International Journal of Weather, Climate Change and Conservation Research, 10(1),21-41, 2024
Print ISSN: ISSN 2059-2396 (Print)
Online ISSN: ISSN 2059-240X (Online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development -UK

Characterization and Classification of Soil Along a Toposequence and its Implications on Crop Production in Dundaye District Sokoto, Nigeria

[1]Ukoh Ikpe Patrick, [1]Samaila S. Noma and [2]Elisha Ikpe

[1]Department of Soil Science and Agric. Engineering, Usmanu Danfodio University, Sokoto
[2]Department of Geography Education, Federal College of Education, Odugbo, Benue State
Corresponding Author's Email/Number: ukohpatrick123@gmail.com - +234-8068329224

doi: https://doi.org/10.37745/ijwcccr.15/vol10n12141 Published January 31, 2024

Citation: Patrick U.I., Noma S.S., and Ikpe E. (2024) Characterization and Classification of Soil Along a Toposequence and its Implications on Crop Production in Dundaye District Sokoto, Nigeria, *International Journal of Weather, Climate Change and Conservation Research,* 10(1),21-41

ABSTRACT: *This study characterized and classified soils along a toposequence and its implications on agricultural activities in Dundaye district of Sokoto State, Nigeria. Two pedons on three (3) different topographical positions (summit, shoulder and foot slope) on a toposequence were studied. The Summit was on relatively flatland with an elevation of 283m above sea level; shoulder was a gently sloppy land with an elevation of 271m above sea level, while the foot slope was on a low land with an elevation of 262m above sea level. Morphological properties of the soils revealed that soils of the upper slope were shallow and perfectly drained and were generally sandy in texture. Those on shoulder were deep and well drained while those at the foot slope have subangular blocky structure with evidence of biological activities at the surface. Physical properties of the soils indicate a relatively high bulk density and high porosity. The dominant exchangeable bases were Ca and Na. The soils were slightly acidic in reaction with pH range of 5.3 to 5.4, 5.2 to 5.4 and 6.5 to 6.7. Organic matter content of the soils was generally low range from 0.33 to 0.37, 0.08 to 0.16 and 0.88 to 0.93. The soils were rated low in nitrogen. The results of available phosphorus show an irregular distribution in the profiles. The soils were rated having very low available phosphorus. The implication of these on crop production is that: the pH value was rated slightly acidic to neutral which favours the cultivation of grain crops. The low organic matter content recorded on most of the soils cannot sustain crop production on long time bases. Therefore, the study recommend that the organic matter content must be substantially increased through effective crop residue management; use of mineral and organic fertilizer; addition of more organic manure and crop residue for optimum plant growth.*

KEYWORDS: classification; crops production; catena; soils and toposequence

INTRODUCTION

African soils are characterized by rolling topography and soil properties changes due to the factor of slope which plays a vital role in influencing soil properties as one move from crest position down to the valley bottom (Egbuchua, 2014). Apart from parent material and climate, topography is another important factor that plays important roles in the distribution of soil minerals. Topography/relief determines the drainage and depth of a soil profile; for instance, soils on higher elevation are usually well-drained whereas soil on the lower slope is usually poorly drained and of fined texture (Jimoh, Mbaya, Akande, Agaku, Haruna (2020).

Topography of a landscape can influence soil physicochemical properties, biomass production, incoming solar radiation, precipitation and affect crop production. As topography gradually increases down the slope, there is a significant increase in soil moisture, soil organic carbon while bulk density, pH and soil temperature would be significantly lower at the higher elevations (Nahusenay and Kibebew, 2016). Lawal et al. (2014) states that water velocity on a slope affect the deposition of materials in suspension, sand drops out of suspension first, while clay size particles can be carried further away from the upland before they are deposited on the floodplains. This process of geological sorting of suspended soil materials as they travel along a slope brings about variations in soil texture as we move from upland to lowland.

