Nigerian Journal of Soil Science

Journal homepage:www.soilsjournalnigeria.com

Classification and fertility status of soils on slopes of varying orientations in Umuahia area of Abia State, Nigeria

Aliba, V.O., Onweremadu E.U., Aririguzo, B. N. and Okoli, N. H.

Department of Soil Science and Technology, Federal University of Technology, Owerri

ARTICLE INFO

ARTICLE INFO

Article history:

Received March 20, 2020

Received in revised form March 29, 2020

Accepted April 12, 2020

Available online May 20 2020

Keywords:

Toposequence

Slope orientation

Soil properties

Soil fertility

Soil classification

Corresponding Author's E-mail Address:

nnaemeka.okoli@futo.edu.ng .+2348037687630

https://doi.org/10.36265/njss.2020.300114

ISSN-1597-4488

ABSTRACT

The slope orientation and position of toposequence influence soil properties along the landscape. The study classified and evaluated the fertility status of soils on slopes of varying orientations in Umudike (East-lying Toposequence) and Itu (West-lying Toposequence) located in Olokoro Umuahia, Abia State southeastern Nigeria. Transect soil sampling technique was employed in locating 3 distinct top units (Summit, Midslope and Footslope) along each of the toposequence. Soil profile pit was dug at each top unit, described using FAO guidelines and sampled according to genetic horizons. Soil samples collected were subjected to routine laboratory analyses. Pedons were classified using the USDA Soil Taxonomy System and correlated with World Reference Base while the fertility status was evaluated using elemental ratios. The results indicated that soils of the two toposequence were dominated by sandy clay loam texture. Consistency of the pedons generally varied from very friable (Vfr) to very firm (Vfi) in the two toposequence. Soil pH was very strongly acidic (4.58-4.78) in the east lying toposequence but varied from very strongly acidic to strongly acidic (4.52-5.30) in the west lying toposequence. Organic matter concentration was higher at the epipedons and ranged from 26.44 to 23.36 g kg $^{-1}$ and 18.9 to 30.64 g kg $^{-1}$ in soils of east-lying and west-lying slopes, respectively. K: Mg ratio varied from 0.01-0.12 and 0.01-0.08 at the east and west lying slopes, respectively. The pedons of the summit, midslope and footslope were as classified Grossarenic Paleudalfs, Typic Paleudalfs and Arenic Hapludalfs for respectively for the east-lying slope and Arenic Glossudalfs, Typic Paleudalfs and Typic Ferrudalfs, respectively for the west-lying slope. Generally, the two toposequences were of poor fertility status.

1.0. Introduction

Soils differ in their characteristics primarily because of topography (Aduloju and Tetengi, 2011). According to Mulla and McBratney (2001), variability in soil properties at the series level is often caused by small changes in topography that affect the transport and storage of water across and within the soil profile.

The topography is a significant factor which controls most surface processes taking place on earth (soil formation and soil development). Topography has an influence on soil chemical and physical properties and also on the pattern of soil distribution over the landscape (Kalivas et al., 2002; Esu et al., 2008). One reason for variation in soil properties with topographic settings is the orientation of hill slopes on which soils develop, and this affects the microclimate, as in north versus south-facing slopes, (Iqbal et al., 2004). Slope aspect has been shown to affect the temperature of the soil, vegetation establishment, and moisture levels. These factors, in turn, can affect the distribution of soil organic matter, the presence or absence of an E horizon (in more humid areas), pH, and nutrient levels (Birkeland, 1984). North facing slopes generally have less sunlight because of its higher moisture levels and greater vegetation establishment resulting in more organic matter. Soil pH trends and nutrient levels are usually associated with vegetation and can also be affected by the slope aspect. Mesic vegetation types are usually found on the North facing slopes, while more xeric vegetation is found on the south-facing slopes (Birkeland 1984).

The study and understanding of soil properties and their distribution over an area has proved useful for the development of soil management plan for efficient utilization of limited soil resources and agrotechnology transfer (Buol et al., 2003). In Nigeria, many works on the relationship between landscape positions and soil properties were documented (Annan-Afful et al., 2004; Abe et al., 2009). For instance, Ogban et al. (1999) deduced that nutrient status and soil properties are related to the topography of the land area. Also, Osodeke et al. (2005) reported differences in quantity and forms of sesquioxides as influenced by geomorphic positions. They observed that the soils of the profiles at higher slopes were dominated by the crystalline forms of iron (Fe) and aluminium (Al)-oxides while the soils of the valley bottom were dominated by the amorphous forms of Fe and Al. Elsewhere, Osodeke and Osondu (2006) observed a wide variation in phosphorus (P) distribution along a toposequence in southeastern Nigeria where highest total P was observed at the upper slope while the lowest value was noted at the middle slope.

With the emphasis being shifted to precision farming in Nigeria to meet up food requirement of a rapidly growing population, investigations on properties of soils on different landscape positions are necessary. Potentials of soils can readily be tapped when information on its physical, chemical and biological properties are available. It will also be equally essential to classify the soils using their inherent characteristics. In a manner that will ease communication and transfer of knowledge about such soils to farmers, stakeholders and soil scientists since soil data are primarily needed as a first step in sustainable land use and soil management decisions (Chukwu, 2013). Non-use of soil survey data has resulted in soil and soil-related environmental problems like nutrient depletion (Onweremadu, 2006) compaction, flooding, and reduced yield (Zinck, 1990).

Olokoro Umuahia is an agrarian state; its dwellers are mainly commercial farmers of both small scale and large scale production of several staple crops such as cassava, yam, maize and tree crops like oil palm among others are their primary produce. There is limited data on soils of this area. Previously, Nuga et al. (2006) classified soils along a toposequence in this area without considering the orientation of the slope. Slope orientation is vital in the development of soils, but the position of soil on a slope has also been found to affect the properties of soil. In light of the above, it is of paramount importance to have in-depth knowledge on the characteristics and taxonomical classification of soils on varying slope orientations and positions, to manage and use the resources based on their potentials and limitations and thereby maximize crop production to the allowable genetic potential limits and conserve the soils for future use. Therefore the primary objective of the study was to classify and evaluate the fertility of soils on slopes of varying orientation in Olokoro Umuahia Southeastern Nigeria using USDA Soil Taxonomy System and correlate with the World Reference Base.

2.0. Materials and methods

2.1. Description of the Study Area

Two locations, Itu and Umudike in Olokoro Umuahia Abia State, southeastern Nigeria with toposequence of varying orientations (East lying and west lying) were used for the study. Olokoro Umuahia lies between Latitudes 5° 26'N and 5°37'N; and Longitudes 7°23'E and 7°36'E. Soils of the study area were derived from Coastal Plain Sand (Benin formation) (Orajaka, 1975). The area lies within the lowland and plain areas of southeastern Nigeria geomorphology with the primary hydrologic resource of the area being the Imo River and its tributaries. The study area is characterized by a humid tropical climate with two seasons, namely, the wet and dry seasons (Obi, 1982). The relative humidity is high (above 80%) especially during the wet season with an average annual rainfall of about 2500 mm while annual temperature varies from 260C to 310C (NIMET, 2008). The predominant vegetation in the area is tropical rainforest. Gmelina arborea is the dominant plant occupying about one half of the area of the forest reserve while Tectona Grandis is the secondary dominant tree plant. However, secondary forest dominates the area due to anthropogenic activities. The significant socio-economic activity in the area is farming, with about 70% of the total land area under crop cultivation. Commonly cultivated crops include maize, cassava and yam.

