CHARACTERIZATION OF CHEMICAL PROPERTIES OF SOILS IN RELATION TO LANDSCAPE POSITION IN SOUTHWESTERN ANAMBRA STATE, NIGERIA.

Kamalu O. J[1]., Enyioko C. O[2]., Nwokocha, C.C[3] and Amadi-Raphael, K. A. S[1].
[1] Department of Crop and Soil Science, University of Port Harcourt River State.
[2] Department of Soil Science Technology, Federal College of Land Resources Technology, Owerri, Imo State.
[3] National Root Crops Research Institute, Umudike Abia State.
Corresponding Author: Enyioko, C. O. Email: chimexa@yahoo.com. Phone: +234(0)8068611483

ABSTRACT
This study has assessed the relationship between landscape position and soil chemical properties within a catchment in Southwestern part of Anambra State, Nigeria. A total of 54 soil samples were collected (14 samples from genetic horizons from three soil pedons and 40 samples from the minipedons at four predetermined depths of 0 - 20, 20 – 40, 40 - 60 and 60 – 80 cm). The three profiles were located at the upper, middle and foot slopes along the landscape positions. The ranges of Total Organic Carbon and ECEC were 2.0 to 27.30 gkg^{-1} and 3.17 to 5.57 cmolkg^{-1} respectively with relatively higher values recorded in the foot slopes. The same trend was also recorded for exchangeable cations with soils of the upper slope having lower values than the foot slope soils, attributably to excessive drainage from higher elevations. The study indicated that the soils of the upper slope were shallow while the foot slope soils were medium to deep. Soil pH, available phosphorus and base saturation had lower variability and therefore less affected by topography. TOC and Nitrogen showed moderate variation along the catena while ECEC was highly affected by landscape position with a CV of 44%. The study showed that most of soil nutrients significantly increased down the slope due to translocation of materials from upper to the foot slope. Within the catchment, soils of the foot slope are more stable and suitable for arable agriculture while the middle slope and upper slope are suited for plantation agriculture and forestry. Representative pedons of the upper, middle and foot slope were classified as Typic Psammentic Ferrustalf, Typic Psammentic Cambustalf and Typic Psammentic Haplustepts, respectively.
Key words: *landscape, minipedon, transect, catena*

INTRODUCTION
Strong relationship exists between topographic position and soil properties in a given landscape or catchment area. Topography is about the most expressive factor of soil formation, impacting variably on both physical and chemical soil properties as well as use and management of the underlying soils. Topography has been described as both an external and internal factor in pedogenesis. According to Verburg and Overmars (2009), landscape positions and land use are the major factors that influence soil erosion, soil temperature and thus soil formations, leading to changes in soil properties along a toposequence. Researches have been carried out on changes in soil properties along catena as well as their impacts on land management and the properties of soils (Mbagwu and Auerswald, 1999; Amusan *et al.*, 2006). Soil catena-specific management is the process of managing soils based on localized conditions within catena which affects crop yield. To be effective, management schemes must address both soil variability and soil properties that limit yield (Musa, 2015). Several researchers have correlated clay distribution with depth, pH and soil organic matter status along landscape positions. Reports of relative higher clay content, higher organic matter and higher soil pH at the foot slope have been very popular (Onweremadu, 2007; Ogban and Babalola, 2009; Obalum *et al.,* 2011). They also reported that soils on foot slope positions were found to be higher in organic carbon content with greater aggregate stability and higher clay content than those on summit or upper slope positions.

Soil properties vary in vertical and lateral directions and such variations follow systematic changes as a function of the landscape position (slope), soil forming factors and/or soil management practices (land use) (Mbagwu and Auerswald, 1999; Amusan *et al.*, 2006). Land use and soil management practices influence the soil nutrients and soil processes, such as erosion, oxidation, mineralization, leaching, etc, and consequently modify the processes of transport and re-distribution of nutrients. Inappropriate land use can aggravate the rate of soil degradation affecting soil biological and physico-chemical qualities (Saikh *et al.*, 1998). Landscape influences soil texture, root development, exchangeable basic and acidic cations, as well as soil nutrient budget (Bruand *et al.*, 2004). In this study efforts have been made to relate landscape positions to selected soil chemical properties. Changes in land use within the catena in south western part of Anambra State were also related to soil health status and soil management practices.