A toposequence is defined as a succession of sites from crest to the valley bottom which replace catena in soil topography relationship studies (Okusami, *et al,* 1985). Ogunkunle and Onasanya (1992) reported that different soil units exist on a toposequence and may require different management systems. The influence of gradient is higher than that of parent material on the properties of soil units on a toposequence (Olatunji *et al*., 2007). Topography is concerned with local detail in general, including relief, vegetative and artificial features, local history and culture. A geomorphic surface is a portion of a landscape created by surface or specifically defined in space and time or a part of the land surface with definite geomorphic boundaries formed by one or more agency in a given period (Daniels, Gamble and Cady, 1970). They are reasonably smooth and approximately horizontal planes that cut across structural and lithological boundaries (Gerrard, 1981).

Since Dundaye district is an agrarian community outskirt of Sokoto town and not much study has been done on the soils of the area, characterization and classification will help reveal information that could be useful in the management and use of the soils on a sustainable manner. The objective of this research, therefore, is to characterize and classify the soils of Dundaye District and examine its implication on crop production.

Previous studies (Akamigbo, 1999; Adekayode and Akomolafe, 2011; Jimoh, Mbaya, Akande, Agaku, Haruna, 2020; Oriako, Obineche, Ezechike and Ezema, 2022) reported that topography played a major role in influencing soil characteristics and distribution; landscape position was found to have influenced both morphological and physical properties of the soils as indicated by the differences in soil properties between soils of the summit, shoulder and foot slope with series of implication on crop production. This study will go a long way to supporting researchers, farmers and agriculturist who will want to embark on massive agricultural production in the study area and Nigeria at large that have similar land terrain and it can be expanded to accommodate other regions of the world at large.

MATERIALS AND METHODS

The Study Area

Sokoto State is in the North-West Sudano-Sahelian Savannah ecological belt of Nigeria between Latitudes 11° 03' and 13° 50' N of the Equator and Longitudes 4° 14' and 6° 40' E of the Greenwich Meridian (Abubakar, 2006). Its headquarters is at Sokoto. It has an area of 25,973 Km^2. It is bounded by Niger Republic to the north, Zamfara State to the east and south and Kebbi State to the west. Presently, the State has twenty-three (23) Local Government Areas (LGAs) (see Figure 1).

The climate of Sokoto is tropical continental and is dominated by two opposing air masses: tropical maritime and tropical continental. The tropical maritime is moist and blows from the Atlantic, while the tropical continental air mass, is dry and blows from the Sahara Desert. The rainy seasons are usually short, which is often within the ranges of four to five months (May/June to September/October). Evapotranspiration is usually high most especially in the dry season (Desanker and Magardza, 2001). The annual rainfall is between 500mm in the north and 800mm to the south. The showers rarely last long and are far from the regular torrential rain known in wet tropical regions. According to Odjugo (2010), this short growing season affect crop yield and makes it difficult to cultivate crops that require longer growing season and high amount of rainfall; but favours grains like millet, sorghum and maize which have short growing season and require low amount of rainfall.

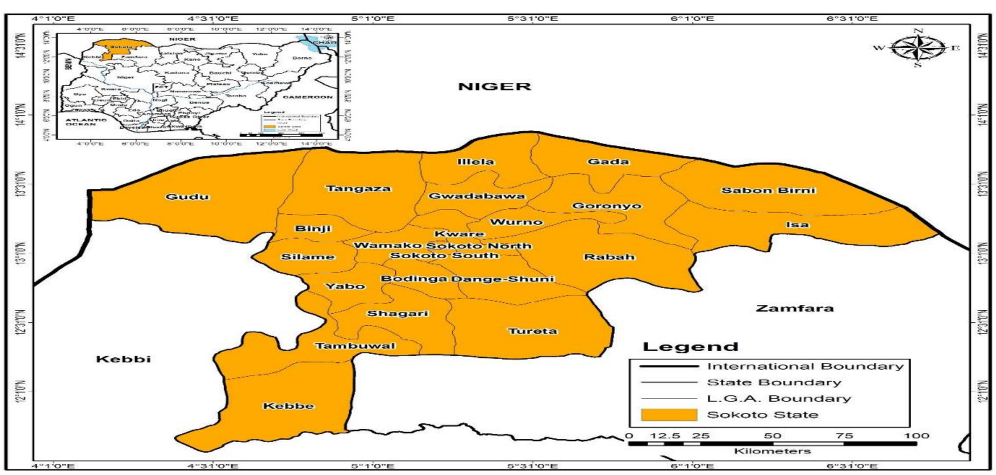

Figure: 1. Sokoto State (Study Area)
Source: Administrative Map of Sokoto State (2022).