2.2. Detailed Field Work and Soil Sampling

Transect soil survey technique was used in field sampling. With the aid of a compass, east lying and west lying slopes were located in Umudike and Itu, respectively. Guided by transect sampling technique, one profile pit was sunk each in the summit, midslope and footslope of the Umudike east -lying and Itu-west toposequencies. Hence, a total of six (6) profile pits were used in the study. All soil profiles were georeferenced using a handheld Global Positioning System (GPS) Receiver (Garmin Ltd, USA). The profile pits were described using FAO (1998) guidelines, and soil samples were collected according to horizon differentiation. Undisturbed soil samples for determination of bulk density were also collected using core samplers. The soil samples collected were air-dried, crushed and sieved through a 2 mm sieve. Also, the soils used for organic matter and total nitrogen determinations were further ground to pass through 0.5 mm mesh.

2.3. Laboratory Analyses

Particle size distribution was determined by the hydrometer method of Gee and Or (2002), Soil bulk density was determined by the core sampler method, Silt/clay ratio was determined by dividing the value of silt with clay value while soil pH was measured using glass electrode pH meter (Thomas, 1996). Exchangeable bases (Ca, Mg, K and Na) were extracted using 1NNH_4OAc buffered at pH 7. Calcium and magnesium were then determined by complexometric titration method (Thomas 1982) while potassium and sodium were read on the flame photometer. Total nitrogen was determined by the Macro Kjeldahl method (Bremner and Mulvaney, 1996), Organic carbon was ob-

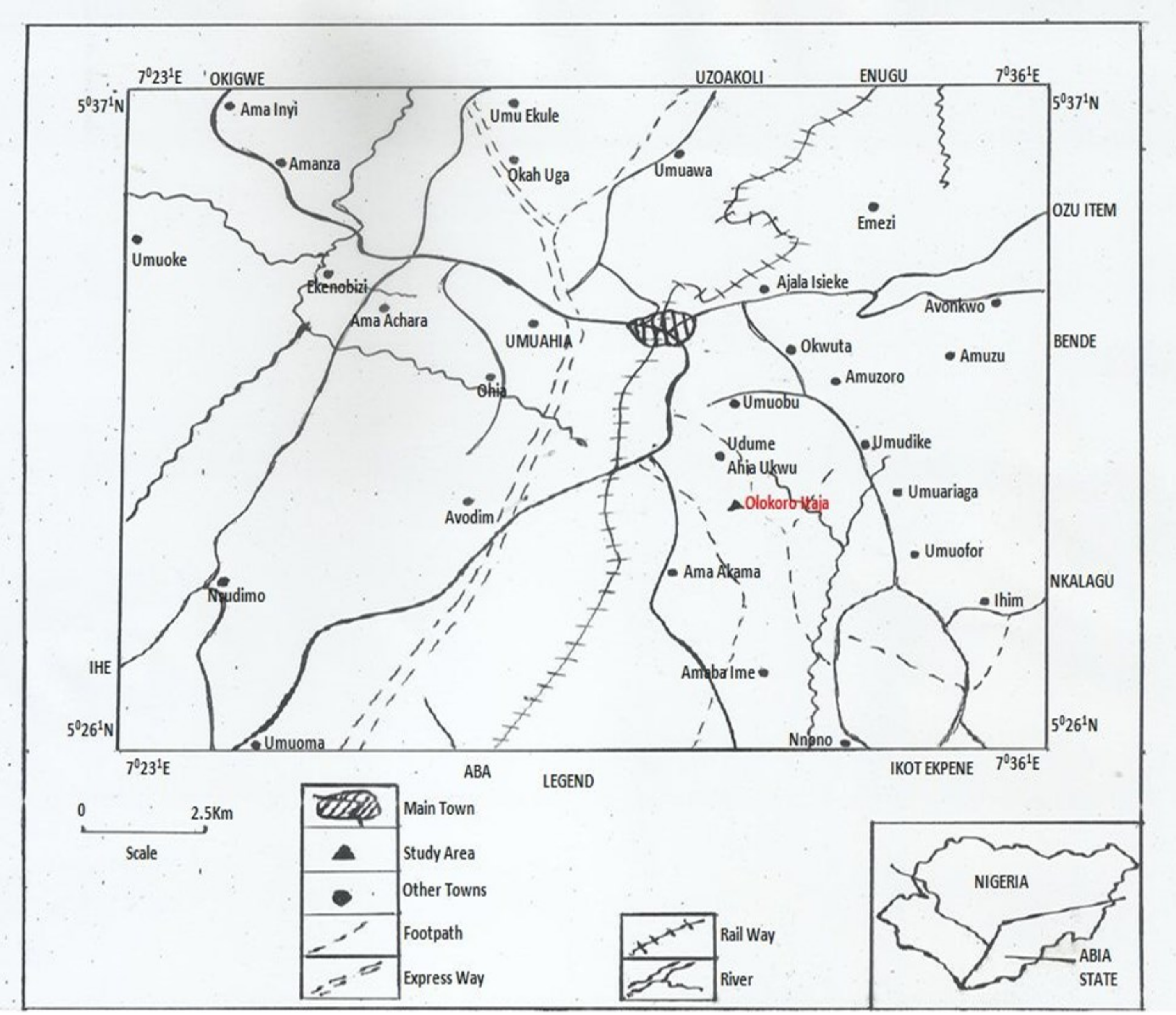

Figure 1: Location map of the study area

Table 1: Geographical coordinates of the sampled sites

Site	Topounit	Slope	Latitude (N) (⁰)	Longitude (E) (⁰)	Elevation (M)
Itu (WLT)	Crest	5.7º	5º28'.844"	7º31'.352"	143
Itu (WLT)	Midslope	6.8º	5º28'.844"	7º31'.304"	142
Itu (WLT)	Footslope	5.2º	5º28'.804"	7º31'.265"	135
Umudike (ELT)	Crest	5.0º	5º28'.914"	7º31'.395"	141
Umudike (ELT)	Midslope	7.2º	5º28'.546"	7º31'.414"	138
Umudike (ELT)	Footslope	7.9º	5º28'.983"	7º31'.458"	121

WLT = West-Lying Toposequence, ELT = East-Lying Toposequence tained by chromic wet oxidation method (Nelson and Sommers, 1996) and organic matter derived by multiplying with the Van Bemmelen's factor while cation exchange capacity was determined by NH_4OAc saturation method (Udo *et al.*, 2009). Ca: Mg ratio was obtained by the diving value of exchangeable Ca with a value of exchangeable Mg. Similarly, the K: Mg ratio was obtained by dividing the value of exchangeable K with a value of exchangeable Mg. Total exchangeable acidity was extracted with IM KCl and then titrated with 0.01M NaOH (Udo *et al.*, 2009) while percentage base saturation was calculated as the proportion of exchangeable complex occupied by exchangeable bases.

2.4. Soil Classification

The data obtained from the field study and Laboratory analyses were used to classify the pedons according to the USDA Soil Taxonomy System (Soil Survey Staff, 2010) and then correlated with World Reference Base for Resources (IUSS Working Group WRB, 2010).

2.5. Statistical Analysis

Data generated were subjected to coefficient of variation and variation ranked according to the procedure of Wilding *et al*. (1994) where CV < 15% = least variation, CV >15 < 35% = moderate variation, CV > 35 <100% = high variation.

3.0. Results and Discussion

3.1. Soil Morphological Properties

Results of the morphological properties of both toposequences studied are presented in Tables 2 and 3. It was observed that regardless of the slope orientation, the soils were generally shallow at all the slope positions. At Umudike east-lying slope, the soil depth varied from 0-130 cm, 0-150 cm and 0-150 cm for the summit, midslope and footslope, respectively (Table 2). In contrast, at Itu west-lying slope, it ranged from 0-120 cm, 0-110 cm and 0 -180 cm in the summit, midslope and footslope, respectively (Table 3). However, generally, the soils had similar horizon pattern of A, AB, Bt_1, Bt_2 and Bt_3 except for Umudike summit that had BA as the third horizon.

