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Effects of Topography on Soil Properties and Their Implications for Agricultural Land Use in Ipinu-Oju, Benue, Nigeria

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Abstract: Assessing soil properties and providing information on their variability is critical to understanding the potential of soils and their response to agricultural management. This study investigated the variations in soil morphological, physical and chemical properties along a toposequence in Ipinu-Oju, Benue State. A total of 16 soil samples were collected along altitudinal transect ranging from 160m to 201m. The transect was divided in four slope positions: Crest, upper, middle, and toe slope positions, each with different floristic composition and structure. The collected soil samples were analyzed for morphological, physical and chemical properties using standard field and laboratory procedures. The laboratory results were then analyzed using ANOVA. The results showed a strong relationship between topography and certain soil properties. A transition from yellowish to grayish soil color was observed from the upper slope to the lower slope areas. In addition, soil depth and structure improved downslope. Topography significantly influenced chemical and physical properties, including sand, clay, silt, pH, total nitrogen, organic carbon and matter, available phosphorus, potassium, sodium, exchange acidity, cation exchange capacity, and base saturation. Based on the USDA Soil Taxonomy and the World Reference Base, soil units I, III, and IV were classified as Arenic Haplustalfs and Eutric Lixisols, while soil unit II was classified as Eutric Haplustalfs and Eutric Leptisols. These differences in soil characteristics not only affect crop selection, but also present unique management challenges. Upland soils face issues such as surface runoff, erosion and water retention as their main management problems, while lowland soils do not have significant management problems. Over all, this study highlights the importance of considering soil variability and the influence of topography on soil properties. Understanding these variations can help in making informed decisions regarding soil management and agricultural practices.

Keywords: Topography, Topo Sequence, Soil Morphology, Soil Physical and Chemical Properties, Land Use, Soil Classification

1. Introduction

The relationship between topography and soil characteristics has long been recognized as a critical factor influencing land use decisions and agricultural productivity. According to [1], understanding how topographic features shape soil properties is essential for sustainable land management and optimization of agricultural practices. Variations in soil characteristics, which are primarily influenced by climate, are controlled by slope and aspect. Topography, as one of the soils forming factors, causes changes in the morphological and physicochemical properties of soils in agricultural landscapes as one moves from ridge positions to valley bottoms [2]. The topography of a landscape can influences soil biomass, incoming solar radiation, soil physicochemical properties, and precipitation, which affect crop production. While soil properties such as bulk density, temperature, and clay particle size decrease with increasing elevation, deposition and accumulation of soil organic carbon and moisture are usually higher in floodplains [3]. Topography not only contributes to the variation in soil properties, but also determines the types of crops that can be grown in different landscapes. The removal and redistribution of weathered materials, primarily caused by erosion effects, leading to variations in soil nutrient composition in different landscapes, is determined by topography [4, 5]. Understanding the contribution of topography in the agricultural landscape will help in quantifying the fertility and productivity of such soils, which will subsequently lead to better soil conservation development strategies that can eliminate uniform soil management resulting in uneven application of inputs in the agricultural landscape located on topography [6]. Good land management planning is key to achieving sustainable agriculture. Therefore, studying soil morphological and physiochemical properties in relation to slope will provide basic soil management information needed for crop production [7]. Variations in soil properties can be attributed to the flow of water from upslope to downslope, which causes the removal, transport, deposition, and accumulation of weathered materials [8, 9]. While clay particles are transported further down the slope during runoff, sand particles in soil solution are first removed and deposited in the upper slope. The influence of topography on soil properties is mediated by two main processes. While many attempts have been made to understand the factors responsible for the spatial distribution of soils in Ipinu-Oju, Benue, little attention is given to the contribution of topography to soil morphological and physicochemical properties and their potential implications for crop production. This Study was therefore carried out to investigate the effects of topography on soil morphological and physicochemical properties along the Oju-Benue toposequence and their implications for crop production.

2. Materials and Methods

2.1. Study Area

The study was carried out along a transect at the latitudes 6^{o} N and 6^{o} 30’ N and longitudes 8^{o} and 8^{o} 30’ E (see Figure 1) in Ipinu-Oju which is located in the South-east of Benue State, Nigeria. The transect is 1000 m long and 50 m wide with elevation ranging from 160 m on the toe slope to 232 m on the crest. The underlying bedrock within the study area consists primarily of sandstone. Soils located on the toe and middles slopes were classified as Ustic Epiaquerts, upper slope were classified as endoaqualfs, and the crest Arenic paleustalfs [10]. The drainage pattern in Ipinu-Oju is mainly influenced by the tributaries of river Oyongo which flows through the area.