The average temperature during the dry season is about 40.6ºC. However, maximum daytime temperatures are for most of the year generally under 40°C. The hottest months are February to April when daytime temperatures can exceed 45°C. Dwyer, Ghannoum, Nicotra and Caemmerer (2006) reported that high temperature affects C4 plants such as maize through its effects on the availability of water which is very important in the process of photosynthesis. From late October to February, during the dry season, the climate is dominated by the Harmattan wind blowing Sahara dust over the land (Abubakar, 2006).

The topography of Sokoto State is dominated by the famous Hausa plain of northern Nigeria. It comprises extensive tracts of almost level to gently undulating landscape. The highest and most impressive massifs occur in the south-east. On the plains the general height difference between valleys and adjacent domes is only 10-20 meters. Typical cross-sections consist of a broad dome area; long, straight middle slopes of less than 2º and short, steep lower slopes showing signs of physical weathering (Schultz, 1975). The vast floodplains (fadama land) of the Sokoto-Rima River systems dissect the Hausa plain into rich alluvial soils that is suitable for the cultivation of a variety of crops. Most of the agricultural activities in the state are carried out along the vast floodplain's areas.

Sokoto is located within the Illumeden basin, which is surrounded to the east and south by the Precambrian basement complex. The general geology of the Sokoto basin is classified into three: one, the Pre-Cretaceous basement rocks exposed in the south-eastern part of the state. This comprise of older granites, undifferentiated meta-sediments and metamorphic rocks. Two, Cretaceous sedimentary formations which consist of the Gundumi, the Illo and the Rima group formations. Three, the sedimentary formations in the north-western area of the state. This consists of the Sokoto group formations and the Gwandu formation. Quaternary Sediments particularly covers the above three systems along the rivers (Udo, 1970). The geology of Sokoto State is very important as it determines the parent material from which soil is formed. The parent materials determine the kind of soil that could be found in an area.

Sokoto is drained by the Rima River. The Goronyo dam impounds the Rima in Goronyo. Most of the tributaries of the Goronyo River have their source in the northwestern part of the State and in the neighbouring Zamfara State, while the Bunsuru and Gangere rivers flow in a northerly direction, joining the Rima near Sabon Birni, the Sokoto, Zamfara and Ka tributaries, on the other hand, flow west wards to join the Rima (Sani, 2005). According to Abubakar (2006), there are other smaller seasonal rivers and swamp/depression that surrounds Sokoto. The presence of these rivers enables farmers in the state to grow crops during the dry season through irrigation system.

The study area combines both sandy and alluvial type of soils. On the upland, soil types such as sandy soil can be found, while along the Fadama areas soils like loamy and alluvial soils are found. The fadama soils are mostly hydromorphic soils which are clayey and loamy with grey or black colour (Sheik and Aliyu, 2017). Vegetation in the study area is typical of Sudan Savannah, characterized by short grasses, trees and sparse shrubs interrupted by medium-sized isolated trees. The Sudan savannah is influenced by many physical and human factors (Davis 1982). There is more continuous cover of grasses during the rainy season, but during the dry season it is bare except for small scrubby plants.

Sample preparation

The samples were air-dried, gently crushed using a wooden mortar and pestle and then sieved through a 2mm-mesh. The sieved samples were stored in labeled polythene bags for physical and chemical analyses. Particle size distribution was determined by the hydrometer method (Gee and Bauder, 1986).

Bulk density determination

Bulk density was determined by drying the undisturbed core sample to a constant weight at 105^{0}C for 24hours. The oven-dried weight of the soil sample was divided by its volume according to Blake and Hartge (1986). The bulk density of the soils was calculated using the formula:

$$Db = \frac{M}{Vb}$$

where,
M= mass of the oven-dried Weight of the soil (Mg)
Vb= bulk volume of core sampler (M^3)

Porosity determination

Porosity was determined using the expression:

$$F = 1 – (bd/pd) x100$$

Where, db = bulk density (Mg/m^3)
pd= particle density (Mg/m^3)

Electrical conductivity (EC)

Electrical conductivity meter was used to determine the electrical conductivity of the soils in a paste of 1:1 soil/water (Jones, 2001).