Soil colour is probably the most important feature to assess the soil moisture required in landscape (Peter Schmitt *et al*., 1996). Soil colour of Umudike east-lying slope varied from very dark greyish brown (10YR3/2) moist at A horizon of summit soil position, while strong brown (7.5YR5/8) moist was observed at the Bt_3 horizon. The greyish colour of A and AB horizons may be attributed to poor internal drainage condition (Esu, 2010). At the midslope of Umudike toposequence, dark brown (7.5YR3/2) moist colour was recorded at the A-horizon. At the same time, it had strong brown (7.5YR5/8) moist colour at the Bt_3 horizon whereas, dark grey (5YR4/1) moist and reddish yellow (7.5YR6/8) colour characterized A horizon and Bt_3 horizon of Umudike footslope, respectively (Table 2). On the other hand, the summit of Itu west lying slope was characterized by brown (7.5YR4/2) moist and yellowish red (5YR5/6) moist colour at the A and Bt_3 horizons, respectively. In contrast, at the midslope, very dark grey (7.5YR3/1) moist and yellowish red (5YR3/2) moist characterized the upper and bottom horizons, respectively. Very dark greyish brown (10YR3/2) moist and reddish yellow (5YR6/6) moist colour dominated A and Bt_3 horizons respectively of this footslope (Table 3).

The topsoil of Umudike east-lying slope was fine crumb at the summit and midslope while at footslope, the very coarse blocky structure was observed. In contrast, at the Itu west-lying slope very fine gravel was observed for summit and midslope but very coarse blocky for the footslope. However, soil structure was fine crumb, very coarse blocky and medium crumb at the lower horizon of the summit, midslope and foot slope of Umudike east-lying slope, respectively. On the other hand, lower horizons of Itu west-lying slope were fine crumb, blocky crumb and very crumb angular blocky at the summit, midslope and footslope, respectively (Tables 2 and 3).

Expectedly, roots and faunal activity was generally observed to be in abundance in the epipedons of both the west and east lying toposequence However, while very few roots and faunal activity was observed at the lower horizon of the midslope and footslope, few roots and faunal activity was recorded at the summit of Umudike slope (Table 2). At Itu west-lying slope, abundance and very few roots and faunal activity were recorded in the epipedon and lower horizon of summit and footslope, respectively. In contrast, at the midslope, an abundance of roots and faunal activity was recorded at the A horizon. In contrast, there was an absence of roots and faunal activity at the lower horizon.

Consistency of the soils generally varied from very friable (Vfr) to very firm (Vfi) at the soil position irrespective of toposequence (Tables 2 and 3). The observed difference in soil consistency could probably be as a result of variation in particle size distribution, particularly clay content and also the nature of the clay particles. Moradi (2013) had earlier asserted that soil consistency varies with soil texture. At the Umudike east-lying toposequence, clear smooth (cs) dominated epipedon of the top units while the diffuse smooth (Ds) boundary dominated the sub-soil horizons (Table 2). A similar trend of boundary pattern was also observed in Itu toposequence except for the footslope, where the opposite trend was recorded (Table 3). The variations like the horizon boundaries may indicate the existence of variations in processes that have formed the soils (Cools and De Vos, 2010).

3.2. Soil Physical Properties of the East and West Lying Slopes

Results of the selected soil physical properties of Umudike east-lying toposequence and Itu west-lying toposequence are shown in Tables 4 and 5, respectively. At the Umudike east-lying toposequence, sand particles varied from 764-618 g kg $^{-1}$, 724-418 g kg $^{-1}$, and 664-504 g kg $^{-1}$ for the summit, midslope and footslope respectively (Table 4), whereas at the Itu West-lying slope, sand particles ranged from 724-604 g kg $^{-1}$, 684-524 g kg $^{-1}$ and 604-564 g kg $^{-1}$ at the summit midslope and footslope, respectively (Table 5). Generally, the sand particle slightly decreased with depth in both toposequences. Except for the summit of the

Table 2: Morphological properties of the Umudike east-lying toposequence

Horizon	Depth (cm)	Colour (moist)	Structure	Consistence (moist)	Roots	Faunal activity	Boundary
		Umudike East-lying summit (Grossarenic Paleudalfs)					
A	0-5	Very dark greyish brown 10YR3/2	0, cr, f	Vfr	Abt	Abt	Ds
AB	5-23	dark grayish brown 10YR4/2	3, abk, vc	Fr	Abt	Abt	Cs
Bt1	23-56	Brown 7.5YR4/4	2, cr, m	Fi	M	M	Ds
Bt2	56-95	Reddish brown 5YR5/4		Fi	F	F	Ds
Bt3	95-130	Strong brown 7.5YR5/8	0, cr, f	Vfi	F	F	Ds
		Umudike East-lying midslope (Typic Paleudalfs)					
A	0-7	Dark brown 7.5YR3/2	0, cr, f	Vfr	Abt	Abt	Cs
AB	7-37	brown 7.5YR4/2	3, bk, c	Fr	M	M	Cs
Bt1	37-66	brown 7.5YR5/4	2, cr, m	Fi	M	M	Ds
Bt2	66-100	Reddish yellow 7.5YR6/6	0, cr, f	Fi	F	F	Ds
Bt3	100-150	Strong brown 7.5YR5/8	3, bk, c	Vfi	Vf	Vf	Ds
		Umudike East-lying footslope (Arenic Hapludalfs)					
A	0-7	Dark gray 5YR4/1	3, bk, vc	Vfr	Abt	Abt	Cs
AB	7-20	brown 7.5YR4/3	0, cr, f	Fr	M	M	Cs
Bt1	20-52	Light reddish brown 5YR6/4	0, cr, f	Fi	M	M	Ds
Bt2	52-98	Reddish yellow 7.5YR6/6	0, cr, f	Fi	F	F	Ds
Bt3	98-150	Reddish yellow 7.5YR6/8	2, cr, m	Vfi	Vf	Vf	Ds

Key: 0=structuress, 1=weak, 2=moderate, 3=strong, cr= crumb, m =medium, abk=angular blocky, bk=blocky, vc=very coarse, f =fine, sbk =subangular blocky, gr=granular, c = coarse, mFr =moderately friable, Vfi= very firm, Vfr= very friable, fr= friable, Abt=abundant, f= few , Vf=very few, Cs=clear smooth, Ds = diffuse smooth.

Umudike East-lying slope where low (CV ≤ 15%) variability in the distribution of sand, particles were observed, other topo units recorded medium (CV ≥ 15 ≤ 35%) variability. However, low variability was recorded for all the pedons of Itu west-lying slope in the distribution of sand particle size, which indicated homogeneity of this soil property.

For silt particle size, mean values of 62 g kg $^{-1}$, 63.6 g kg $^{-1}$ and 66 g kg^{-1} were recorded for the summit, midslope and footslope, respectively at the Umudike east-lying toposequence. In contrast, at the Itu west lying toposequence, mean values of 82 g kg $^{-1}$, 126 g kg $^{-1}$ and 102 g kg $^{-1}$ were noted for the summit, midslope and footslope, respectively. Generally, regardless of slope orientation, the results indicated a decrease in silt content with depth and high variation (CV > 35%) in the distribution of silt in all the pedons studied. Clay particles did not follow similar distribution trend with sand, and silt particles in the pedons as the values increased with soil depth in all the pedons studied which may be due to the illuviation pedogenic processes that might have taken place within the pedons. For the Umudike east lying toposequence, the highest mean value of 345.6 g kg $^{-1}$ was recorded in the midslope while for the Itu west lying slope, the highest mean value of 306 g kg $^{-1}$ was observed in the footslope.