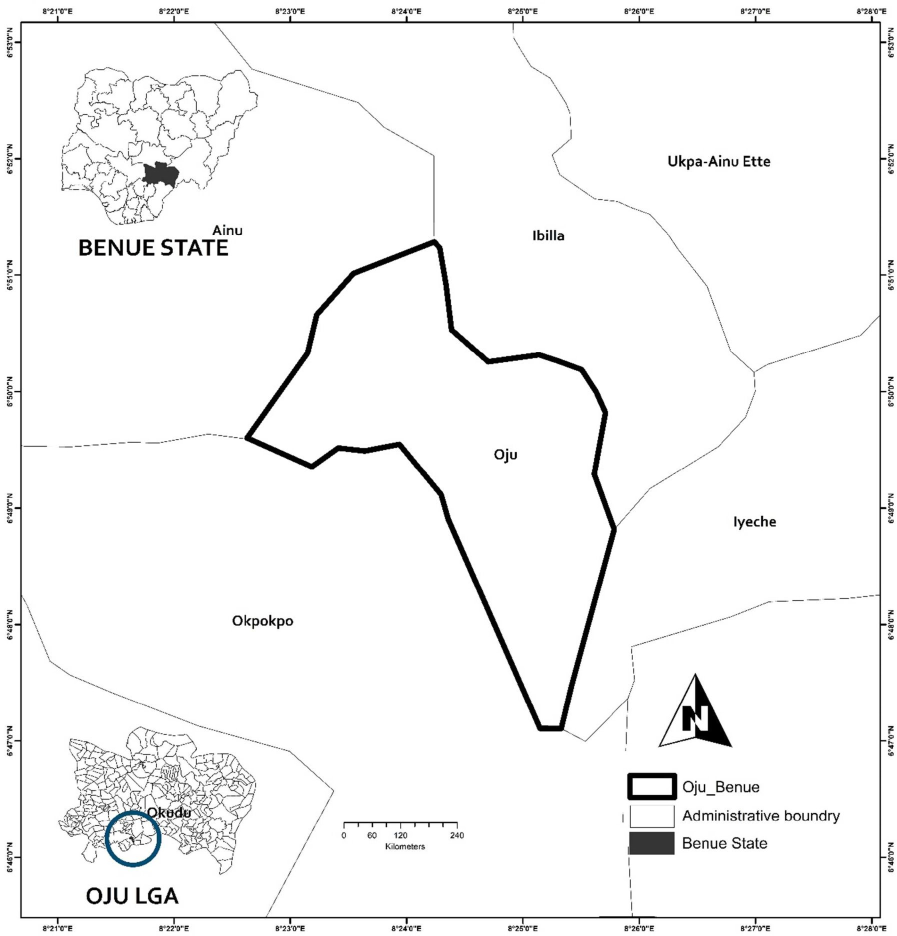

Figure 1. *Map of Study Area.*

Major crops grown in the area include; yam (*Dioscorea spp*), cassava (*Manihot esculenta*), maize (*Zea mays*), millet (Pennisetum glaucum), rice (*Oryza sativa*) and vegetables. The vegetation in Ipinu-Oju falls within the Guinea Savanna vegetation zone. Common trees include; mango (*Mangifera indica*), oil palm (*Elaeis guineensis*), orange (*Citrus species*), pawpaw (*Carica papaya*), obeche (*Triplochiton scleroxylon*), mahogany (*Khaya iveronsis*), gmelina and grasses such as spear grass (*Impereta cylindrica*), guinea grass (*Panicum maximum*) and yam which is the major staple crop is grown in large mounds 1m x 1m on the toe slope and 3 m - 4 m on the upper slope due to the shallow soil.

2.2. Field Investigations

The field investigations involved excavation of four (4) profile pits located on the crest measuring 5 m × 4 m × 0.76 m at the altitude of 232 m, upper slope measuring 5 m × 4 m × 0.28 m at the altitude of 201 m, middle slope measuring 5 m × 4 m × 1.30 m at the altitude of 198 m, and toe slope measuring 5 m × 4 m × 1.4 m at the altitude of 160 m manually (see Figure 2). A total of 16 soil samples were collected from the four profile pits for laboratory analysis. The horizons were identified by observing the different soil color in each profile. Bulk samples were collected manually. The morphological description of the profiles was done by feel and using the Munsell soil color chart, and soil structure and consistence evaluation were performed following the guidelines of Food and Agricultural Organization of USA [11] by feel when dry, moist, and wet and drop and shatter method for soil structure. The bulk soil samples were air dried and gently crushed using a mortar and pestle, and sieved through a 2 mm sieve. The fine soil fraction (<2 mm) was ready for physical and chemical analysis. The texture of the soils in each profile was determined using USDA soil textural triangle.