Soil reaction

The soil pH was determined using a glass electrode pH meter. The determination was done in water using 1:1 soil solution ratio (Mclean, 1982). Organic carbon was determined by the modified Walkley-Black Method (Nelson and Sommers, 1982). Total nitrogen was determined by Micro-kjeldhal digestion-distillation method (Bremner, 1965). The available phosphorus was determined by Bray Number-one method (Bray and Kurtz, 1945). The exchangeable bases were determined using the ammonium acetate extract from cation exchangeable capacity (CEC) determination. Flame photometer was used to determine the potassium and sodium content. While Calcium and magnesium were determined using EDTA, the CEC was determined by neutral ammonium acetate method buffered at pH7 (Thomas, 1982).

Soil samples were leached with potassium chloride solution. The Aluminum (Al) and Hydrogen (H) ions in the leachate were titrated against standard NaOH solution using phenolphthalein as indicator (Jones, 2001).

Base saturation
Base saturation is the total exchangeable bases divided by CEC. Exchange capacity is expressed as a percentage. Exchangeable sodium percentage (ESP) was calculated using the Formula:

$$\frac{\text{Exchangeable } Na^{+}}{\text{CEC Cmol/kg}} \text{ X } 100\%$$

Sodium adsorption ration (SAR) was calculated using the Formula

$$\frac{[Na^{+}]}{\sqrt{½ \{[Ca^{2+}] + [Mg^{2+}]\}}}$$

Statistical analysis
Measured variables in the data set were analyzed using descriptive statistic.

RESULTS AND DISCUSSSION

Description of the toposequence

The summit was on relatively flatland with an elevation of 283m above sea level. The vegetation was characterized by thorny species with a scattered acacia species in all the soil units. The shoulder was a gently sloping land with an elevation of 271m above sea level while foot slope is a lowland with an elevation of 262m above sea level. The tributaries follow the same pattern with Rima-Sokoto rivers.

Soil morphological properties
The summit is made up of material of aeolian deposit (sand deposit) over ironstone. The soils were generally well-drained and young with a weakly developed marked AC horizon. The soils were light red (5YR 6/6) at the surface and changed to red (2.5YR 4/8) at the subsurface. The soils were generally shallow because of the presence of ironstones (hardpan) and perfectly drained. Texturally, the soils were sandy at the surface and loamy sand at subsoil. The structure of the soils was generally strong medium to coarse, angular blocky structure. In terms of consistency, the soils were generally firm. There were many fine roots and many fine pores. Similarly, large and small coarse fragments (ironstones) were found in the surface horizon of the soils and subsurface. The boundary was gradually smooth.

Shoulder

The colour of the soils were red (5YR 8/4) at the surface, changing to reddish yellow (7.5YR 8/6) at the subsurface. The soils were well drained but shallow in depth. The soils were generally loose with subangular blocky structure. The soils had developed from aeolian-colluvial sandy material (Sokoto cover sand). The texture of the soil varied from sandy on the surface to loamy sand at the subsoil; it has diffused horizon boundary and evidence of microbial activities at the surface between 10cm to 25cm of the soil depth. The shoulder was overlain by the Gwandu formation which is covered by loose sand and laterite. The sediments are of continental Lacustrine origin.

Foot Slope

The soils of the foot slope were red (5YR 4/2) at the surface and changed to dark reddish gray (5YR 4/1) at a depth of 61cm, very dark gray (10YR 3/1) at the subsurface, with bands of rusty reddish black (10YR 3/3) mottles. Mottling occurs right at the subsurface horizon. There were few fine roots, few fine pores with subangular blocky structure. The soil developed from colluvial and aeolian material. The morphological properties of the soils presented in Table 2.