In general, sand particles dominated the mineral matter in all the topo units studied which may be partly attributed to the dominance of quartz in the coastal plain sands parent material from which the soils were derived (Obi, 2015). Part may be due to geological processes involving sorting of soil materials by biological activities, clay migration through eluviation and illuviation, or surface erosion by runoff or their combination (Akinbola *et al*., 2009). Texture varied from sandy loam to sandy clay loam, sandy loam to clay and sandy loam to sandy clay at the Umudike east lying summit, midslope and footslope, respectively while at the Itu west lying toposequence, texture varied from sandy loam to sandy clay loam for the summit and midslope. In contrast, in the foot slope, it varied from sandy loam to sandy clay. Silt Clay Ratio (SCR) of the soils followed a similar decreasing trend with clay. It ranged from 0.93-0.04 and 0.7-0.04 in the summit of the two toposequences, 1.26-0.04 and 1.59-0.27 in the midslope whereas in the floor slope, it varied from 0.66-0.04 and 1.08-0.14 in the East and West Lying Slopes respectively. Silt to clay ratios has been used to study the degree of pedogenic weathering in soils (Sombroek and Zonneveld, 1971). Generally, low values (< 0.75) indicate old age of soils; values between 0.75 and 1.5 indicate moderate pedogenic weathering processes, while high values (>1.5) indicate recent pedogenic processes (Sombroek and

Table 3: Morphological properties of the Itu west-lying slope

Horizon	Depth (cm)	Colour (moist)	Structure	Consistence (moist)	Roots	Faunal activity	Boundary
		Itu West-lying summit (Arenic Glossudalfs)					
A	0-6	Brown 7.5YR4/2	0, gr, Vf	Vfr	Abt	Abt	Cs
AB	6-38	Brown 7.5YR5/2	0, gr, f	Fr	M	M	Cs
Bt1	38-83	Strong brown 7.5YR4/6	1, cr, m	Fi	F	F	Ds
Bt2	83-106	Strong brown 7.5YR5/6	1, cr, f	Vfi	Vf	Vf	Ds
Bt3	106-120	Yellowish red 5YR5/6	1, cr, f	Vfi	Vf	Vf	Ds
		Itu West-lying midslope (Typic Paleudalfs)					
A	0-7	Very dark grey 7.5YR3/1	0, gr, Vf	Fr	Abt	Abt	Cs
AB	7-26	brown 7.5YR4/3	0, gr, f	Fi	M	M	Cs
Bt1	26-50	Yellowish red 5YR4/6	3, bk, c	Fi	F	F	Ds
Bt2	50-73	Yellowish red 5YR5/6	2, cr, m	Vfi	Ab	Ab	Ds
Bt3	73-110	Yellowish red 5YR5/8	3, bk, c	Vfi	Ab	Ab	Ds
		Itu West-lying footslope (Typic Ferrudalfs)					
A	0-8	Very dark greyish brown 10YR3/2	3, abk, vc	Vfr	Abt	Abt	Ds
AB	8-29	Dark brown 7.5YR3/2	3, sbk, vc	Fr	M	M	Ds
Bt1	29-86	Dark brown 7.5YR3/2	3, bk, c	Fi	F	F	Cs
Bt2	86-110	Reddish yellow 5YR6/6	3, bk, vc	Vfi	Vf	Vf	Cs
Bt3	110-180	Reddish yellow 5YR6/6	3, abk, vc	Vfi	Vf	Vf	Cs

Key: 0=structuress, 1=weak, 2=moderate, 3=strong, cr= crumb, m =medium, abk=angular blocky, bk=blocky, vc=very coarse, f =fine, sbk =subangular blocky, gr=granular, c = coarse, mFr =moderately friable, mVfi= moderately very firm, Vfr= very friable, fr= friable, Abt=abundant, f= few , Vf=very few, Cs=clear smooth, Ds = diffuse smooth.

Zonneveld, 1971). Therefore, the mean values of SCR of the present study revealed old age of soils of both toposequences which may be due to high temperature and annual rainfall prevalent in the study area which probably encourages rapid weathering. However, high (CV > 35%) variability of SCR in the study indicated non-homogeneity of SCR distribution.

Mean bulk density ranged from 1.37-1.32gcm^{-3} in the west lying toposequence while it varied from 1.36-1.32g cm^{-3} in the east lying toposequence (Tables 4 and 5). Mean values of BD recorded in the study were below the critical minimum value of 1.5g cm^{-3} for root compaction, thus, adequate for crop production. Bulk density (BD) of the soils of the different slope orientations generally increased with depth. Increase in bulk density with depth could be attributed to a decrease in organic matter accumulation with depth, less root penetration and compaction caused by the weight of the overlying layers (Brady and Weil, 2004).

3.3. Soil Chemical Properties of the East and West Lying Slopes

Selected soil chemical properties of the two toposequences studied are shown in Table 6 and 7. The results revealed that the soils were generally acidic, which slightly increased with depth in the top units except for the summit of Itu west-lying slope. In the east lying toposequence, the highest value of 4.78 was recorded in midslope followed by 4.64 in the summit and 4.58 in the footslope. However, in the west lying toposequence, soil pH decreased with decreasing slope percentage. The highest value of 5.3 and the lowest value of 4.52 were recorded in summit and footslope, respectively. Generally, the pH of the two slopes lying in different positions varied from extremely acidic to moderately acidic (FAO, 2004). The low (CV ≤15%) variability observed in the distribution of pH in both toposequences, indicated uniformity of this property irrespective of the top units and orientation of the slopes.

Organic matter contents of the soils were generally low and decreased with depth in both toposequences. Highest mean values of 26.44 and 30.64 g kg^{-1} were observed in the midslopes of the east and west lying slopes, respectively. In contrast, the lowest mean values of 23.26 and 18.9 g kg^{-s1} were recorded in the summit of east and west toposequences, respectively (Table 6 and 7). The low organic matter recorded in the study could be attributed to high rate of mineralization of organic matter in the soils

Table 4:Physical properties of the Umudike east-lying toposequence

Horizon	Depth (cm)	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	TC	SCR	BD (g cm^{-3})
		Umudike East-Lying Summit (Grossarenic Paleudalfs)					
A	0-5	764	114	122	SL	0.93	1.23
AB	5-23	664	94	242	SCL	0.39	1.26
Bt1	23-56	618	54	328	SCL	0.16	1.33
Bt2	56-95	664	14	322	SCL	0.04	1.44
Bt3	95-130	624	34	342	SCL	0.1	1.54
Mean		666.8	62	271.2		0.324	1.36
CV		8.769	66.89	33.96		112.28	9.49
		Umudike East-Lying Midslope (Typic Paleudalfs)					
A	0-7	724	122	154	SL	1.26	1.21
AB	7-37	644	114	242	SCL	0.47	1.24
Bt1	37-66	604	14	382	SC	0.04	1.26
Bt2	66-100	418	34	548	C	0.06	1.41
Bt3	100-150	564	34	402	SC	0.08	1.49
Mean		590.8	63.6	345.6		0.382	1.32
CV		19.17	78.68	48.89		136.68	9.19
		Umudike East-Lying Footslope (Arenic Hapludalfs)					
A	0-7	664	94	242	SL	0.66	1.19
AB	7-20	604	54	342	SCL	0.16	1.25
Bt1	20-52	604	14	382	SC	0.04	1.39
Bt2	52-98	504	54	442	SC	0.12	1.41
Bt3	98-150	504	114	382	SC	0.3	1.47
Mean		576	66	358		0.26	1.34
CV		17.25	59.07	36.11		95.59	8.73

Key: TC=textural class, S=sand, SL=sandy loam, SCL=sandy clay loamy, SC= sandy clay, BD=bulk density.

