 1.59 | 4.18 |
| Bt1 | 21 – 114 | 7.5YR5/6 | Mmsbk | Sssp | 410 | 380 | 210 | Loam | 1.45 | 1.81 |
| Bt2cv | 114 -140 | 10YR6/6 | Mmabk | Vsvp | 410 | 340 | 250 | Loam | 1.56 | 1.36 |
| | | **Upper Slope** | | | | | | | | |
| | Latitude | N11 07 0 | Longitude | E7 40 40 | Elevation 624.00m | | | | | |
| Ap | 0 – 40 | 10YR5/4 | Sg | Nsnp | 410 | 500 | 90 | Loam | 1.3 | 5.56 |
| Bt | 40 – 120 | 10YR6/2 | Ma | Sssp | 510 | 280 | 210 | Sandy Clay Loam | 1.54 | 1.33 |
| | | **Middle Slope** | | | | | | | | |
| | Latitude | N11 07 19 | Longitude | E7 40 30 | Elevation 625.00m | | | | | |
| Ap | 0 – 27 | 10YR5/3 | Wfsbk | Sssp | 310 | 500 | 190 | Loam | 1.56 | 2.63 |
| Bt1 | 27 -75 | 10YR4/3 | Mmabk | Sssp | 310 | 500 | 190 | Loam | 1.51 | 2.63 |
| Bt2 | 75 – 148 | 10YR5/4 | Ma | Sssp | 210 | 560 | 230 | Silt Loam | 1.36 | 2.43 |
| Bt3c | 148 – 165 | 10YR6/2 | Ma | Vsvp | 410 | 400 | 190 | Loam | 1.71 | 2.11 |
| | | **Valley Bottom** | | | | | | | | |
| | Latitude | N11 07 03 | Longitude | E7 40.42 | Elevation 621.00m | | | | | |
| Ap | 0 – 25 | 10YR5/4 | Sg | Nsnp | 620 | 280 | 100 | Sandy Loam | 1.67 | 2.80 |
| Bt1 | 25 – 36 | 10YR4/4 | Sg | Nsnp | 630 | 260 | 110 | Sandy Loam | 1.44 | 2.36 |
| Bt2 | 36 – 58 | 10YR4/6 | Sg | Nsnp | 610 | 280 | 110 | Sandy Loam | 1.44 | 2.55 |
| 2Bt1 | 58 – 90 | 10YR4/6 | Ma | Sssp | 710 | 100 | 190 | Sandy Loam | 1.35 | 0.53 |
| 2Bt2 | 90 – 135 | 10YR5/3 | Ma | Vsvp | 350 | 460 | 190 | Loam | 1.45 | 2.42 |
| 2Cr | 135 – 145 | 10YR4/6 | Sg | Nsnp | 710 | 200 | 90 | Sandy Loam | 1.41 | 2.22 |

**Legend**
Horizon: Ap=plough layer, Bt=B horizon with silicate clay, C=C horizon, v =plinthite c= concretion
Structure: Wfsbk = Weak, fine, sub angular blocky, Mmabk=Medium moderate angular blocky, Scabk=strong coarse angular blocky Ma = massive, Sg=single grain
Consistence Wet: vs = very sticky, Ss = slightly sticky, s= sticky, and ns = non sticky
Plasticity: vp= very plastic, sp= slightly plastic, p= slightly plastic, np= non plastic.

**Table 1.** *Soil morphological and physical properties of Zaria toposequence.*

Generally, the crest and middle slope have well-developed profile as evidenced with clay accumulation at lower depth while the upper slope and valley bottom soils are weakly developed due to constant surface wash on the upper slope leading to moderately deep soils while in some cases shallow soils and deposition of material which distort soil development in the valley bottom because the materials deposited are not structurally developed before another will be deposited.