Table 2: Morphological properties of the soils of Dundaye District

Pedon	Horizon	Depth (cm)	Colour (Moist	Textural class	Structure	Consist.	Mottling	Roots	Pores	Coarse fragment %	Boundary
					***Typic Haplustepts* (Summit)**						
	Ap	0-15	5YR $^{6}/_{6}$	S	Abk	Fi		Mfr	Mfp	-	GS
1	AC	15-22	2.5YR $^{4}/_{8}$	LS	Abk	Fi		Ffr	Ffp	Mcf	D
	C1	27-39	2.5YR $^{4}/_{6}$	S	Sabk	Lo		Mfr	Tp	Mcf	GS
	C2	39-58^{+}	2.5YR $^{3}/_{6}$	LS	Abk	Lo		Mfr	Fp	Mcf	-
	Ap	0-23	5YR $^{5}/_{6}$	S	Abk	Fi		Ffr	Mp		D
2	AC	23-47	5YR $^{5}/_{6}$	LS	sabk	Fi		Ffr	Mp	-	GS
	C1	47-78	2.5YR $^{4}/_{6}$	S	abk	Lo		Fbr	Ffp	-	GS
	C2	78-97^{+}	2.5YR $^{5}/_{6}$	LS	Pl	Fr		Ftr	Ffp	Mcf	-
					***Vermic Ustorthents*(Shoulder)**						
	Ap	0-24	5YR $^{8}/_{4}$	S	Abk	Lo		Ffr	Mp	-	D
3	AC	24-76	7.5YR $^{8}/_{6}$	S	Sabk	Lo		Ffr	Fp	-	GS
	C_1	76-122	5YR $^{7}/_{6}$	LS	Sabk	Fi		Fr	ftp	-	GS
	C_2	122-175^{+}	7.5YR $^{2}/_{6}$	LS	Abk	Fi		-	Tp	-	-
	Ap	0-40	7.5YR $^{4}/_{2}$	S	Sabk	Fi		Bfr	Mp	-	GS
4	AC	40-80	5YR $^{4}/_{4}$	LS	Abk	Fi		Ftr	Fp	-	GS
	C1	80-119	5YR $^{4}/_{6}$	LS	Sabk	Fi		Fr	Fp	-	D
	C2	119-158^{+}	5YR $^{7}/_{6}$	S	Abk	Lo		-	Tp	-	-
					***Typic Endoaquents* (Foot Slope)**						
	Ap	0-24	5YR $^{4}/_{2}$	SL	abk	Fi		Mfr	Ffp	-	GS
5	AC	24-61	5YR $^{4}/_{1}$	LS	Sabk	Fi		Fbr	Fp	-	D
	C1	61-103	5YR $^{5}/_{1}$	LS	Sabk	Fi	5YR4/6	Fr	Tp	-	GS
	C2	103-145^{+}	10YR $^{3}/_{1}$	LS	Abk	Fi	2.5YR3/6	-	Ffp	-	-
	Ap	0-38	10YR $^{3}/_{3}$	LS	Abk	Fi	7.5YR2/6	Mr	Mp	-	GS
6	AC	38-75	5YR $^{5}/_{4}$	LS	Sabk	Fi		Ftr	Fp	-	GS
	Cg1	75-106	10YR $^{4}/_{3}$	LS	Sabk	Fi	10YR3/3	Ffr	Ffp	-	D
	Cg2	106-162^{+}	5YR $^{4}/_{2}$	LS	Abk	Fi		Fr	Fp	-	-

All the parameters are determined at field condition: Symbols or codes according to FAO (2006).

Structure: Sabk= subangular blocky, Abk,= Angular blocky. **Roots :**1=few 2=moderate 3=many, fr = few roots, Mr = many root, Fbr= few big root, Mfr=Many few root. **pores:**1=few 2=moderate 3 =many, Ffp =few fine pores, Fp= few pores, Tp=thin porses **consistence:** fi=firm, lo=loose, **Coarse fragment:** mcf = many coarse fragment, **Texture**: S= sand, LS = loamy Sand, SL = Sandy loam. **Boundary**: G = gradual, S = smooth.

Physical Properties of the Soils - Soil texture

The soils of the summit were generally sandy in texture in both surface and subsurface horizons, the average sand content of the soils was 92% in the summit while the silt content of the soils ranged from 7% to 9% (8% average), and the clay content of the soils was 1% in all the horizons of this pedon. This is presented in (Table 3).