Table 5: Physical properties of the Itu west-lying toposequence

Horizon	Depth (cm)	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	TC	SCR	BD (g cm^{-3})
		Itu West-Lying Summit (Arenic Glossudalfs)					
A	0-6	724	114	162	SL	0.7	1.21
AB	6-38	624	134	242	SCL	0.55	1.29
Bt1	38-83	604	114	282	SCL	0.4	1.37
Bt2	83-106	638	14	348	SCL	0.04	1.48
Bt3	106-120	724	34	242	SCL	0.14	1.51
Mean		662.8	82	255.2		0.37	1.37
CV		49.103	61.50	51.27		237.98	119.44
		Itu West-Lying Midslope (Typic Paleudalfs)					
A	0-7	684	94	222	SL	1.59	1.19
AB	7-Jul	564	194	242	SCL	0.8	1.23
Bt1	26-50	564	114	322	SCL	0.35	1.29
Bt2	50-73	564	94	342	SCL	0.27	1.46
Bt3	73-110	524	134	342	SCL	0.39	1.5
Mean		580	126	294		0.68	1.33
CV		10.46	27.21	36.99		80.67	10.40
		Itu West-Lying Footslope (Typic Ferrudalfs)					
A	0-8	604	154	242	SL	1.08	1.17
AB	8-29	664	154	182	SL	0.85	1.24
BA	29-86	564	94	342	SCL	0.27	1.28
Bt1	86-110	564	54	382	SC	0.14	1.42
Bt2	110-180	564	54	382	SC	0.14	1.48
Mean		592	102	306		0.50	1.32
CV		10.63	49.22	43.11		88.51	9.75

Key: TC=textural class, SL=sandy loam, SCL=sandy clay loamy, SC= sandy clay, BD=bulk density.

occasioned by the humid tropical conditions prevalent in the area which encourages rapid losses of organic matter. The decrease of organic matter values with soil depth in all the pedons probably might be due to decreased floral and faunal activities in the underlying horizons, as suggested by Browaldh (1995). Total nitrogen (TN) of the soils generally followed a decreasing trend like organic matter. In the east lying slope, mean TN varied from 1.26-1.43 g kg^{-1}, while in the west-lying slope, it ranged from 1.10-1.36 g kg^{-1}. According to Havlin *et al*. (2012), TN of the soils is considered generally low when values are < 1.5 g kg^{-1}. Thus, the two slopes under study were low in TN and may be due to the low organic matter content of the soil since total nitrogen is associated with organic matter fraction of the soils (Brady and Weil, 2016).

The exchangeable bases were higher in the west lying toposequence relative to the east lying toposequence. In Umudike east-lying slope, total exchangeable bases (TEB) ranged from 7.3-12.2 cmol kg^{-1} whereas, in Itu west lying slope, it varied from 8.919-14.336 cmol kg^{-1}. Exchangeable bases were higher in the footslope and midslope of east and west lying slopes, respectively (Table 6 and 7). Also, low variability in the distribution of TEB was observed at the summit and footslope of the east lying slope, whereas its distribution varied highly (CV > 35%) at the midslope. This may be due to the effect of slope percentage, which might have resulted in an unstable distribution of basic cations at this soil position. However, the total base saturation of Itu west-lying slope showed moderate variation in distribution except for footslope that had more homogeneity in distribution evident in the low variability recorded (Table 7). Cation exchange capacity (CEC) of both toposequences studied did not follow any particular trend down the profile and slope. However, on a mean value basis, in Umudike east lying slope, its abundance across the topo units was in the order of footslope (13.79 cmol kg^{-1}) > summit (10.06 cmol kg^{-1}) > midslope (8.63 cmol kg^{-1}) while in the Itu west lying slope, the order of abundance was midslope (16.31 cmol kg^{-1}) > footslope (15.77 cmol kg^{-1}) > summit (10.42 cmol kg^{-1}). According to the rating of CEC given by Landon (1996) (in cmol kg^{-1}) where > 40 very high, 25-40 high, 15-25 medium, 5-15 low. Therefore it can be inferred that except for midslope and foot slope of Itu west lying toposequences which attained medium CEC level, the other topo units studied had low CEC. The low CEC of these soils indicates the low capacity of these soils to retain nutrient elements. Low cation exchange capacity, which might be as a result of low clay and organic matter contents of the soils, may render soils unsuitable for intensive agriculture (Kparmwang *et al*., 2004). For the Percentage base saturation (% BS) of the soils, mean values of 87.76, 82.44 and 86.33 % were noted in the summit midslope and footslope of the Umudike east-lying slope (Table 6) while in Itu west-lying slope, average values of 85.51, 87.50 and 90.76 % were recorded for the summit, midslope and footslope, respectively (Table 7). The high mean values of % BS values recorded for the top units in this present study which were above the recommended 80% limit to be maintained in most cropping systems (Hodges, 2002) indicated that top units when properly managed could be highly productive. Low variability (CV ≤15%) recorded for % BS in all the pedons studied indicated homogeneity of this soil property across soil depths.

3.4. Classification of the Pedons of the Two Toposequences of Varying Orientations

The soils of the pedons dug at the topo units of the east, and west lying toposequences were classified according to the USDA Soil Taxonomy System (Soil Survey Staff, 2010) and then correlated with World Reference Base for Resources (IUSS Working Group WRB, 2010). The differing soil physical, chemical and morphological properties formed the basis for the classification. The pedon dug at the Umudike east lying summit has a clay bulge indicating argillation and was sandier than all other top units with the mean sand value of 666.8 g kg^{-1}. At the same time, the organic carbon decreased consistently with depth and meant the base saturation value of 87.76 % observed. Consequently, at the order level, the pedon was classified as Alfisol (Table 8). Due to the Udic moisture regime and 7.5 YR with chroma of 5-8 at the lower horizons observed, the pedon was classified as Udalf and Paleudalf at the suborder and subgroup levels, respectively. In contrast, at the Great group level, the pedon was classified as Grossarenic Paleudalfs since there is the presence of sandy particle size throughout the argillic horizon of the profile. Investigation of the pedon dug at the midslope of the Umudike east lying slope showed prominent clay bulge, a consistent decrease in organic matter with soil depth, high base saturation, udic moisture regime and chroma value of 6-8. Based on these findings, the pedon was classified as Alfisol, Udalf, Paleudalf and Typic Paleudalf at the order, suborder, subgroup and great group levels, respectively (Table 8). Examination of footslope pedon of the Umudike east lying slope indicated the presence of clay bulge with the apex at the Bt1 and Bt 2 horizons, high percentage base saturation, low organic matter which consistently decreased with soil depth, Udic moisture regime and dominance of sandy particle size class throughout the horizon extending from the mineral soil surface to the top of the argillic horizon to a depth of 50 cm. Consequently, at the order and suborder levels, the pedon was classified as alfisol and Udalf, respectively. In contrast, at the subgroup and great group levels, the pedon was classified as Kandidalf and Arenic Kandidalf, respectively (Table 8).