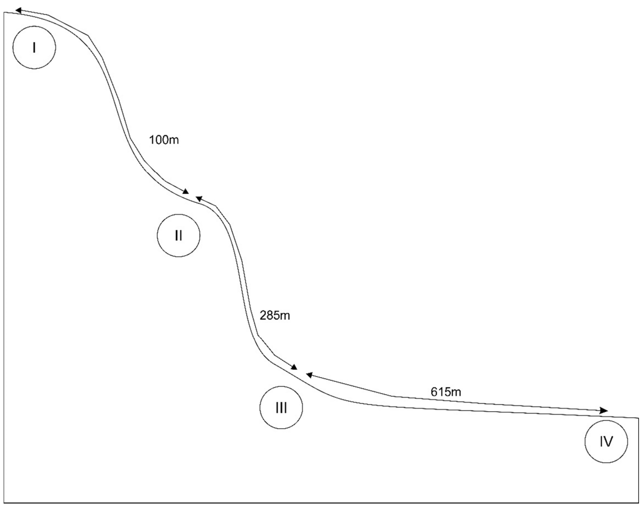

Figure 2. *Profile Pits along the Topo-sequence.*

2.3. Laboratory and Statistical Analysis

Soil pH was determined potentiometrically in H_2O at the soil to water solution of (1:1) using a combined electrode pH meter [12]. The soil particle sizes were measured using the Bouyoucous method [13] after removing the organic matter using hydrogen peroxide and dispersing the soils with Sodium hexametaphosphate (calgon). Organic carbon was determined using the Walkley-Black method [14], total nitrogen (TN) of the soils was determined through digestion, distillation and titration procedures of macro-Kjeldahl using Kjedahl method [15], the available phosphorus (avP) was determined using the Bray No. 1 method [16]. Exchange Acidity was determined by titration [17], exchangeable cations (Ca, Mg, Na, K) and CEC in the soils were determined by atomic absorption spectrophotometer method [18], exchangeable Calcuim (Ca), Magnesium (Mg), Potassium (K), and Sodium (Na) were measured by saturating the soil samples with 30 ml of ammonium acetate (1N NH_4OAC) solution at a pH of 7.0. Subsequently, potassium (K) and sodium (Na) were determined with a flame photometer, while Mg and Ca were determined by atomic absorption spectrometer The cation exchange capacity was calculated by summing the exchangeable bases and the exchange acidity. Percentage base saturation was obtained by dividing the sum of bases (Ca, Mg, K and Na) by the CEC and multiplying by 100. The soils were classified according to USDA soil taxonomy and World Reference Base. Statistical analysis was performed using Microsoft Excel 365. ANOVA was used to determine the significance of differences in soil physical and chemical characteristics between different soil units along the toposequence. ANOVA evaluates whether there are statistically significant differences in means between soil units (I – IV). Variation was considered when the P-value was less than the alpha value (0.05), and not significant when it was otherwise.

3. Results and Discussion

3.1. Soil Morphological Properties

All the soil units had a shallow to moderately deep profiles (Table 1). Fewer (2) horizons were identified on soil unit II (upper slope) in comparison to other units. The fewer horizons in unit II can be attributed to soil instability caused by continuous processes of soil erosion respectively [19]. The morphological results showed that discernible variation in horizon thickness occurred in the study area as shown in table 1. For example, a horizon was shallow (13 cm) in soil unit I (crest) in comparison to other soil units with thickness of 15 cm on the upper slope, 18 cm on the middle slope and 30 cm on the toe slope. Thickness variation may be attributed to the influence of slope length, steepness, and shape that facilitated the rate at which water moves into and out of the soil. The erosion effects of this running water may cause the removal of the soils on slopes resulting in thinner surface layer, A horizon [19]. On the other hand, the increment in A horizon thickness down the slope could be attributed to soil deposition at the lower landscape positions and this agrees with the previous findings of [20]. This result indicated that soil unit II was most susceptible to topographic and gradient effects when compared to soil units II, III, and IV. In addition, the horizon of the soil profiles was characterized by gradual smooth to diffuse irregular boundaries as shown in table 1. This change in profile boundary can be attributed to predominance of volcanic ash deposit where plants added organic matter to form an A horizon. The color of the soils ranged from reddish brown, brownish dark to very dark grey. The occurrence of different colors in the study area revealed that soil color is influenced by topography.

Table 1. *Morphological Description of the Soils along the Topo sequence.*

Horizon	Depth(cm)	Color	Mottle	Texture	Structure	Consistence	Inclusion	Boundary
Soil Unit I		Matrix						
A	0–13	10YR 5/8		SL	1MCR	SSW	Cfr	GS
Ap	13–50	5YR 5/8	2.5Y 2/0	SL	2SBK	VSW	Ffr	AS
B	50–76	5YR 2/2	2.5Y 2/0	SL	2SBK	SPW	Vffr	
Soil Unit II Ap	0–15	5YR 2/3		SL	2FCr	SSW	Cfr	GS
AC	15–28	7.5YR 6/8		SL	2SBK	SW	Fcr	
Soil Unit III								
A	0– 18	10YR 4/3		SL	3GS	NSW	Mmr	DS
A1	18–68	7.5YR 5/8	7.5YR ¾	SL	2SBK	NPW	Cr	DI
B	68–130	5Y 4/3	5Y 4/3	SCL	2FSBK	SSW	Cs	
Soil Unit IV								
A	0–30	7.5YR 4/4	2.5Y 2/0	SL	2FCR	NSNPW	Cmr	DS
A1	30–80	5YR 5/8	2.5Y 2/0	SL	CSBK	SSSPW	Ffr	D
AB	30–110	7.5YR 5/2		SL	1FSBK	SSSPW	Vfmr	Ds
B	110–140	5YR 5/2	2YR 4/8	SCL	3SBK	VSVPW	Mcg	