The soils of the shoulder were sandy at the surface but loamy sand at subsurface. The sand content of the soils ranged from 88% to 90% (89% average). The silt content of the soils of the shoulder ranged from 7% to 9% (8% average), while the clay content was 3% in almost all the horizons in soils of the shoulder.

The soils of the foot slope were generally sandy in texture. The sand content of the soils ranged from 90% to 92% (91% average) while the silt content of the soils ranged from 7% to 9% (8% average) and the average clay content of the soils of the foot slope was1%.

In general, the soils of the study area were, found to have high sand content in the summit as well as the foot slope, with the shoulder soils being mostly loamy sand in texture. Sombroek and Zonneveld (1971) reported that soils on younger surface are generally sandy because they are formed on aeolian sand cover. The silt content of the soils was generally low with higher values recorded in soils of the shoulder. There was a decrease in silt content with depth in all the pedons. The relatively moderate amount of silt in the soils of the summit indicates that they were formed in parent materials richer in sand and silt. Morbeg and Esu (1991) and Kparmwang (1993) in the studies of soils in the savanna region of northern Nigeria reported the influence of harmattan dust in contributing silt to soils. The sand content in soils of the shoulder and foot slope were slightly lower than that in the soils of the summits. The movement of sand especially in soils of shoulder and foot slope were observed and may be attributed to pedogenic process. Nuga, Eluwa, Akinbola and Wokocha (2006) reported similar high sand content in a toposequence in Abia State.

The silt clay ratio ranged from 7% to 9% (8% average) in the summit 2% to 3% (3% average) in the shoulder and 6% to 7% (6% average) in the foot slope. Silt/clay ratio has been used to study the degree of pedogenic weathering in soils (Ashaye, 1969; Lal, 1980; Van Wameke, 1962; Somebroek and Zonnedeld, 1971). Silt/clay ratios were generally higher in summit and foot slope than the shoulder in the surface horizons and decreased with increase in depth. Yakubu (2006) reported similar results on the soils of Sokoto State. Result of this study shows that all the soils have silt/clay ratios above 0.15 which shows that the soils are young. The results were in line with Akamigbo (1999) and Adekayode and Akomolafe (2011). As posit by Medugu, Majid and Choji (2008) the issue could be resolved by tree planting to protect the soil from being eroded.

Table 3: Physical Properties of the Soils of Dundaye District.

Pedon	Horizon	Depth (cm)	Particle Size Dist. Sand	Silt	Clay	Silt/clay ratio	Textural class	Bulk density Mg/m^3	Particle density Mg/m^3	Porosity (%)
					Typic Haplustepts (Summit)					
	Ap	0-15	92	7	*1*	9	S	1.1	2.6	57
1	AC	15-27	92	7	1	9	S	1.6	2.6	41
	C1	27-39	92	7	1	9	S	1.4	2.5	43
	C2	$39\text{-}58^+$	92	7	1	9	S	1.5	2.5	38
		W A	**92**	**7**	**1**	**9**		**1.4**	**2.5**	**45**
	Ap	0-23	92	9	1	7	S	1.7	2.6	66
	AC	23-47	92	7	1	9	S	1.3	2.6	49
2	C1	47-78	92	7	1	9	S	1.4	2.5	57
	C2	$78\text{-}97^+$	92	7	1	9	S	1.4	2.5	54
		WA	**92**	**8**	**1**	**9**		**2.0**	**2.6**	**57**
					***Vermic Ustorthents* (Shoulder)**					
	Ap	0-24	88	9	3	3	LS	1.5	2.5	58
	AC	24-76	88	9	3	3	LS	1.7	2.5	66
3	C_1	76-122	88	9	3	3	LS	1.6	2.6	63
	C_2	$122\text{-}175^+$	88	7	3	2	LS	1.6	2.6	62
		WA	**88**	**9**	**3**	**3**		**1.6**	**2.6**	**62**
	Ap	0-40	90	7	3	2	S	1.7	2.5	68
	AC	40-80	88	7	3	2	LS	1.8	2.5	71
4	C1	80-158	90	9	3	3	S	1.7	2.5	67
	C2	$158\text{-}199^+$	90	8	3	2	S	1.6	2.5	64
		WA	**89**	**8**	**3**	**2**		**1.7**	**2.5**	**68**
					***Typic Endoaquents* (Foot Slope)**					
	Ap	0-24	90	9	1	7	S	1.6	2.4	68
5	AC	24-61	90	9	1	7	S	1.8	2.4	73
	C1	61-103	90	7	1	6	S	1.7	2.4	70
	C2	$103\text{-}145^+$	92	7	1	6	S	1.7	2.4	63
		WA	**90**	**8**	**1**	**7**		**1.7**	**2.4**	**69**
	Ap	0-38	90	9	1	7	S	1.7	2.5	65
6	AC	38-75	92	7	1	6	S	1.6	2.5	63
	Cg1	75-106	92	7	1	6	S	1.6	2.5	64
	Cg2	$106\text{-}162^+$	92	7	1	6	S	1.6	2.5	63
		WA	**92**	**8**	**1**	**6**		**1.6**	**2.5**	**64**