MATERIALS AND METHODS
Location
The study was carried out in Southwestern part of Anambra State, Nigeria. The area is geographically located on latitude 5°58′24″ N and longitude 6°49′43″ E (Joel and Egbuonu, 2012) (Fig. 1). The study area falls within the humid tropical zone. Jungerius (1964) noted that the area has uniformly high temperature and seasonal distribution of precipitation with humidity being generally high except during the

desiccating weather of harmattan. There are two major seasons, wet and dry, with the former lasting eight months (March – October) and the later four months (November – February). Total annual mean rainfall, ranges from 1590.7 - 2273.4 mm, while the maximum temperature, ranges from 32.5˚ - 36.7 ˚C and minimum temperature, ranges from 22.4˚ - 24.1˚C (Table 1). The major land use / land cover classes included natural lowland forest, bush fallow, small scale cultivation and large scale agriculture.

Soil and Geology of the Study Area

The soils are lateritic in nature and are derived from the underlying Sandstone and Shale units. The soils are dark reddish brown and clayey at the surface and underlain by yellowish and light grey with strongly mottled dark red sandy clay in the lower horizons. The thickness varies from a few centimeters to more than 10 m. The soils are well drained and weakly consolidated in most part of the study area. The study area falls within the Ogwashi-Asaba formation which is Oligocene to Miocene in age. The lithology consists of alteration of clayey shale with seam lignite.

Field Studies

The study was carried out along a transect that is about 10 km. A total of 54 soil samples were collected for the study (14 samples from the pedons and 40 samples from the minipedons). Three (3) representative soil profiles were sunk at the summit, middle and foot slope along the transect. Ten (10) minipeds (each being 80 cm deep) were dug along the transect. 14 genetic horizon soil samples were collected from the three profiles (Four from the profile at the summit and five samples each from the profiles at the middle and foot slope positions). At the minipedons, samples were collected at predetermined depths of 0 – 20 cm, 20 – 40 cm 40 – 60 cm and 60 – 80 cm.

Laboratory Analyses

Soil pH was determined using 1:2.5 soil water suspension using a pH meter (IITA, 1982). Organic carbon was determined by the wet oxidation method (Nelson and Sommers, 1982). Total nitrogen was determined using the Micro-Kjeldal method (Bremner and Mulvaney, 1982), while available phosphorous was by the Bray P-I method (Olsen and Sommers, 1982). Exchangeable bases (Ca, Mg, Na, and K) were extracted with 1 N NH_4OAc buffered at pH 7.0 (Thomas, 1982). Exchangeable acidity (EA) was determined by titration with 0.05N NaOH, while effective CEC was taken as the summation of exchangeable bases and total exchangeable acidity (IITA, 1982). Soil variability was estimated using discrete sampling. This involved collecting soil samples at predetermined locations (crest, hillslope and valley floor) and depths (soil profile horizons) along the toposequence (Mulla and McBratney, 2001). Measures of spread about the mean used the range and coefficient of variation. The coefficient of variation (CV) gives a normalized measure of spread about the mean and was estimated using the equation:

$$CV= \frac{s}{v} X\ 100\%$$

where; S = standard deviation, which is the square root of the sample variance.

v = is the mean of measured values.

Properties with larger CV values are more variable than those with smaller CV values. Wilding (1985) classification scheme for identifying the extent of variability for soil properties based on their CV values was applied in which CV values of 0 - 15, 16 - 35 and > 36% indicate low (least), moderate and high variability, respectively.

RESULTS AND DISCUSSION

Results of chemical properties of the minipedons and the soil profiles are presented in Tables 2 and 3 respectively.

Soil Reaction (pH)

The soils were generally moderate to slightly acidic with pH range of 5.3 – 6.3 as shown in Table 2. Gebeyaw (2007) reported that a lower pH value in cultivated land was attributed to a high rate of organic matter oxidation. This is important to produce organic acids and provide H^+ to the soil solution thereby reducing soil pH values. This explanation was also supported by Butros *et al.* (2010) who reported that soil pH was increased with soil depth along the gradient due to carbonate content of the soil and rain fall.