Legend: SL = Sandy Loam, SCL = Sandy Clay Loam, 1MC= Weak Medium Crumb, 2SBK = Moderate Sub Angular Blocky, 3GRS= Strongly Granular, 2FSB = Fine Sub Angular Blocky, CSB=Coarse Sub Angular Blocky, 3SB=Strong Sub Angular Blocky, SSW=Slightly Sticky Wet, VSW=Very Sticky Wet, SW=Sticky Wet, NSW=Not Sticky Wet, NSNPW=Non Sticky Non Plastic Wet, SPSSW =Slightly Plastic Slightly Sticky Wet, VSVPW =Very Sticky Very Plastic Wet, NPW=Non Plastic Wet, CFR=Common Fine Root, FFR = Few Fine Root, CR= Common Roots FCR= Few Common Roots, VFFR = Very Few Fine Root, MMR= Many Medium Root, CMR = Common Medium Root, VFMR = Very Few Medium Root, CS= Common Stone, MCG = Many Coarse Gravels, D=Diffuse, CS= Clear Smooth, DS=Diffuse Smooth, GD= Gradual Diffuse.

The variation in soil color ranging from reddish brown to a very dark grey in the upper and lower horizons on the different topographic positions indicated good drainage conditions of these soils under study. The toe slope had darker surface (7.5 4/4) compared to sub-surface horizons (5YR 5/8) due to high organic matter content of surface horizon. Similarly, the dark grey color (7.5 YR 4/4) recorded on the surface horizon of soil unit IV (toe slope) could be attributed to the clotting of calcium and iron with humus components. Similarly, the difference in soil color along the toposequence may be due to soil drainage and Fe content. The result of similar study reported by [19] showed that soil color appears to be a function of chemical and mineralogical composition and textural structure of soils and is conditioned by topography. The wide range of soil color (yellow-dark) recorded may be due to the different drainage patterns and chemical weathering that occur in different topographic positions [21]. The consistencies of the soil at moist varied from friable to firm, non-sticky to very sticky and non-plastic to slightly plastic wet. However, the dry consistence ranged from loose to hard. The friable consistent indicates that the soil can easily be worked on at good moisture level [19]. The overall sticky to slightly plastic shows the dominant of smectite in the study area. Despite the fact that consistency is some intrinsic soil characteristics, the changes in soil consistency in the study area can be attributed to the presence of high organic matter in the surface horizons. Roots were found in all the soil units with very few medium roots confined up to the depth of 110 cm. The presence of mottles in the profiles indicates wetting and drying processes occurring within the soil profile. The Soil structure in the profiles varied from strong granular to strong sub angular blocky, with granular structure associated with the surface horizons and blocky structure associated with the subsurface horizons. The granular structure in the surface horizons of the crest and upper slopes is indicative of high biological activity in the study area [22]. On the other hand, the presence of moderate to sub angular blocky in the lower horizons may be attributed to increase in clay content, tillage, climate and soil compaction [23].

3.2. Soil Particle Size Distribution

The combination of the field and laboratory textural analyses results indicated that the soils in the study area was dominated by sandy loam. The textural classes were all sandy loam. The results of Table 2 showed that mean percentage values of sand ranged from 71.93 to 75.44 %, silt (10.97 to 12.48 %, and clay (13.05 to 16. 67 %). The highest value of 75.44 % for sand was obtained in upper slope and lowest (71.93 %) in toe slope. The highest (12.48 %) silt mean value was recorded in soil unit IV (toe slope) and lowest (10.97 %) in soil unit I (crest). Similarly, the highest mean value (15.67 %) of clay was obtained in unit III and lowest value (13.05 %) was recorded in soil unit II. Soil particle sizes were significantly influenced by topographic positions at ($p<.05$) as shown in table 2. The percentage of sand decreased from the top slope to the bottom slope. The higher percentage of sand fraction recorded on the upper slope may be attributed to the initial deposition of sand particles in the runoff. During runoff, sediments with higher density are deposited first, while lighter particles are carried further to the lowlands. Also, findings by [24] suggested that the high percentage of sand fractions reflects the dominance of sand-forming minerals in the parent materials from which soils are formed. The increasing values of silt with decrease elevation also agreed with the findings of [24]. Similarly, the higher value of clay recorded on soil unit IV (toe slope) can be attributed to the removal, transport and deposition of fine soil particles from the upper slope to the lowland. The general increase in clay content with depth could be attributed to vertical translocation of clay through the process of lessivage and illuviation. The higher clay content in soil unit III was consistent with the findings of [23, 25] who reported that illuviation and destruction of clay particles were the factors responsible for the variation in clay distribution in different agricultural landscapes.