**Topography and soil depth effects on soil physical properties**

The mean value of sand fraction was irregularly distributed most especially in the valley bottom which may be attributed to irregular deposition of material on the unit (Table 1). The trend of distribution was in the following order, valley bottom > upper slope > crest > middle slope, probably due to the effect of slope which accelerated the movement of sand particles by run-off water, wind, and gravity. The valley floor

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was significantly higher (*P<0.001*) in the sand among all the four units (Table 3). According to (Esu *et al.,* 2008), topography has an influence on the pattern of soil distribution over the landscape. The mean value of silt decrease with depth in the crest, upper slope, middle slope and valley bottom, though the difference was not significant. The middle slope was significantly higher (*P<0.05*) in the silt content among all the four units. The clay contents generally increase with depth in all the geomorphic units which suggest eluviation and translocation of clay from top to subsoil and the subsoils were significantly higher (*P<0.05*) than topsoils. Middle slope means clay value was significantly higher (*P<0.05*) along the toposequence. Generally, sand dominates the particle size fraction of the soils followed by silt then clay similar results have been reported by Malgwi *et al.* (2000) and Odunze and Kureh (2009) in their works within the Zaria region. High sand fractions in the surface soils reflect the granitic origin of the parent materials (Wilson, 2010).

The soil texture varied from loam on the crest, upper and middle slope to sandy loam on the valley bottom. The result shows that sand and silt varied significantly (*P<0.05*) within the topography and clay content varied significantly (*P<0.05*) with soil depth. This result is in line with the report of Nahusenay and Kibebew (2016) who reported that there is a significant difference in particle size due to the effects of land use and soil depth in highlands of Ethiopia. The mean value of bulk density varies between 1.53 g $cm^{-3}$ to 1.46 g $cm^{-3}$. Plants perform best in bulk densities below 1.4 g $cm^{-3}$ and 1.6 g $cm^{-3}$ for clayey and sandy soil respectively (Miller and Donahue, 1990). The bulk density generally decreases with an increase in profile depth over the crest, middle slope, and valley bottom while it increases with depth over the upper slope position. There was no significant difference in the bulk density along the toposequence and between the surface and subsoils.

Bulk density value was less than 1.60 g $cm^{-3}$, thus rated medium, a range considered not to impede root penetration (Donahue *et al.,* 1990; Odunze, 2006), which indicates that air and water movement in the soils are optimum for plant growth and development (Esu, 2010). However, the bulk density values of all the soils will support crop growth and development. The mean value of silt clay ratio was higher than 1.5. Older parent materials are reported to have a silt/clay ratio below 0.15 while silt/clay ratios above 0.15 are indicative of younger parent materials (Van Wambeke, 1962). The results of this study show that all the geomorphic units have silt/clay ratio above 0.15 indicating that the soils are relatively young with a high degree of weathering potential. Silt/clay ratios are relatively higher in the surface horizons and decrease with increased depth in the pedons, though the difference was not significant. The decrease in silt/clay ratio with incease in soil depth is an indication that subsoils horizons are more weathered than top soils.

**Topography and soil depth effects on soil chemical properties**

Soil pH ranges from 6.30 to 6.80 (Table 2). The pH value was rated slightly acidic to neutral which is the pH requirement for optimum plant growth. Generally, pH values are relatively higher in the surface horizons and decrease with increasing depth in all pedons which could be attributed to a decrease in organic carbon content (Jimoh *et al.*, 2016). pH value decreases down the toposequence and there was no significant difference in the soil reaction of all the geomorphic units.

Soil organic carbon (OC) was generally rated low been lower than 10 g $kg^{-1}$ (Malgwi, 2007). Several authors (Sharu *et al.,* 2013 and Fasina *et al.*, 2015) have also reported low organic carbon in soils of savanna region and attributed it to continuous cultivation and burning of plant residues which destroy most of the organic materials that would have contribute more to the soil organic matter. Organic carbon content decreases with depth which could be attributed to a decrease in plant materials with depth, this confirms the report of Idoga and Azagaku (2005) and Nahusenay and Kibebew (2016) who also reported a decrease in Organic matter with soil depth. Surface soils were significantly higher (*P<0.05*) in OC than subsoils (Table 3). Adewumi (2015) also reported a decrease in organic carbon with depth.

The middle slope recorded higher organic carbon which could be attributed to the stable state of the unit which allows the accumulation of organic materials, while the upper slope that recorded lower value could be attributed to erosion as a result of the steep slope in the unit. More clayey soils generally tend to contains higher level of organic matter mainly because of the tendency of clay to slow down microbial degradation of organic matter as clay form clay-humus complexes with organic matter (Brady and Weil, 1999), unlike the upper slope and valley bottom positions which are interrupted by constant erosion and deposition of materials. The low organic matter content recorded on most of the soils cannot sustain crop production on long time bases. Therefore, the organic matter content has to be substantially increased through effective crop residue management and the use of mineral and organic fertilizer.