Available phosphorus

Available P ranged from 17.8 to 32.5 mg/kg (Table 2) in the study area. Available P was moderate probably due to the moderate to slightly acid nature. The presence of organic matter in the top soil induces the solubility and availability of phosphorus. The available P was not strongly adsorbed by the soil colloids.

Table 1: Some climatic data of the study area from 2010-2014.

Parameters	2010	2011	2012	2012	2014
Annual mean max temp (˚C)	32.8	35.3	36.7	32.5	32.7
Annual mean min temp (˚C)	-	23.8	24.1	22.4	23.2
Annual mean rainfall (mm)	1590.7	1910.3	2026.8	2056.7	2273.4
Annual mean radiation (˚C)	18	18.1	18.3	18.6	18.3

Source: National Bureau of Statistics (2015)

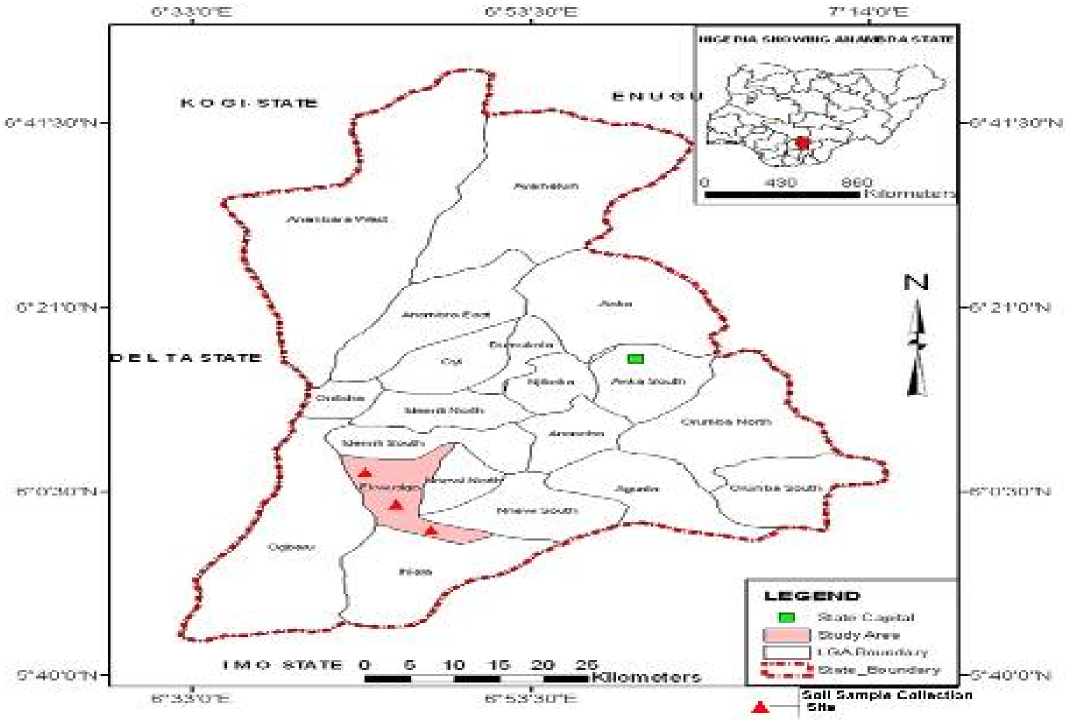

Fig 1: Map of Anambra State Showing the Study Area (Joel and Egbuonu, 2012).

Total Organic Carbon and Total Nitrogen

Total organic carbon (TOC) in the soils was moderate to high and generally decreased with depth in all minipeds and landscape positions (Table 2). Total organic carbon ranged from 1.08 to 2.73% for the surface soils and 0.20 to 1.54% for the subsurface soils. For tropical soils, the organic carbon content is relatively low with a moderate variation along the catena. Total nitrogen was relatively low to moderate and has a positive correlation with organic matter contents. It varied from 0.088 to 0.21% with mean of 0.113% on the surface and 0.018 to o.16% on the subsurface. The result showed that organic matter is the main source of total N as reported by Musa (2015) in his study on catenary variations in soil properties.