Table 2. *Particle Size Distribution and Soil Texture.*

Soil Unit	Sand (%)		Silt (%)		Clay (%)		P-value	Texture (class)
	Mean	STD	Mean	STD	Mean	STD		
I	74.84	0.94	10.97	0.05	14.19	0.93	9.3594E-11*	Sandy loam
II	75.44	0.91	11.51	0.69	13.05	0.21	4.0142E-06*	Sandy loam
III	72.17	4.56	12.16	1.04	15.67	3.75	1.1418E-06*	Sandy loam
IV	71.93	3.45	12.48	0.56	15.58	3.18	2.6015E-10*	Sandy loam

Key: STD: Standard Deviation Alpha Value: 0.05 NS = Not Significant * = Significant

3.3. Soil Chemical Properties

The mean values of pH (in water) ranged from 6.19 to 6.54 (Table 3) which is slightly acidic [26] and fall within the range of most crop requirements. The results of soil pH showed that pH values were significantly affected my topographic positions at $p<0.05$ (Table 3). Highest pH value of 6.54 was recorded in the toe slope and this could be attribute to accumulation of soluble cations on the toe slope [27]. On the other hand, the lowest pH value of 6.19 obtained in the middle slope may be due to microbial oxidation that produces organic acids that supply H+ ions to the soil solution thereby lowering the soil pH. The mean percentage values of organic carbon (OC) content of the soils ranged from 0.39 to 0.56 % (Table 3) and was rated medium and high [28]. The highest OC value of 0.56 % was recorded in soil unit I (crest) and this could be attributed to the effect of elevation on temperature, vegetation composition, soil and water balance, soil erosion and geological deposition processes, soil microbial and, soil and water balance, soil erosion and geological deposition processes, soil microbial and biological activities, and other processes, which in turn affect the content and changes in OC. The accumulation of OC usually decreases with increase in temperature and moisture of the soil as suggested by [29]. The results of table 3 indicated that topographic positions significantly influenced the percentage OC content of the soils under study. The variability in OC along the toposequence could be due to differences in temperature and precipitation between different topographic positions. In general, the percentage OC content of the study area increased with increased in altitude. The mean percentage nitrogen values ranged from 0.44 to 1.42 %. (Table 3) and was classified as moderate according to the soil nitrogen rating of [30]. The moderate to high value of total N recorded suggests that soils with more than 0.15% total N have high mineralization capacity, while soils with less than 0.07% have low N mineralization. The TN result (Table 3) showed that highest value (1.42 %) was obtained on the toe slope and lowest value (0.44 %) on the middle slope. The result showed a discernible significant variation due to topographic effect. The highest value of total N recorded on the toe slope could be attributed to mass movement by water resulting in the transport of organic material and clay particles from the upper slope to the toe slope. On the other hand, the lowest total N recorded in the middle slope may be attributed to intensive cultivation, plant uptake and volatilization due to high temperatures [31]. Similarly, [32] reported lower N values at lower slope positions in Nigerian soils. The values of available phosphorus (avP) varied from 4.13 to 5.03 ppm (Table 3) and was rated low [32].

Table 3. *Chemical Properties of the Study Area.*

Soil Unit		I		II		III		IV		F-value	P-value
Statistic		Mean	STD	Means	STD	Mean	STD	Mean	STD		
pH	-	6.29	0.03	6.50	0.14	6.19	0.12	6.54	0.24	106.35	6.87E-10*
OC	(%)	0.56	0.07	0.54	0.06	0.39	0.09	0.52	0.07	37.06	3.98E-06*
OM	(%)	0.96	0.11	0.93	0.11	0.67	0.15	0.90	0.15	25.40	4.79E-05*
N	(%)	0.51	0.05	0.49	0.01	0.44	0.05	1.42	2.05	14.61	0.000931*
P	(ppm)	5.03	0.15	4.85	0.35	4.73	0.31	4.13	0.62	25.56	4.61E-05*
Ca	cmol/kg	3.17	0.15	2.85	0.07	2.80	0.20	2.80	0.56	0.40	0.SS534284NS
Mg	cmol/kg	3.00	0.20	2.65	0.07	1.70	1.21	2.90	0.27	0.04	0.844209NS
K	cmol/kg	0.26	0.03	0.30	0.01	0.28	0.04	0.28	0.03	45.22	9.29E-07*
Na	cmol/kg	0.23	0.02	0.26	0.00	0.24	0.04	0.26	0.03	46.33	7.73E-07*
EA	cmol/kg	1.07	0.06	1.09	0.08	1.06	0.04	1.08	0.07	20.02	0.000189*

Soil Unit		I		II		III		IV		F-value	P-value
Statistic		Mean	STD	Means	STD	Mean	STD	Mean	STD		
CEC	cmol/kg	7.73	0.39	7.14	0.07	6.97	0.60	7.58	0.60	148.06	3.04E-11*
BS	(%)	86.37	0.67	84.80	0.99	84.73	1.45	85.63	1.76	24411.44	5.31E-35*