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| Horizon | Depth (cm) | pH H2O | OC (g/kg) | TN (g/kg) | Ap (mg/kg) | Ca | Mg | K | Na | H+Al | CEC (cmol/kg) | BS % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **Crest** | | | | | | | |
| Ap | 0 – 21 | 6.80 | 7.3 | 0.14 | 2.10 | 4.24 | 0.43 | 0.19 | 0.50 | 0.40 | 9.00 | 59.56 |
| Bt1 | 21 – 114 | 6.70 | 2.5 | 0.21 | 1.93 | 3.49 | 0.51 | 0.17 | 0.46 | 0.30 | 7.50 | 61.73 |
| Bt2cv | 114 -140 | 6.80 | 2.1 | 0.21 | 1.75 | 4.30 | 0.50 | 0.45 | 0.35 | 0.20 | 12.50 | 44.80 |
| | | | | | **Upper Slope** | | | | | | | |
| Ap | 0 – 40 | 6.50 | 7.3 | 0.14 | 3.15 | 5.29 | 0.41 | 0.11 | 0.46 | 0.60 | 9.30 | 67.42 |
| Bt | 40 – 120 | 6.60 | 1.0 | 0.07 | 2.28 | 2.83 | 0.51 | 0.22 | 1.91 | 0.60 | 7.60 | 71.97 |
| | | | | | **Middle Slope** | | | | | | | |
| Ap | 0 – 27 | 6.80 | 6.5 | 0.14 | 2.10 | 5.51 | 0.46 | 0.18 | 0.52 | 0.20 | 11.90 | 56.05 |
| Bt1 | 27 -75 | 6.70 | 2.9 | 0.14 | 2.98 | 4.19 | 0.44 | 0.13 | 0.32 | 0.40 | 8.50 | 59.76 |
| Bt2 | 75 – 148 | 6.90 | 3.8 | 0.07 | 3.15 | 4.29 | 0.47 | 0.18 | 0.45 | 0.20 | 7.70 | 70.00 |
| Bt3c | 148 – 165 | 6.30 | 3.8 | 0.14 | 2.28 | 3.96 | 0.46 | 0.18 | 0.49 | 0.60 | 8.70 | 58.51 |
| | | | | | **Valley Bottom** | | | | | | | |
| Ap | 0 – 25 | 6.90 | 3.6 | 0.07 | 4.38 | 3.50 | 0.46 | 0.24 | 2.17 | 0.20 | 7.00 | 91.00 |
| Bt1 | 25 – 36 | 6.80 | 4.0 | 0.14 | 3.15 | 3.74 | 0.46 | 0.20 | 0.32 | 0.20 | 5.80 | 81.38 |
| Bt2 | 36 – 58 | 6.50 | 3.6 | 0.14 | 4.73 | 5.76 | 0.41 | 0.19 | 0.34 | 0.60 | 9.80 | 68.37 |
| 2Bt1 | 58 – 90 | 6.30 | 3.4 | 0.14 | 4.90 | 4.30 | 0.43 | 0.19 | 0.30 | 0.80 | 8.30 | 62.89 |
| 2Bt2 | 90 – 135 | 6.70 | 4.4 | 0.21 | 6.13 | 3.52 | 0.47 | 0.34 | 0.46 | 0.20 | 7.60 | 63.03 |
| 2Cr | 135 – 145 | 6.70 | 6.0 | 0.14 | 3.85 | 5.90 | 0.46 | 0.15 | 0.33 | 0.20 | 10.20 | 67.06 |