Exchangeable Cations and Base Saturation

Exchangeable cations, Ca, Mg, Na and K were relatively low and exhibited low variations along the catena with a CV of 8% (Table 2). Calcium ranged from 0.52 to 1.34 $Cmolkg^{-1}$, Mg ranged from 0.56 to 1.23 $Cmolkg^{-1}$, K ranged from 0.70 to 1.26 $Cmolkg^{-1}$, while Na ranged from 0.51 to 0.87 $Cmolkg^{-1}$. Although ECEC was low, observed base saturation percentage was relatively high ranging from 75.2 to 83.5% and the highest mean of 78.53% was observed at the foot slope. Cation exchange capacity ranged from 3.17 to 5.57$cmolkg^{-1}$ (Tables 2 and 3). This level is generally low for tropical soils.

Table 2: Chemical properties of representative minipedons

Pedon ID	TOC gkg^{-1}	Total N gkg^{-1}	pH	Avail. P (mg/kg)	Ca	Mg	K	Na	TEB	EA	CEC	BS %
							$Cmolkg^{-1}$					
MP1 (0-20)	15.8	1.14	6.3	18.2	1.32	1.00	1.26	0.87	4.45	1.12	5.57	79.89
(20-40)	10.7	0.65	6.3	20.3	1.34	0.98	1.06	0.82	4.20	1.00	5.20	80.76
(40-60)	8.0	0.52	6.0	18.0	0.91	0.87	1.00	0.84	3.62	0.90	4.52	80.00
(60-80)	4.8	0.43	6.2	18.0	0.92	0.82	0.98	0.75	3.47	0.91	4.38	79.22
MP2 (0-20)	10.8	0.88	5.9	22.4	1.21	1.05	1.05	0.76	3.02	0.93	5.00	60.40
(20-40)	6.2	0.78	6.1	20.6	1.19	1.07	1.00	0.81	4.07	0.97	5.04	80.75
(40-60)	4.4	0.62	6.1	20.2	0.91	0.89	1.00	0.82	3.62	0.76	4.38	82.65
(60-80)	4.4	0.57	5.8	18.9	0.67	0.72	0.88	0.74	3.01	0.70	3.71	81.11
MP3 (0-20)	27.3	1.65	6.0	26.4	1.00	1.21	1.19	0.75	4.15	0.98	5.13	80.89
(20-40)	12.0	0.33	5.8	25.9	1.00	0.98	1.20	0.78	3.96	0.82	4.78	82.28
(40-60)	6.3	0.80	5.8	24.8	0.86	0.87	0.91	0.65	3.29	0.83	4.12	79.85
(60-80)	3.7	0.98	5.7	20.1	0.54	0.62	0.77	0.69	2.62	0.84	3.46	75.72
MP5 (0-20)	21.0	1.38	5.5	20.5	1.22	1.09	1.00	0.91	4.22	0.82	5.04	83.73
(20-40)	11.5	0.65	5.7	19.2	1.25	0.92	1.01	0.87	4.05	0.74	4.79	84.55
(40-60)	4.6	0.44	5.8	19.6	0.81	0.78	0.86	0.72	3.17	0.61	3.78	83.86
(60-80)	2.0	0.18	5.6	17.8	0.57	0.66	0.71	0.60	2.54	0.70	3.24	78.40
MP9 (0-20)	17.6	1.35	5.8	28.7	1.00	1.08	0.98	0.76	3.82	1.00	4.82	79.25
(20-40)	10.0	0.90	5.6	28.0	1.01	0.81	0.86	0.56	3.24	0.67	3.91	82.86
(40-60)	8.4	0.72	5.6	24.6	0.65	0.74	0.74	0.51	2.64	0.78	3.42	77.19
(60-80)	3.9	0.36	5.4	22.6	0.61	0.61	0.72	0.54	2.48	0.71	3.19	77.74
MP10 (0-20)	14.8	1.08	6.2	32.5	1.21	1.11	0.99	0.76	4.07	1.01	5.08	80.12
20-40)	10.7	0.90	6.3	29.8	1.00	0.87	1.00	0.62	3.49	0.89	4.38	79.68
(40-60)	6.1	0.77	5.8	25.7	0.78	0.56	0.87	0.58	2.79	0.70	3.49	79.94
(60-80)	4.5	0.50	5.7	21.0	0.65	0.57	0.72	0.58	2.52	0.72	3.24	77.77