The Itu west lying summit was classified as Alfisol at the order level since there is pronounced presence of clay bulge with a mean sand value of 662.8 g kg^{-1} and high base saturation. At the suborder level, the pedon was classified as Udalf due to the observation of Udic moisture regime. However, at the subgroup and great group levels, the pedon was classified as Glossudalf and Arenic Glossudalf due to the presence of glossic horizon and sandy particle size class throughout a horizon which extended from the mineral soil surface to the top of an argillic horizon up to a depth of 50 cm. Investigation of the pedon dug at the midslope of the Itu west lying slope indicated distinct clay bulge, low organic matter level which decreased with depth, high base saturation, udic moisture regime and chroma of 6-8. Guided by these findings, the pedon was classified as Alfisol and Udalf at order and suborder levels

Table 6: Chemical properties of the east-lying toposequence

Horizon	Depth (cm)	pH (H_2O)	OM (gkg^{-1})	TN (gkg^{-1})	Ca	Mg	K	Na ($Cmolkg^{-1}$)	TEB	CEC	%BS
Umudike East-Lying Summit (Grossarenic Paleudalfs)											
A	0-5	4.5	40	2.3	5.2	4.8	0.132	0.417	10.549	11.75	89.78
AB	5-23	4.4	29.3	1.4	5.2	1.6	0.065	0.348	7.213	8.41	85.77
Bt1	23-56	4.7	20	0.98	5.6	3.2	0.039	0.356	9.195	10.56	87.07
Bt2	56-95	4.8	17.8	0.91	6	2.4	0.049	0.478	8.927	9.97	89.53
Bt3	95-130	4.8	9.2	0.7	4.8	3.2	0.042	0.304	8.346	9.63	86.67
Mean		**4.64**	**23.26**	**1.26**	**5.36**	**3.04**	**0.065**	**0.381**	**8.846**	**10.06**	**87.76**
CV		**3.92**	**50.63**	**50.52**	**8.51**	**39.03**	**58.969**	**17.795**	**13.782**	**12.19**	**2.06**
Umudike East-Lying Midslope (Typic Paleudalfs)											
A	0-7	4.6	42.3	2.4	5.6	1.6	0.107	0.304	7.611	8.81	86.39
AB	7-37	4.8	38.4	1.68	5.2	3.6	0.08	0.461	9.341	10.7	87.30
Bt1	37-66	4.6	31.5	1.4	4.4	3.6	0.137	0.478	8.615	9.9	87.02
Bt2	66-100	4.9	12.6	0.98	2	0.4	0.047	0.339	2.786	4.23	65.86
Bt3	100-150	5	7.4	0.7	4	3.6	0.05	0.495	8.145	9.51	85.65
Mean		**4.78**	**26.44**	**1.43**	**4.24**	**2.56**	**0.084**	**0.415**	**7.300**	**8.63**	**82.44**
CV		**3.74**	**59.03**	**46.05**	**33.09**	**58.04**	**45.53**	**21.049**	**35.646**	**29.58**	**11.13**
Umudike East-Lying Footslope (Arenic Hapludalfs)											
A	0-7	4.2	44.8	2.56	4.8	3.6	0.141	0.33	8.871	10.07	88.09
AB	7-20	4.4	31	1.4	5.2	1.6	0.076	0.365	7.241	8.76	82.66
Bt1	20-52	4.8	25.9	1	4	2.8	0.046	0.391	7.237	8.68	83.38
Bt2	52-98	4.7	20.6	0.91	21.2	6	0.089	0.461	27.75	29.65	93.59
Bt3	98-150	4.8	9.8	0.7	7.6	2	0.032	0.269	9.901	11.8	83.91
Mean		**4.58**	**26.42**	**1.31**	**8.56**	**3.2**	**0.077**	**0.363**	**12.2**	**13.79**	**86.33**
CV		**5.86**	**48.96**	**56.42**	**84.02**	**54.49**	**55.345**	**19.622**	**71.855**	**64.93**	**5.30**

Key: OM= organic matter, TN=total nitrogen, TEB=total exchangeable bases, CEC= cation exchange capacity, %BS=percentage base saturation.

Table 7: Chemical properties of the west-lying toposequence

Horizon	DEPTH (cm)	pH (H_2O)	OM ($g\ kg^{-1}$)	TN ($g\ kg^{-1}$)	Ca	Mg	K	Na	TEB ($Cmolkg^{-1}$)	CEC	%BS
Itu West-Lying Summit (Arenic Glossudalfs)											
A	0-6	5.3	42.4	2.1	5.2	1.6	0.127	0.443	7.37	8.73	84.42
AB	6-38	5.8	25.3	1.4	5.4	2.6	0.063	0.321	8.384	9.74	86.08
Bt1	38-83	5.9	12.6	0.98	7.2	1.2	0.039	0.495	8.934	10.53	84.84
Bt2	83-106	5	9.2	0.56	8.4	3.6	0.029	0.304	12.333	13.61	92.50
Bt3	106-120	4.5	5	0.44	5.2	2	0.033	0.343	7.576	9.5	79.75
Mean		5.3	18.9	1.10	6.28	2.2	0.058	0.381	8.919	10.42	85.51
CV		10.921	80.251	61.74	23.141	42.64	69.862	21.875	22.524	18.176	4.545
Itu West-Lying Midslope (Typic Paleudalfs)											
A	0-7	4.5	43.6	2.24	12.8	7.6	0.153	0.374	20.927	22.27	93.97
AB	7-26	4.6	38	1.48	9.2	2	0.133	0.391	11.724	13.4	88.35
Bt1	26-50	4.7	31.5	1.12	6.8	4.8	0.052	0.452	12.104	13.95	86.77
Bt2	50-73	4.8	24.1	1.1	10	4	0.06	0.522	14.582	16.5	88.38
Bt3	73-110	4.8	16	0.84	8.2	3.6	0.064	0.478	12.342	15.42	80.04
Mean		4.68	30.64	1.36	9.4	4.4	0.092	0.443	14.336	16.31	87.50
CV		10.921	80.251	61.74	23.141	42.64	69.862	21.875	22.524	18.176	4.545
Itu West-Lying Footslope (Typic Ferrudalfs)											
A	0-8	4	44.8	1.98	8.8	5.2	0.094	0.408	14.502	15.78	91.90
AB	8-29	4.5	36.2	1.12	7.2	4.4	0.057	0.495	12.152	13.83	87.87
BA	29-86	4.6	24.7	0.98	13.2	6.8	0.07	0.522	20.592	22.36	92.09
Bt1	86-110	4.6	17.6	0.84	8.2	3.6	0.045	0.452	12.297	12.66	97.13
Bt2	110-180	4.9	7.2	0.56	8.4	3.2	0.062	0.382	12.044	14.2	84.81
Mean		4.52	26.1	1.10	9.16	4.64	0.066	0.452	14.317	15.77	90.76
CV		7.237	56.93	48.887	25.481	30.842	27.872	12.899	25.506	24.428	3.373

Key: OM= organic matter, TN=total nitrogen, TEB=total exchangeable bases, CEC= cation exchange capacity, %BS=percentage base saturation of classification. In contrast, at the subgroup and great group levels, the pedon was classified and Paleudalf and Typic Paleudalf, respectively (Table 8). Pedon dug at the Itu west lying footslope was classified as Alfisol at the order level due to the prominent presence of argillic horizon, low organic matter which consistently decreased with soil depth. However, the pedon was classified as Udalf and Ferrudalf at the suborder and subgroup levels, since Udic moisture regime and chroma of 2 up to a depth of 86 cm were observed. At the great group level, the pedon was classified as Typic ferrudalf, since other conditions like mottles were not prominent at that depth. When correlated with the world reference base at this level, the pedon was classified as Haplic Albeluvisols (Table 8).

3.5Fertility Status of the Two Toposequences of Varying Orientations using Elemental Ratios

Using Ca/Mg and K/Mg elemental ratios, the fertility status of the Umudike east lying toposequence and Itu west lying toposequence were assessed and the findings presented in Tables 9 and 10. The results showed that at the Umudike East lying toposequence, mean Ca/Mg values of 2.01, 2.45 and 2.66 were observed for the summit, midslope and footslope, respectively while at the Itu west lying toposequence, mean values of 3.25, 2.49 and 2.03 were recorded for the summit, midslope and footslope. Johnstone (2011) had earlier asserted that the Ca/Mg ratio of fertile soils is usually in the range of 3:1-7:1. Also, Landon (1991) reported that the Ca/Mg ratio of less than 3:1 is typical of unfertile soils. Going by the assertions above, only the summit of the Itu west lying toposquence could be considered fertile while the other top units were of reduced fertility. The very low Ca/Mg observed in the majority of the pedons indicated possible Ca deficiency and inhibition of P uptake in the soils (Udo *et al*., 2009).