**Table 2.** *Soil chemical properties of Zaria toposequence.*

| Location | Sand | Silt | Clay | B D | SCR | pH | O C | TN | Ap |
|---|---|---|---|---|---|---|---|---|---|
| | g kg$^{-1}$ | | | g cm$^{-3}$ | | | mg kg$^{-1}$ | | |
| **Crest** | 416 ab | 393 ab | 190 a | 1.53 | 2.45 | 6.76 | 3.96 | 0.19 | 1.93 b |
| **Upper Slope** | 476 ab | 353 b | 170 ab | 1.46 | 2.74 | 6.56 | 3.10 | 0.09 | 2.57 b |
| **Middle Slope** | 276 c | 520 a | 203 a | 1.47 | 2.56 | 6.8 | 4.40 | 0.12 | 2.74 b |
| **Valley bottom** | 615 a | 266 b | 118 b | 1.5 | 2.36 | 6.75 | 3.98 | 0.12 | 4.14 a |
| **P-value** | 0.001 | 0.018 | 0.081 | 0.9 | 0.98 | 0.20 | 0.83 | 0.2 | 0.03 |
| **LOS** | ** | * | NS | NS | NS | NS | NS | NS | * |
| **Depth** | | | | | | | | | |
| **Surface** | 442 | 435 | 122 b | 1.53 | 3.79 a | 6.75 | 6.2 a | 0.12 | 2.93 |
| **Subsoils** | 465 | 355 | 208 a | 1.46 | 1.76 b | 6.70 | 2.6 b | 0.14 | 3.02 |
| **P-value** | 0.581 | 0.24 | 0.028 | 0.8 | 0.08 | 0.84 | 0.05 | 0.87 | 0.61 |
| **LOS** | NS | NS | * | NS | NS | NS | * | NS | NS |

| Location | Ca | Mg | K | Na | H+Al | CEC | BS |
|---|---|---|---|---|---|---|---|
| | cmol kg$^{-1}$ | | | | | | % |
| **Crest** | 4.01 | 0.48 | 0.27 | 0.44 | 0.3 b | 9.7 | 55 b |
| **Upper Slope** | 3.65 | 0.48 | 0.18 | 1.43 | 0.6 a | 8.2 | 70 ab |
| **Middle Slope** | 4.66 | 0.46 | 0.16 | 0.43 | 0.26 b | 9.4 | 62 ab |
| **Valley bottom** | 4.03 | 0.46 | 0.22 | 0.95 | 0.28 b | 7.3 | 79 a |
| **P-value** | 0.56 | 0.71 | 0.45 | 0.41 | 0.04 | 0.4 | 0.09 |
| **LOS** | NS | NS | NS | NS | * | NS | NS |
| **Surface** | 4.63 | 0.44 | 0.18 | 0.91 | 0.35 | 9.3 | 68.5 |
| **Subsoils** | 3.56 | 0.48 | 0.26 | 0.75 | 0.37 | 7.3 | 63 |
| **P-value** | 0.28 | 0.23 | 0.29 | 0.95 | 0.96 | 0.3 | 0.65 |
| **LOS** | NS | NS | NS | NS | NS | NS | NS |

**Key:** BD = bulk density - NS= not significant - SCR= silt clay ratio - *= significant at P<0.05 - **= significant at P<0.01 – LOS = Level of significant

**Table 3.** *Ranking of mean of physiochemical properties of Zaria toposequence.*

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Total nitrogen value was rated low (Malgwi, 2007). The crest and valley bottom value increase with depth while upper slope and middle slope value decrease with depth. The irregular distribution pattern of total nitrogen with depth could be ascribed to the influence of continuous cultivation common in Nigerian caused by crop residues removal to feed animals (Noma *et al*., 2011). Generally, total nitrogen value decreases down the toposequences. There was no significant difference within all the geomorphic units and between surface and subsoils. Available phosphorus (Avail. P) mean was also rated low similar to OC and TN. Crest and upper slope value decrease with depth while middle and valley bottom value increases with depth. Avail. P values increase down the profiles and the valley bottom was significantly higher ($P<0.05$) than the other geomorphic units which could be attributed to higher moisture conditions of the units which slow the rate of organic matter decomposition. The result tallied with the report of Maniyunda and Gwari, (2014) and that Avail. P decreased with depth following the organic carbon trend. The significant difference in soil organic matter with depth was also reported by Nahusenay and Kibebew (2016), as well as the relationship between organic carbons, total nitrogen and phosphorus.

Exchangeable Ca was rated medium and it's dominated the exchange site. Similar results have been reported by Sharu *et al.* (2012) on soils of Sokoto and Nahusenay and Kibebew (2016) in Ethiopia. Ca value decreases with depth over the crest, upper and middle slope but increases with depth over the valley bottom which could be attributed to variation in the content of material been deposited. Ca content was irregularly distributed over the toposequence and there was no significant difference in Ca value within the toposequence and between surface and subsoils. The middle slope and surface soils recorded the highest Ca amount.