TOC = Total Organic Carbon; ECEC = Effective Cation Exchange Capacity; TEB = Total Exchangeable Bases; EA = Exchangeable Acidity; BS = Base Status

Table 3: Chemical Properties of the Genetic Soil Profiles

Pedon Id	Depth (cm)	TOC (gkg^{-1})	pH	Avail. P (mg/kg)	Total N (gkg^{-1})	Ca	Mg	K	Na	TEB	EA	ECEC
						($Cmolkg^{-1}$)						
US	0 – 29	11.7	5.6	26.7	1.60	0.74	0.97	0.72	0.82	3.25	0.78	4.03
	29- 80	11.3	5.7	26.4	1.40	0.76	0.72	0.67	0.82	2.97	0.86	3.83
	80- 142	7.20	5.5	20.4	1.00	0.69	0.65	0.71	0.82	2.87	0.76	3.73
	142-200	3.50	5.9	22.1	0.80	0.85	0.95	0.83	0.76	3.39	0.90	4.29
MS	0 - 22	14.20	6.1	19.6	1.90	0.98	1.28	1.08	0.86	4.20	0.82	5.02
	22- 54	12.50	6.0	28.2	1.60	0.80	1.01	0.98	0.73	2.52	0.92	4.44
	54-115	11.70	5.7	20.7	1.30	0.79	0.98	0.76	0.74	3.27	0.87	4.14
	115-165	11.70	5.9	23.5	1.00	0.82	1.06	0.79	0.75	3.42	0.72	4.14
	165-200	5.70	5.9	26.5	0.60	0.68	0.63	0.66	0.92	2.89	0.79	3.68
FS	0- 31	20.10	6.0	24.8	2.10	1.28	1.24	1.15	1.11	4.78	0.98	6.09
	31-62	15.40	5.7	20.6	1.50	1.14	1.16	1.25	0.85	4.40	0.92	5.87
	62- 123	12.20	5.3	19.8	1.00	1.87	0.88	0.96	0.82	4.53	1.31	5.35
	123-167	7.80	5.5	20.3	1.00	0.89	0.91	1.08	0.98	3.86	0.78	4.22
	167-200	4.60	6.0	28.2	0.80	0.83	0.71	0.81	0.87	3.22	0.73	3.95

US (Upper Slope) ; MS (Middle Slope) ; FS (Foot Slope)

Variability in chemical properties along the Landscape

The degree of variability in soil properties within of the Profiles and surface soils are presented in Tables 4 and 5 respectively.

The variation in chemical properties along the landscape related some worth with the land use potential. Most of soil nutrients significantly increased down the slope due to translocation of materials and its deposition at the foot slope. pH, available Phosphate and base saturation showed low variability thus, less affected by topography. Total Organic Carbon and Nitrogen showed moderate variation along the catena while ECEC was highly affected by landscape position. These changes in soil properties across the slope positions would influence land use and management at the different slope positions along the transect.

Along the catena, the minipeds showed low variation in pH having a CV of 5%. Among the minipedons, Mp10 had the highest variation of 5% while most of the minipeds varied lowly with increase in depth having CV of 2%. The soils of the upper and middle slope vary generally with 3% while the foot slope varied with 5%. Low variation in available P existed at the top soils along the catena. MP 2 had the lowest variation with CV of 7% while MP 8 had the highest variation of 19% as depth increases. Generally, available P decreased with depth. The upper, middle and toe slope had CV of 0.13%, 0.17 and 0.16, respectively. The highest variation in TOC was observed at MP 9 with a CV of 57% while the lowest occurred at MP 1 with CV of 9%. TOC was highest at the toe slope and lowest at the upper slope showing an interaction between slope and organic carbon content. Most of the minipeds showed variability of as low as 1% in the ECEC, while MP 2 showed highest variability of 14%. The cations were generally highest at the foot slope.

Generally, the interaction effects of slope, land uses and soil depths along the catena were highly variable. Along the catena, CEC varied highly with a CV of 44%. This variation was highest in MP10 (21%) and lowest in MP1 (11%). In soil profiles, the upper, middle and foot slopes had variations of 20%, 17% and 18%, respectively. It was greater in the lower slope and also showed the highest variation along the catena. This agrees with the reports by Brady and Weil, (2002) that cation exchange capacity increased with the ability of plant root to anchor soil mass and not rugged landscape which is less vulnerable to landslide due to elevation differences.