Alpha Value: 0.05 NS = Not Significant * = Significant

The results of Table 3 revealed that topographic positions significantly influenced the available P content of the soil. The highest value of 5.03 ppm was recorded on the crest and the lowest value (3.3 ppm) on toe slope. The values of available phosphorus in the study area decreased down the slope agreeing with the findings of [33] who suggested that parent materials and topography are the main factors of variation in soil phosphorus. The highest value of available P recorded on the crest showed that there is a strong relationship between SOC and available P. The mean Exchange Acidity (EA) values varied from 1.06 to 1.09 cmol/kg (Table 3) was rated very low [34]. The results of exchange acidity showed that topography significantly influenced its distribution in the study area, and the variation was attributed to water flow and organic matter content. The highest value of 1.09 cmol/kg was obtained in soil unit II (upper slope) and the lowest (1.06 cmol/kg) was recorded in soil unit III. Exchange acidity values decreased from soil unit II to soil unit III and later increased in soil unit IV (toe slope) as shown in Table 3. This result showed that there was a significant difference in Exchange Acidity distribution in the study area. The mean values of exchange cations ranged from 2.80 to 3.17 cmol/kg for calcium, 1.70 to 3.00 cmol/kg for magnesium (Mg), 0.26 to 0.30 cmol/kg for potassium (K) and 0.23 to 0.26 cmol/kg for sodium (Na). (Table 3) and the values were low [32]. Exchangeable Ca was dominant on the exchange sites followed by Mg, K and Na. The dominance of Ca over Mg, K and Na in the soils may be due to the fact that, among the exchangeable cations, Ca is the least leached from the soil environment studied [35]. The concentration of basic cations was significantly influenced by topographic positions, whereby the highest and lowest values were recorded in soil unit I and III respectively. The low value of exchangeable bases may be attributed to the high weathering intensity and low soil organic carbon content. [36] observed that low organic matter has a low capacity to hold cations in exchangeable form. The prevalence of Ca followed by the rest in the exchangeable site of soils is favorable for crop production. The mean values of cation exchange capacity varied from 6.79 to 7.73 cmol/kg (Table 3). The highest value of 7.73 cmol/kg was obtained in upper slope and the lowest (6.97 cmol/kg) in middle slope, and this could be attributed to the removal and deposition of EC by water and erosion [19]. The CEC was significantly different ($P<0.05$) in relation to topographic position as shown in Table 3. Base saturation represents the percentage of CEC occupied by bases (Ca^+, Mg^+, K^+, and Na^+) and the values ranged from 84.73 to 86.37 and was considered high [36]. The highest value of base saturation recorded in soil unit I can be attributed to the contribution of soil organic matter. The base saturation distribution was similar to CEC. The percentage base saturation result is also correlated with the pH distribution in the study area and this is in agreement with the finding of [37] who reported that percentage base saturation increases with soil pH. The variations in the mean value of base saturation in relation to slope positions indicated that topography has a strong influence on percentage base saturation in the study area. The lowest and highest values obtained in soil units III and I could be attributed to plant nutrient uptake and leaching [38]. The soils were classified according to the USDA soil taxonomy [39] and correlated with the World Reference Base (WRB) of the soil classification system. The results showed that soil unit 2 does not have an argillic horizon with base saturation greater than 50% (Na4OAcpH 8.0). This qualifies soil unit II as Entisol at the soil order level, well drained soils with no evidence of any form of mottling, indicating that the ustic soil moisture regime dominated its development and are classified as Ustent. The soils are minimally developed and qualify as Haplustent. The very high base saturation qualifies them as Eutric Haplustent at the subgroup level. In the World Reference Base, the soil is qualified as Haplic Leptosols, (Eutric, Arenic). The other soil units I, III and IV have well-developed B horizons and base saturations greater than 80% and developed under ustic soil moisture regimes. Thus, they were classified as Alfisol at the soil order level and Ustalf at the suborder level.

The lack of a clear C horizon indicates that the soils are in the early stages of their development, and therefore they were designated Haplustalf at the major group level and Arenic Haplustalf at the subgroup level due to their very high sand fractions. The soils were classified as Eutric Lixisols (Haplic, Arenic) according to the World Reference Base classification (Table 4).

Table 4. *Soil Classification after USDA Soil Taxonomy and WRB.*

Soil Units	USDA Soil Taxonomy	World Reference Base
I	Arenic Haplustalf	Eutric Lixisols (Haplic, Arenic)
II	Eutric Haplustalf	Eutric Leptisols (Eutric, Arenic)
III	Arenic Haplustalf	Eutric Lixisols (Haplic, Arenic)
IV	Arenic Haplustalf	Eutric (Haplic, Arenic)

Key: USDA: United State Department of Agricultur

4. Conclusions

The soils of the Ipinu-Oju, Benue, Nigeria topo sequence showed variability in morphological and physicochemical characteristics as influenced by topography. While soils of middle and toe slopes were deep with well-developed horizons, soils of upper slope were shallow with poorly developed horizons. Similarly, soil color and texture were influenced by topography, as mid- and toe-slope soils were dark grayish and loamy, while upslope soils were dark reddish and coarse. In addition, topographic position strongly influenced some soil chemical properties such as organic carbon, organic matter, total nitrogen, available phosphorus, exchange acidity, potassium and sodium cations, cation exchange capacity, base saturation, and soil ph. In contrast, both magnesium and calcium were influenced by topography. Overall, there was significant variation between soil properties and topographic positions in the study area. These relationships are further influenced by land use and management such that the different facets of the toposequence are limited to different crops and management practices such as fertilizer application, irrigation and drainage. Soils of the crest, middle slope and toe slope were classified by FAO as Arenic Haplustalf and Eutric Lixisols (Haplic, Arenic) in the World Reference Base. Soils of the upper slope unit were classified as Eutric Haplustent and Haplic Leptisols (Eutric, Arenic) in the World Reference Base. Differences in soil properties were caused by removal, transport, deposition, and accumulation of eroded materials and mobile chemical constituents by erosion and runoff. Soil variability with slope position was caused not only by pedogenic processes but also by leaching and soil moisture regimes. Further studies are recommended to determine whether topography is the only factor responsible for soil variability in the study area.