Exchangeable Na rank next to Ca. Exchangeable Na was rated higher being greater than 0.3 cmol(+)kg$^{-1}$ (Malgwi, 2007). The crest, middle slope, and valley bottom Na content decrease with depth while the upper slope Na content value increases with depth. Generally, exchangeable Na content increases down the toposequence, though there was no significant difference in exchangeable Na in the toposequence and between surface and subsoils. Exchangeable Mg was rated medium (Malgwi, 2007). Generally, Mg content of crest and upper slope increases with depth which could be attributed to leaching of basic cations while the valley bottom shows a decrease in Mg content with depth. Mg content decreases down the toposequence though there was no significant difference in Mg content within the toposequence. Exchangeable K was generally rated medium (Malgwi, 2007). K content of crest and upper slope increases with depth which could be attributed to leaching of basic cations while the middle and valley bottom values show a decrease in K content with depth. The crest and valley bottom recorded higher value while the upper and middle slope recorded the least value though there was no significant difference in the K content across the toposequence and between surface and subsoils.

Exchangeable acidity values were classified as generally low (<1.0 cmol(+)kg$^{-1}$), and suggests that the soils have little or no acidity problems. Raji and Mohammed (2000) also reported less than 1.0 cmol(+)kg$^{-1}$ value of exchangeable acidity and submitted that the contribution of exchange acidity to potential acidity is very low in soils of Nigerian savannas. Exchangeable acidity increases with depth on the crest while a decrease with depth was observed on the middle and valley bottom. Exchangeable acidity generally decreases down the toposequence, upper slope was significantly higher ($P<0.05$) in exchangeable acidity than the other geomorphic unit but there was no significant differences between the surface and subsoils.

Cation exchange capacity (CEC) was rated medium according to Malgwi (2007) rating of <6 low, 6-12 medium and >12 high. Odunze and Kureh (2009) also reported a similar medium level of CEC for some pedon in Zaria. The medium value of CEC suggests a dominance of sesquioxides and kaolinite clays (Tan, 2000) over 2:1 clay mineral. Crest and valley bottom CEC value increase with depth which could be attributed to leaching while upper slope and middle slope CEC value decrease with depth. Generally, CEC value decreases from the crest down to valley bottom with the exception of middle slope which also recorded higher value though there was no significant difference in CEC value along the toposequence.

FAO (1999) reported that soils with the base saturation of >50 % are regarded as fertile soils while soils with less than 50% were regarded as non-fertile soils. Based on this, therefore, the soils are generally fertile. The crest and valley bottom BS values decrease down the profile while upper and middle slope increases with depth. The decrease in BS with depth could be attributed to plant nutrient uptake while the increase in BS with depth could be due to leaching of basic cation through eluviations-illuviation processes. Idoga and Azagaku (2005); Atofarati (2012) Nahusenay and Kibebew (2016) also reported higher base saturation

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of sub-surface horizons which was attributed to the contribution of clay colloids which increases with depth. Generally, BS increases down the toposequence with the valley bottom recording the highest value which could be attributed to the downward movement of material deposited on the valley bottom which enriches the unit. Soil properties are not always uniform in all slope segments of the catena. Several studies have shown that organic matter and soil nutrient levels are higher in the lower slope segment of the topography (Abrams *et al.,* 1997, Kravchenko and Bullock 2000). Soils in lower or river channels receive considerable quantities of sediments and organic debris transported from upslope or upstream which enhances their organic matter and nutrient status. This condition could be responsible for the higher organic carbon content in the middle slope while the low organic carbon of the valley bottom of this present study could be as a result of runoff which washed into the river the transported organic debris instead of being deposited (Aweto and Enaruvbe, 2010).

**Soils classification**

All the soils were characterized as ochric epipedon because they were either too light in colour, too low in organic carbon content or too shallow to be mollic, umbric, histic or plaggen epipedon by USDA *Soil Taxonomy* System (SSS, 2010). The diagnostic subsurface horizon of the crest and middle slope had argillic horizons and moderate base saturation (>35%). The prevailing soil temperature regime is isohyperthermic. Therefore, at the order level, the crest and middle slope were classified as Alfisols, while the upper slope and valley bottom as inceptisols due to the weakly developed horizon. The crest and middle slope were classified as Ustalfs, upper slope as Ustepts at the suborder level because of their ustic moisture regime while valley bottom as *Aquaepts* by virtue of its *Aquic* moisture regime. At the Great Group and Subgroup the crest and middle slope were classified as *plinthustalfs*, and at the group level as *Typic Plinthustalfs* (SSS, 2010). The valley bottom was classified as *epiaquepts* because of its saturation within 200cm and *redoximorphic* features in all layers between either the lower boundaries of an Ap horizon. The unit did not meet the criteria of other *Aquaepts* hence classified as great group *Endoaquepts*, and at subgroup level as *Typic Endoaquepts* because it does not meet the criteria for other *Endoaquepts*.