Classification of Soils of the Study Area

The soils of the study area were classified using the USDA Soil Taxonomy (Soil Survey Staff, 1975, 1999}. The study area falls within the humid tropical zone with about eight months of rainfall (March – October) and four months (November – February) of dry season. Total annual mean rainfall ranges from 1590.7-2273.4 mm, while the maximum temperature, ranges from 32.5˚ - 36.7 ˚C and minimum temperature, ranges from 22.4˚ - 24.1˚C. Soils in the area are therefore moist for about 200 - 210 days in the year leading to ustic soil moisture regime. The moisture is limited but is present during growing season. The two pedons of the Upper and middle slope have surface with mainly mollic and ochric epipedons and well developed B-horizon but with weak expression of illuvial clay deposition, which makes them Cambic horizon. The presence of both mollic and ochric epipedons is indicative that these profiles could either belong to Alfisols, Ultisols or Inceptisols. Both Upper and middle slope pedons have argillic horizon with base saturation higher than 35% and therefore belong to the Alfisol order while the Foot slope pedon with juvenile features associated with various cycles of deposition belong to the soil order of Inceptisols.

Profile 1 (Upper slope): The soil at the upper slope is classified as Typic Psammentic Ferrustalf. It is generally dominated by sand fraction with texture ranging from fine sand to sandy loam. Presence of argillic and agric horizon which had been formed under cultivation contained significant amounts of illuvial silt and clay. The soil is generally red coloured showing presence of iron oxides with high base saturation greater than 50%. It has a hyperthemic temperature regime with mean annual soil temperature greater than 22˚C.

Profile 2 (Middle slope): The soil at the middle slope is classified as Typic Psammentic Cambustalf. It is also dominated by sand fraction and texture ranges from very fine sand to loamy fine sand with some weak indication of argillic horizon, it has a redder hue at the subsoil. There was presence of iron oxides under- going weathering with high base saturation greater than 50%.

Profile 3 (Foot slope): The soil at the foot slope is classified as Typic psammentic Haplustepts having also predominantly sand texture ranging from sand to sandy loam. It has a follistic epipedon with high amounts of organic carbon and low bulk density. The soil is not saturated with water more than few days after heavy rains. It has ustic moisture regime. There is difficulty in horizon differentiation due to lack of mature profile development. This might be due to frequent and recent deposit or the relatively cold condition of the environment slowing down weathering process.

CONCLUSION

This study revealed that there were changes in soil properties along the soil catena in the study area as shown in the ten minipeds and the three profiles located at designated topographic locations. Some soil properties varied more than others. Most of the chemical properties: pH, available phosphorus and base saturation, showed low variability, thus, less affected by topography. Other chemical properties such as Total Organic Carbon and Nitrogen showed moderate variations along the catena while ECEC was highly affected by landscape position.

Table 4: Soil physico-chemical properties of the Profiles

Landscape position		**Clay gkg^{-1}**	**TOC gkg^{-1}**	**pH**	**Av.P mg/kg**	**TN gkg^{-1}**	**ECEC $Cmolkg^{-1}$**	**BS %**
Upper slope	**Range**	36.0-200.0	5.70-11.70	5.5-5.9	20.4-26.7	0.80-1.60	3.39-4.03	77.54-80.60
	Mean	99.0	8.90	5.68	23.9	1.21	3.75	78.53
	SD	6.45	0.29	0.17	3.14	0.20	0.27	1.63
	CV	0.65	0.33	0.03	0.13	0.12	0.07	0.02
Middle slope	**Range**	140.0-216.0	5.70-14.20	5.7-6.1	19.6-28.2	0.60-1.90	3.68-5.02	56.76-83.67
	Mean	198.30	11.20	5.68	23	1.16	4.30	75.51
	SD	3.89	0.39	0.17	3.84	0.20	0.49	12.66
	CV	0.19	0.32	0.03	0.17	0.14	0.12	0.17
Foot slope	**Range**	180.0-260.0	9.60-20.10	5.3-6.0	19.8-28.2	0.80-2.10	3.82-5.09	74.95-91.47
	Mean	219.20	15.70	5.7	22.74	1.28	5.10	82.22
	SD	2.83	0.41	0.31	3.65	0.70	0.97	6.30
	CV	0.13	0.25	0.05	0.16	0.29	0.19	0.08