Table 8: Classification of the soils of the east and west lying toposequences

Location	USDA Soil Taxonomy System (Soil Survey staff 2010)	World Reference Base, 2010
UELS	Grossarenic Paleudalfs	Mollic Luvisols
UELMS	Typic Paleudalfs	Mollic Luvisols
UELFS	Arenic Hapludalfs	Mollic Luvisols
IWLS	Arenic Glossudalfs	Haplic Albeluvisols
IWLMS	Typic Paleudalfs	Haplic Albeluvisols
IWLFS	Typic Ferrudalfs	Haplic Albeluvisols

Key UELS; Umudike East Lying summit, UELMS: Umudike East Lying midslope
UELFS: Umudike East Lying Footslope, IWLS: Itu West Lying Summit
IWLMS: Itu West Lying Midslope, IWLFS: Itu West Lying Footslope

K/Mg ratio of the soils of the two toposequences varied across the top units and slope orientation. At the Umudike east, lying toposequence, values ranging from 0.01-0.04, 0.01-0.07, 0.01-0.05 were noted for the summit, midslope and footslope, respectively (Table 9). However, at the Itu west lying toposequence, values in the range of 0.01-0.08 were observed at the summit, 0.01-0.07 at the midslope while 0.01-0.02 was noted at the footslope (Table 10). It has been reported that ideal K/Mg ratio in the fertile soils is in the range of 0.2-.0.35 and K/Mg ratio greater than 2:1 may inhibit the uptake of Mg (Udo *et al*., 2009). Consequently, the pedons of the two toposequences of varying orientations were considered infertile. However, inhibition of Mg uptake is not expected in the soils. Generally, there was no well-defined pattern of distribution of the K/Mg ratio in the soils and high variation in distribution was observed.

4.0. Conclusion

The findings of this study showed that the soils of the two toposequences of varying orientation were highly weathered and dominated by sandy clay loam texture. Bulk density values in the east and west slopes were adequate for agricultural production. The soils of the two toposequences were acidic. Organic matter in both toposequences was generally low likewise total nitrogen. There was a clear dominance of Calcium in total basic cations of the soils, especially at the foot slopes. The Ca/Mg, and K/Mg ratios were higher at midslope and foot slope of east lying slope whereas, the reverse was the case in west lying slope where high values were recorded in summit and midslope.

Table 9: Selected fertility indices of the east-lying toposequence

Horizon	Depth (cm)	Ca/Mg	K/Mg
	Umudike East-lying summit		
A	0 -5	1.08	0.03
AB	5-23	3.25	0.04
Bt1	23-56	1.75	0.01
Bt2	56-95	2.5	0.02
Bt3	95-130	1.5	0.01
Mean		**2.016**	**0.022**
CV		**42.743**	**59.265**
	Umudike East-lying midslope		
A	0-7	3.5	0.07
AB	7-37	1.44	0.02
Bt1	37-66	1.22	0.04
Bt2	66-100	5	0.12
Bt3	100-150	1.11	0.01
Mean		**2.454**	**0.052**
CV		**70.385**	**85.355**
	Umudike East-lying footslope		
A	0-7	1.33	0.04
AB	7-20	3.25	0.05
Bt1	20-52	1.43	0.02
Bt2	52-98	3.53	0.01
Bt3	98-150	3.8	0.02
Mean		**2.668**	**0.028**
CV		**44.688**	**58.685**

C/N = Carbon-nitrogen ratio,Ca/Mg = Calcium-magnesium ratio,K/Mg = Potassium –magnesium ratio, CV= Coefficient of variation.

Table 10: Selected fertility indices of the west-lying toposequence

Horizon	Depth	Ca/Mg	K/Mg
	Itu West-lying summit		
A	0-6	3.25	0.08
AB	6-38	2.08	0.02
Bt1	38-83	6	0.03
Bt2	83-106	2.33	0.01
Bt3	106-120	2.6	0.02
Mean		**3.252**	**0.032**
CV		**43.921**	**76.594**
	Itu West-lying midslope		
A	0-7	1.68	0.02
AB	7-26	4.6	0.07
Bt1	26-50	1.42	0.01
Bt2	50-73	2.5	0.02
Bt3	73-110	2.28	0.02
Mean		**2.496**	**0.028**
CV		**44.962**	**76.594**
	Itu West-lying footslope		
A	0-8	1.69	0.02
AB	8-29	1.64	0.01
BA	29-86	1.94	0.01
Bt1	86-110	2.28	0.01
Bt2	110-180	2.63	0.02
Mean		**2.036**	**0.014**
CV		**20.519**	**39.123**

Key: Ca/Mg = Calcium-Magnessium ratio, K/Mg = Potassium –Magnesium ratio, CV= Coefficient of variation.

It can, therefore, be inferred that slope angle and orientation of these toposequencies played a prominent role in regulating these fertility indices. The pedons of the summit, midslope and footslope were as classified Grossarenic Paleudalfs, Typic Paleudalfs and Arenic Hapludalfs, respectively for the east-lying slope and Arenic Glossudalfs, Typic Paleudalfs and Typic Ferrudalfs, respectively for the west-lying slope. Generally, regardless of the influence of top units and slope orientation, the two toposequences were of poor fertility status.

References

Abe S.S, Oyediran G.O, Masunaga T, Yamamoto S, Honna T, and Wakatsuki T (2009). Soil development and fertility characteristics of inland valleys in the rain forest zone of Nigeria: Mineralogical composition and particle -size distribution. Pedosphere, 19:505-514.

Aduloju, M. O. and Tetengi, M. (2011). Physico-chemical properties of soils in a toposequence in Mokwa, Niger State, Nigeria. Crop Res. 42 (1, 2 & 3) : 144-147 (2011) Printed in India.

.Akinbola, G. E., Ojo U. A., and Adigun, M. O. (2009). Variability of properties of some pedons on basement complex of southwestern Nigeria, Proceedings of the 34th annual conference of the soil science society of Nigeria. March 22nd -26th, 2010 Ibadan, Nigeria.

Annan-Afful E, Iwashima N, Otoo E, Asubonteng K.O, Kubota D, Kamidohzono A, Masu M.T, Wakatsuki, T (2004). Nutrient and bulk density characteristics of soil profiles in six land use systems along topo-sequences in inland valley watersheds of Ashanti region, Ghana. Soil Sci. Plant Nutr. 50:649-664.

Birkeland, P. W. (1984). Soils and Geomorphology. Oxford University Press, NY. Pp 448.

Brady, N. C. and Weil, R. R. (2004). The nature and properties of soils, 12th ed. Delhi: Pearson Education.

Brady, N.C. and Weil, R.R. (2010). Elements of the nature and properties of soils. 3rd Edition. Prentice-Hall, Upper Saddle River, NJ.

Bremner, J.M. and Mulvaney, G.S. (1982). Total Nitrogen. In: Page, A.L., Miller, R.H. and Keeney, D.R. (Eds) Part 2 Vol. 9. Methods of soil analysis.American Society of Agronomy. Madison, Wisconsin. Pp 595- 624.

Browaldh, M. (1995). The influence of trees on nitrogen dynamics in an agrisilvicultural system in Sweden. Agroforestry System, 30(3): 301-313.