Author Contributions

All authors contributed to the conception and design of the study. Materials preparation, data collection, and analysis were performed by [Peter Omenka Ogbu], [Shaibu Idoga], [Paul Ogbaji Okwe]. Investigation of data curation, methodology, writing of the original draft review, and editing were performed by Peter Omenka Ogbu. All authors commented on drafts of the manuscript. All authors read and approved the final version of the manuscript.

Data Availability

Available upon request.

Declaration

Conflicts of interest: The authors declare no conflict of interests.

References

[1] Lal, R. (2015). Restoring soil quality to mitigate soil degradation. Sustainability, 7 (5), 5875-5895.

[2] Agbuchu CN (2014) Variability in soil Properties as Influenced by Different Land Use Types in an Utisols of the Tropical Region, Delta State, Nigeria. Agriculture Tropica Et Subtropica Journal. Vol. 2, pp 43-48. DOI: 10.3478/ats-2014-0006.

[3] Nahusenay A, Kibebew K (2015) Land suitability evaluation in Wadla Delanta massif of north central highlands of Ethiopia for rainfed ceop production. Academic Journals. Vol. 10 (13), pp 1595-1611. https://doi.org/10.5897/AJAR2014.9248

[4] Chadwick K, Asner G (2016) Tropical soil nutrient distributions determined by biotic and hill slope processes. Biogeochemistry, 127 (2–3), 273–289. https://doi.org/10.1007/s10533-015-0179-z

[5] Vanacker V, Ameijeiras-Mariño Y, Schoonejans J, Cornélis, J, Minella PG, Lamouline F (2019) Land Use Impacts on Soil Erosion and Rejuvenation in Southern Brazil. Catena, 178, 256- 637266.https://doi.org/10.1016/j.catena.2019.03.024

[6] Oku E, Essoka A, Thomas E (2010) Variability in soil properties along an Udalf toposequence in the HumidForest Zone of Nigeria. Kasetsart Journal (Nat. Sci) 44: 564-573.

[7] Akhtaruzzaman M, Haque EM, Osman TK (2014) Morphological, Physical and Chemical Characteristics of Hill Forest Soils at Chttagong University, Bangladesh. Open Journal of Soil Science. Vol. 4 pp 26-35. DOI: 10.4236/ojss.2014.41004.

[8] Tsui, C, Chen C, Hsieh C (2004) Relationship between Soil Properties and Slope Position in Lowland Rainforest of Southern Taiwan. Geoderma 123 (1-2): 131-142. https://DOI:10.1016/j.geoderma.2004.031.

[9] Moges A Holden N (2008) Soil Fertility in Relation to Slope Position and Agricultural Land Use: A Case Study of 6 Umbulo Catchment in Southern Ethiopia. Environmental Management, 42, 753-763. 601. http://dx.doi.org/10.1007/s00267-008-9157-8

[10] Ogbu J, Shaibu I, Abagyeh SO, Ugese FD, Jabir U (2019) Characterization and Classification of Soils of Obukiyo, Oju Local Government Area of Benue State, Nigeria. Nigerian Journal of Soil Science. 27-34. 10.36265/njss.2019.290203.

[11] FAO (2020) Soil testing Methods-Global Soil Doctors Programme-A farmer-to-farmer training program. Rome. https//doi. Org/10.4060/ca2796en.

[12] Longanathan P (1984) A laboratory manual on soil plant analysis. Sibon books ltd, flat Blk 6, Fourth Avenue Fastac, Lagos.

[13] Bouyocous GJ (1962) Hydrometer method of improved for making particle size analysis of soils. Agronomy Journal, vol.54, Pp 464-465.

[14] Walkley, A., & Black, A. I., (1934). An Examination of the Degtiareff method for Determining Soil Organic Matter and Proposed Modification of the chromic Acid Titration method. Soil sci. 37: 29-38.

[15] Black CA (1965) Methods of soil analysis: part 1 physical and mineralogical properties. American Society of Agronomy, Madison Wisconsin.

[16] Udo EJ, Ibia, TO, Ogunwale, JR Ano AO, Esu IE (2009) Manual of soil, plant and water analysis. Sibon Books 633 ltd. Lagos, Nigeria https://www.scirp.org/(S(351jmbntvnsjt1aadkozje))/reference/referencespapers.aspx?referenceid=2023233

[17] Coscione R, Andrade C, Raji Van (1998) Revisiting titration procedures for the determination of exchangeable acidity and exchangeable aluminium in soils. Communications in Soil Science and Plant Analysis 29: 11. https//doi.org/10.1080/00103629809370086

[18] Senjobi BA (2007) Comparative assessment of the effect of land use and land type on soil degradation and productivity in Ogun State. Nigeria –published ph. D. Thesis submitted to the Department of Agronomy, University of 621 Ibadan, Ibadan 1-161.

[19] Dinku D, Shelem B, Ram N, Walley F, Gala TS (2014) Effects of Topography and Land is on Soil Characteristics along the Toposequence of Ele Watershed in Southern Ethiopia. Catena 115, pp 47-54. DOI: 10.1016/j.catena.2013.11.007.