TOC = Total Organic Carbon; Av. P = Available phosphorus; TN = Total Nitrogen; ECEC = Effective Cation Exchange Capacity; BS = Base Saturation

Table 5: Variations in soil chemical properties of the top soil along the catena

Sample ID	**TOC gkg^{-1}**	Total N gkg^{-1}	**pH**	**Avail. P (mg/kg)**	**BS %**	**ECEC $Cmolkg^{-1}$**
MP1 (0-20)	14.8	1.02	6.3	18.2	79.89	5.57
MP2 (0-20)	10.8	0.88	5.9	22.4	60.40	5.00
MP3 (0-20)	27.3	1.65	6.0	26.4	80.89	5.13
MP4 (0-20)	19.5	1.15	5.4	25.6	83.59	5.12
MP5 (0-20)	21.0	1.38	5.5	20.5	83.73	5.04
MP6 (0-20)	14.6	1.10	6.0	20.8	79.80	4.78
MP7 (0-20)	12.8	0.88	6.1	27.6	80.67	5.07
MP8 (0-20)	14.8	1.05	5.9	30.5	79.18	4.85
MP9 (0-20)	17.6	1.15	5.8	28.7	79.25	4.82
MP10 (0-20)	14.8	1.08	6.2	32.5	80.12	5.08
Mean	16.7	1.13	5.91	25.32	78.65	5.05

SD	0.49	0.048	0.28	4.70	6.64	0.22
CV	0.29	0.025	0.05	0.19	0.08	0.44
Variability	**moderate**	**moderate**	**low**	**low**	**low**	**high**

CV: Low variation ≤ 15%, Moderate variation > 15 ≤ 35%, High variation >35

REFERENCES

Akamigbo, F.O.R. and Asadu, C.L.A. (1986), "The Influence of Toposequence on some Soil Parameters in selected areas of Anambra State, Southeastern Nigeria", *J. Soil Sci.*, 6, 35-46.

Amusan, A. A., Shitu A. K., Makinde, W.O and Orewole, O. (2006). Assessment of Changes in Selected Soil Properties under Different Land Use in Obafemi Awolowo University Community, Ile-Ife, Nigeria. Electronic Journal of Environmental, Agricultural and Food Chemistry, 5(1), 2006: 1178-1184.

Blake, G. R. and Hartge, K. H. (1986). Part 1. Physical and mineralogical methods.Agronomy monograph No. 9. 2nd Ed. American Society of Agronomy, Soil Science Society of America. Madison, Wisconsin.

Bremmer, J.M. and Mulvaney. C. S. (1982). Total N. In: Methods of Soil Analysis. Part 2. Page et al. (eds) 2nd. Agron. Monog. 9. ASA and SSSA, Madison WI. (895-926).

Brady, N. C. and Weil, R. R., (2002). The nature and properties of soils. 13th ed. Prentice Hall Inc., New Jersey. 960p.

Bruand A., Hartmann C., Santi Ratana-Anupap, Pramuanpong Sindhusen, Poss R., Hardy M. 2004 – Composition, fabric, and porosity of an Arenic Haplustaff of Northeast Thailand: Relation to penetration resistance. Soil Science Society of America Journal, 68, 185–193.

Butros, I. H., Awni, Y. Taimeh and Feras, M. Ziadat., (2010). Variation in soil chemical properties along toposequences in an Arid Region of the Levant.Catena 83, 34-45.

Cresswell H.P. and Hamilton, E. (2002) Particle Size Analysis. In: Soil Physical Measurement and Interpretation For Land Evaluation. (Eds. NJ McKenzie, HP Cresswell and KJ Coughlan) CSIRO Publishing: Collingwood, Victoria. pp 224-239.

Danielson, R.E. and Sutherland P.L. (1986). Porosity, pp. 443-461. In Methods of soil analysis.

Gebeyaw, T. (2007). Soil fertility status as influenced by different land uses in Maybar areas of south Wello zone, north Ethiopia, M.Sc. Thesis Submitted to School of Graduate Studies, Alemaya University, Ethiopia. 86p.