The upper slope was classified at the great group as *Haplustepts* because it has an exchangeable sodium percentage of >15 and they did not possess any of the special features in the profile that distinguish the other Great groups. At the group level, it is classified as *Typic Haplustepts*. The valley bottom was classified as *Aquepts* because they have groundwater within 100cm of the mineral soil surface for some time during the year (Aquic moisture regime). They were also all classified as *Endoaquepts*, because the soils are saturated with water in one or more layers within 200cm of the mineral soil surface and also has one or more unsaturated layers, with an upper boundary above a depth of 200cm, below the saturated layer (episaturation) that is, *Aquepts* that have episaturation. At the group level, it is classified as *Fluvaquentic Epiaquepts* because the soil has a slope of less than 25 and at a depth of 125 cm below the mineral soil surface, and organic carbon content (Holocene age) of 0.2 percent. The correlation with World Reference Base 2014 (IUSS, 2015) for soils of the toposequence is presented in Table 4.

| Slope Position | USDA 2010 | WRB 2014 |
|---|---|---|
| Crest | Typic Plinthustalfs, fine loamy-skeletal, isohyperthermic | Eutric Lixisols |
| Upper Slope | Typic Haplustepts, fine loamy, isohyperthermic | Terric Cambisols |
| Middle Slope | Typic Plinthustalfs, fine loamy- skeletal, isohyperthermic | Eutric Lixisols |
| Valley Bottom | Fluvaquentic Epiaquepts, fine loamy, isohyperthermic | Endoeutric Fluvisol |

**Table 4.** *Summary of soil classification by USDA Soil Taxonomy and WRB 2014 of the study area.*

Generally, Soil properties are not always uniform in all slope segments of the catena. Several studies had reported that there no much significant variation in the soils of toposequence though the soil is not also homogeneous. For instance, Aweto and Iyamah (1993) observed no significant variations in soil physical and chemical properties between the upper, middle and lower slopes under swamp forest in the coastal plain of southwestern Nigeria. In addition, Gafar *et al.,* (2004) also reported no significant differences between the upper, middle

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and lower slopes of the catena in Chittagong hill of eastern Bangladesh. Contrarily, Nahusenay and Kibebew (2016) reported that particle size distribution, bulk and particle densities, total porosity, organic matter, total nitrogen contents, C:N ratio and available phosphorus were significantly not affected by topographic position (upper, middle and lower slopes), while soil pH, electrical conductivity, exchangeable bases, cation exchange capacity, base saturation and micronutrient were significantly affected by topographic positions. The above no significant variation of the present study in most of the physiochemical studies with the exceptions of sand, silt, available phosphorus and exchangeable acidity is in line with previous researchers.

## Conclusions

This study aimed at assessing the impact of topography on the soil along a toposequence in Zaria area of Kaduna state Nigeria. The study shows that landscape position, soil depth and drainage significantly influenced variation in soil properties. The soils colour varies from dark yellowish-brown to light gray-brown on the crest to the valley bottom. The crest and upper slope soils were well-drained while middle and valley bottom soils were imperfect to poorly drained. Generally, the soils were low in organic carbon, total nitrogen, and available phosphorus. This will require the addition of organic manure and crop residue. Exchangeable bases were rated medium to higher while CEC was rated medium. The base saturation classified the soils as fertile. Pedogenic processes resulted in clay and CEC enrichment at the crest and middle slope positions while sand was higher at the valley bottom position. Toposequence effect was not only on soil properties but also on soil classification. The classes varied from Typic Plinthustalfs (Eutric Lixisols) on the crest to Fluvaquentic Epiaquepts (Endoeutric Fluvisol) on the valley bottom. The whole toposequence will require addition of organic manure and crop residue since they are all characterized by low organic matter due to intensive continuous cultivation in the study area. The upper slope will require terracing to control the rate of erosion on the units. The addition of more organic manure and crop residue due to low organic matter content as compared to the crest and middle slope will be required. The valley bottom, in addition, will require construction of drainage channels to reduce excess water in the soil for optimum plant growth.

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