[20] Sheleme Beyene (2011) Soil Characterization along toposequence in Gununo area, Southern Ethiopia. Journal of Science Development. Vol 1 (1) pp 31-39.

[21] Georges, KK, Roger KE, Benard KY (2021) Soil organic carbon distribution in a humid tropical plain of Cameroon: Interrelationships with soil properties. Journal of Applied and Environmental Soil Science. http://doi.org/10.1155/2021/6052573

[22] Yitbarek T, Shele YT, Shelem B, Kibebew K, (2016) Characterization and Classification of Soils of Abobo Area, Western Ethiopia. Journal of Applied and Environmental Soil Science. https://doi.org/10.1155/2016/4708235

[23] Mesfin BH, Zerihu W, Zemede A, Ermias L (2023) Impact of Elevation Change on the Physicochemical Properties of Forest Soil in South Omo Zone. Southern Ethiopia. Applied and Environmental Soil Science Journal. DOI: 10.1155/2023/7305618.

[24] Kebede M, Shimbir T, Kasa G, Girma T (2017) Description, characterization and classification of the major Jinka Agricultural Centre, South Western Ethiopia. Journal of Soil Science and Environmental management, 8 (3): 61-69. DIO: 10.5897/JSSEM2015.0498.

[25] Saravanan S, Kamarasan, M (2018) A review on pH level determination of soil using image processing techniques. Journal of Emerging Technologies and Innovative Research, 5 (7), 872-888.

[26] Chun-Chi T, Zuang-Sang C, Chang- Fu H (2004) Relationships between soil properties and slope positions inlowl and of forest Southern Taiwan. Geoderma. https//doi.org/10.1016/j.geodema.2004.01.031

[27] Ravikumar P, Somashekar KR (2013) Evaluation of nutrient index using organic carbon, available P, available K 611 concentrations as a measure of soil fertility in Varahi River basin India. Proceedings of the International 612 Academy of Ecology and Environmental Sciences, 3 (4): 330-343. https://www.iaees.org/publications/journals/piaees/online.version.asp

[28] Jaksic, S., Ninkov J, Milic S, Vasin J, Zivanov M, Jaksic D (2021) Influence of Slope Gradient and Aspect on Soil organic Carbon Content in the Region of Nis, Serbia. Vol. 13 (15). https://doi.org/10.3390/su13158332.

[29] Hazelton, P. A. and Murphy, B. W. (2007) Interpreting Soil Test Results: What Do All the Numbers Mean? CSIRO Publishing, Melbourne. https://doi.org/10.1071/9780643094680

[30] Tolessa, T., Sebenta F., (2018). The Extent of Soil Organic Carbon and Total Nitrogen in Forest Fragments of Central Highlands of Ethiopia. Journal of Ecology and Environment. https://DOI:10.1186/s41610-018-0081-4.

[31] Jimoh IA, Mbaya LA, Akende D, Agaku HS, Haruna S (2020) Impact of Toposequence on Soil Properties and Classification in Zaria, Kaduna State, Nothern Guinea Savanna, Nigeria. International Journal of Environmental Quality. Vol. 38, pp 48-58. DOI: 10.6092/issn-2281-4485/10043.

[32] Tiruneh GA, Alemayehu TY, Vogelmann ES, Reichert JM, Haegeweyn N (2021) Spatial Variability of Soil Chemical 626 Properties Under Different Land-uses in Northwest Ethiopia. PLoS ONE 16 (6): 627. https://doi.org/10.1371/journal.pone.0253156

[33] Susanna, M., Stephen, P., (2013). Parent Material and Topography Determine Soil Phosphorus Status in the Luquillo Mountains of Puerto Rico. Ecosystems, Vol 16, pp 284-294. https://DOI:10.1007/s10021-012-9612-5.

[34] Adamu U, Muhammad A, Adam I (2014) Evaluation of soil reaction, exchangeable acidity and cation exchange capacity of soils from Kano University of science and technology, Wudil Teaching, Research and commercial farm, Gaya. Bayero Journal of Pure and Applied Sciences 7 (1) pp 52-55. http://dx.DOI.org/104314/bajops.v7i1.10

[35] CUCE (2007) Cation exchange capacity (CEC). Agronomy Fact Series #22. Department of Crop and Soil Sciences, College of Agriculture and Life Sciences, Cornell University.

[36] Benard N, Eckhard G, Winfried C, Elke N (2010) Phosphorus uptake from sparingly available soil P by cowpea (Vigna ugunculata) Digital Library. Integrated Plant Nutrient Management in Sub-Saharan Africa: from concept to practice. DOI: 10.1002/jpln.200900210.

[37] FAO (2006) World reference base for soil resources 2006. A frame work for international classification, correlation and communication. Rome FAO.

[38] Havlin, JL (2005) Soil fertility and nutrient management in book: Landscape and land capacity, Boca Raton: CRC Press, second edition. Pp 251-265. DOI: 10.1201/9780429445552-34.

[39] Soil Survey Staff (2014) Keys to Soil Taxonomy.12th Ed. USDA. NRCS Washington D. C.