Gee, G.W. and Or, D. (2002). Particle Size Analysis. In: Methods of Soil Analysis, Dane, J.H. and G.C. Topp (Eds.). ASA and SSSA, Madison WI., (91-100).

Hamilton, A. C. and Bemsted, R. (Eds.) (1987).Forest conservation in the East Usambara Mountains, Tanzania. International Union for Conservation of nature (IUCN) report. Glad.

International Institute of Tropical Agriculture (1982). Selected methods for soil and plant analysis manual. Series 1. Pp. 4-7.

Joel, E. U. and Egbuonu, C. O. (2012).The Impact of Deforestation in Anambra State: The Ekwusigo Example. Journal of Life Sciences. Vol. 6,pp 1150-1157.

Jones, M.I. and Wild, A. (1975). Soils of West African Savannah. The maintenance and improvement of their fertility. Trechnical Communication No. 55 of the Commonwealth Bureau of Soils, Harpenden, UK. Common Wealth Agriculture Bureau (CAB), Farnham Royal, UK., pp: 246.

Jungerius, P.D. (1964). The Soils of Eastern Nigeria. Publication service Geologique de Luxemburge XIV. pp: 185-196.

Maja, S. (2011). Nitrogen and Phosphorus Dynamics Across an Elevational Gradient in a Swedish Subarctic Tundra. Doctoral Thesis, Swedish University of Agricultural Sciences, Umea.

Mbagwu, J.S.C. and Auerswald, K. (1999). Relationship of percolation stability of soil aggregates to land use, selected properties, structural indices and simulated rainfall erosion. Soil & Tillage Research 50 (1999) 197-206.

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

Musa, H. (2015). Catenary Soil Variability and its Management Implication along a toposequence, Northeastern Nigeria International Journal of Science, Environment and Technology, 4, (5), 1279 – 1288.

National Bureau of Statistics (2015). http://www.informationng.com/tag/national-bureau-of-statistics

Nelson, D.W. and Sommers, L.E. (1982). Total Carbon, Organic Carbon and Organic Matter. In: Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties, Wisconsin, A.L. (Ed.). 2nd Edn., ASA and SSSA, Madison, WI., pp: 539-579.

Obalum, S.E., Nwite, J.C., Oppong, J, Igwe, C.A. and Wakatsuki, T. (2011).Variations in selected soil physical properties with landforms and slope within an inland valley ecosystem in Ashanti Region of Ghana. J.Soil Water Res. 6(2):73-82.

Ogban, P.I., Babalola, O. (2009). Characteristics, classification and management of inland valley bottom soils for crop production in subhumid southwestern Nigeria Agro-Sci.8:1-13.

Olsen, S. R., Sommers. L.E. (1982). Determination of available phosphorus. In "Method of Soil Analysis", vol. 2, ed. A. L. Page, R. H. Miller, and D. R. Keeney, 403. Madison, WI: American Society of Agronomy.

Onweremadu, E. U. (2007). Availability of Soil Nutrients in Relation to Land Use and Landscape Position. Int. J. Soil Sci. 2 (2):128-134.

Saikh, H., Varadachari, C. and Ghosh, K. (1998). Effects of deforestation and cultivation on soil CEC and contents of exchangeable bases: A case study in Simlipal National Park, India. Plant and Soil 204: 175-181, 1998.

Soil Survey Staff (1993). New soil survey manual. U.S.D.A. Soil Conservation Service. U.S. Government printing office, Washington D.C. Soils Science.325.html

Soil Survey Staff, (1999). Keys to soil taxonomy 8th ed. United States Department of Agriculture.

Thomas, G.W. (1982). Exchangeable Cations. In: Methods of Soil Analysis, Page, A.L., R.H. Miller and D.R. Keeney (Eds.). ASA and SSSA, Madison, WI. (159-165).

Verburg, P.H. and Overmars, K.P. (2009). Combining top-down and bottom-up dynamics in land use modelling: exploring the future of abandoned farmlands in Europe with the Dyna-CLUE model. Landscape Ecology 24(9): 1167-1181

Wilding, L.P. (1985). Spatial variability: its documentation, accommodation and implication to soil surveys, In: Soil Spatial Variability: Pudoc, D.R. Nielsen and J. Bouma (eds). Wageningen, Netherlands (166-94).