Buol, S.W., Hole, F.D., McCracken, R.J. and Southard, R.J., (1997). Soil Genesis and Classification, 4th edition. Iowa State Univ. Press, Ames, IA.

Chukwu, G.O. (2013). Soil survey and classification of Ikwuano Abia state, Nigeria. J. of Environ. Sci. and Water Resour., 2 (5): 150 – 156.

Cools, N, and De Vos B (2010). Sampling and analysis of soil. Manual part X, 208 pp. In: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests, UNECE, ICP Forests, Hamburg. ISBN: 978-3-926301-03-1. [http://www.icp-forests.org/Manual.htm].

Esu I. E. (2010). Soil characterization, classification and survey. HEBN Publishers, Plc, Ibadan, Nigeria, 232pp.

Esu, I.E. A.U. Akpan-Idiok and M.O. Eyong. (2008) Characterization and Classification of soils along a typical Hillslope in Afikpo Area of Ebonyi State, Nigeria. Nigerian Journal of Soil and Environment, vol. 8, pp. 1-6, 2008.

FAO (Food and Agricultural Organization) (2004). A Provisional methodology for land degradation assessment.Food and Agricultural Organization, Rome.

FAO (Food and Agriculture Organization) (1998) World Reference Base for soil resources 84 World Resources Report. Food and agriculture the Intervention Organization Rome 1998.

Gee, G. and Or D. (2002) Particle size distribution: In Dane J.H., Topp G.C. (eds). Methods of soil analysis Part 4 Physical methods. Soil Sci. Soc. Am Book series No. 5 ASA and SSSA, Madison WI 2002; 225-293.

Havlin, J.L., Beaton, J.D., Tisdale, S.L. and Nelson, W.L. (2012). Soil fertility and fertilizers. An introduction to nutrient management.7th ed. PHI Private Limited, New Delhi-110001. Pp 513.

Iqbal J., Read J.J., Thomasson A.J. and Jenkins J.N. (2004): Relationships between soil-landscape and dryland cotton lint yield. Soil Sci. Soc. Am. J., 69: 1–11.

IUSS Working Group WRB. (, 2010). Addendum to the World Reference Base for Soil Resources: Guidelines for constructing small-scale map legends using the World Reference Base for Soil Resources. FAO, Rome.

Johnston, J. (2011). Assessing soil fertility; the importance of soil analysis and its interpretation. Potash development association pp19.

Kalivas, D.P. Triantakonstantis, D.P. and Kollias. V.J. (2002) "Spatial prediction of two soil properties using topographic information". Global Nest: the Int. J. vol. 4, no. 1, pp. 41-49, 2002.

Kparmwang, T., Chude, V.O. and Abdullahi, D. (2004). The classification and genesis of benchmark soils of Bauchi State, Nigeria. Journal of Soil Science,14: 30-39.

Landon, J.R. (1991). Brooker tropical Soil manual: A handbook for Soil Survey and agricultural land evaluation in the tropics and subtropics, Essex. Addison Wesley Loghan Ltd. Pp 472.

Landon, J.R. (1996). Soil chemistry. Booker tropical soil manual. Longman England.

Moradi S (2013). Impacts of organic carbon on consistency limits in different soil textures. Int. J. Agric. Crop Sci. 5(12): 1381-1388.

Mulla, D.J. and McBratney, A.B. (2001). Soil spatial variability, pp. 343-374. In A.W. Warrick (ed.). Soil Physics Companion. CRC Press. The USA.

Nelson.D.W. and Sommers, L.E. (1982). Phosphorus. In: page, A.L., Miller, R.H. and Keeney, D.R. (Eds). Methods of soil analysis Part 2. Ameri. Soc. Agron. Madison, Wisconsin. Pp. 539 -579.

NIMET (2008). Nigeria Climate Review Bulletin 2007. Nigerian Meteorological Agency. NIMET-No. 001.7.

Nuga, B.O., Eluwa, N.C and Akinbola.G.E. (2006). Characterization and classification of soils along a toposequence in Ikwuano Local Government Area of Abia State Nigeria. Electronic Journal of Environmental, Agricultural and Food Chemistry. ISSN: 1579-4377.

Obi, J. C. (2015). Particle size fractions and pedogenesis of coastal plain sands. Archives of Agronomy and Soil Science 61(10): 1473–1490

Obi, M.E. (1982). Runoff and soil loss from an oxisol in SouthEastern Nigeria under various management practices. Agric. Water Management, 5:193-203. Ogban, P.I. O. Babalola and A.M Okoji. (1999). "Profile Characteristics of a typical toposequence in Southern Nigeria". Africa Soils, vol. 28, pp. 147–165, 1999.

Onweremadu, E.U. (2006). Application of geographic information system (GIs) on soil land use and soil-related environmental problems in southeastern Nigeria. A Ph.D Thesis of the University of Nigeria, Nuskka, Nigeria 2006, 33 pp.

Orajaka, S. O. (1975). Geology. In Nigeria in maps: Eastern States. G. E. K. Ofomata (Ed.) Ethiope publishing house, Benin City, Nigeria.

Osodeke, V. E. and Osondu. N.E. (2006) "Phosphorus distribution along a toposequence of a coastal sand parent material in southeastern Nigeria". Agricultural J., vol. 1, no. 3, pp. 167-171, 2006.

Osodeke, V.E., Nwotiti, I.L. and Nuga, B.O. (2005). "Sesquioxides distribution along a toposequence in Umudike area of southeastern Nigeria". Electronic J. of Environmental, Agricultural and Food Chemistry, vol. 4, no. 61, pp. 117-1124, 2005.

Peterschmitt, E., Fritch, E., Rajot, J.L., Herbillon, A.J., (1996) Yellowing, bleaching and fertilization processes in soil mantle of the Western Ghats, south India. Geoderma 74:235 – 253.

Soil Survey Staff, (2010). Keys to Soil Taxonomy. 11th Edn., United States Department of Agriculture, Natural Resources Conservation Service, Washington DC., U.S.A.

Sombroek, W.G., and Zonneveld, I.S. (1971). Ancient dune fields and fluviatile deposits in the Rima-Sokoto River Basin (NW Nigeria). A soil Survey paper, No. 5. Soil Survey Inst. Wageningen, the Netherlands, 109 pp. Southeastern Nigeria. East Africa Agricultural and Forestry Journal, 48: 81–91.

Thomas G.W. (1996). Soil pH and soil acidity. In: Sparks D.L, Page A.L., Helmke P.A., Loeppert R.H., Soltanpour P.N., Tabatabai M.A., Johnson C.T. and Summer M.E. (Eds.). Methods of Soil Analysis, Part 3. Chemical Methods. Soil Science Society of America, Inc, and American Society of Agronomy, Maidson, WI.The USA. Pp475-49.

Thomas, G.W. (1982). Exchangeable Cation. In A.L. Page R.H. Miller and D.R Ikeeny (eds). Method of Soil Analysis Part 2.2nd Edition. Am. Soc. Of Agron. Madison, Pp 22-27.

Udo, E.J., Ibia, T.O., Ogunwale, J.A., Ano, A.O. and Esu, I.E. (2009). Manual of soil-plant and water analyses. Sibon Book limited, Festac Lagos. Pp. 183.

Wilding L.P., J. Bouma, and D.W. Boss. (1994). Impact of Spatial Variability on Interpretative Modelling. In: Bryant R.B. and R.W. Arnold- Quantitative Modeling of Soil Forming Process. SSSA Special Publ., No. 39: 61-75.

Zinck, A. (1993). Soil Survey: An epistemology of a vital discipline ITC. Journal 1990, 4: 335-350. Soil Survey Division Staff. 1993. Soil Survey Manual. Soil Conservation Service.