WA=Weighted Average.

Bulk density
The bulk density values in the soil ranged from 1.1 to1.6Mg/m^3 (1.4Mg/m^3 average) in the summit; 1.5 to 1.8Mg/m^3 (1.6Mg/m^3 average) in the shoulder and 1.56 to 1.8 Mg/m^3 (1.7Mg/m^3 average) in the foot slope.

The relatively high bulk density values of the surface and subsurface horizons in the pedons may be due to compaction caused by grazing animals, a common feature in the area. Bulk density values between 1.6 and 1.7 Mg/m^3 and above have been described as unfavorable values for crop production. This is because root penetration could be inhibited which could cause poor aeration and slow movement of nutrients for plant use (Brady and Weil, 2002). Therefore, the bulk density of the soil of the summit are favorable for crop production, especially grain crops; that of shoulder and foot slopes may impair root penetration and water percolation.

In addition, the relatively higher bulk density in the surface horizon than in subsoil could be due to nature of the soil and cultivation that is common in the area. These reasons were also stated by Jones and Wild (1975) in the study of the soils of savanna. According to De Geus (1973), bulk densities greater than 1.75 g cm-3 for sands limit root penetration in soils.

Particle density
Average particle density values were 2.54 Mg/m^3 in upper slope, 2.60 Mg/m^3 in middle slope and 2.50 Mg/m^3 in foot slope. Brady and Weil (1999) reported that generally, particle density values decrease with soil depth. Similar results were also reported by Idoga *et al.* (2006) in soils of Samaru area, Kaduna State, Nigeria.

Porosity
Porosity values of the soil of the summit ranged from 45% to 56% (51% average), 62% to 68% (65% average) in the shoulder and 64% to 69% (66% average) in the foot slope. The porosity values were high in all the pedons and could be indicative of good aeration and free water movement in the soils (Jones and Wild, 1975). The high porosity could be due to the sandy nature of the soils.

Plate 1: Pedon 1 (Typic Haplustepts). Located on latitude 13^0 07^1 N and long. 05^0 13^1E.
Note: large coarse fragments of the indurated materials at the surface and subsurface

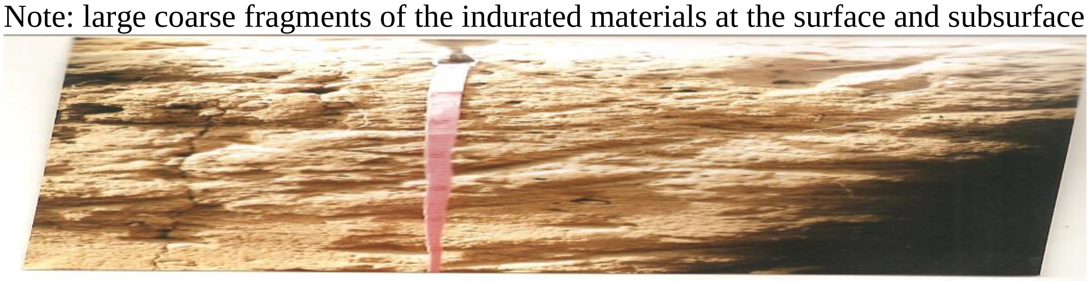

Plate 2: Pedon 2 (Vermic Ustorthents). It is located on Latitude 13^0 07^1 N and Long. 05^0 13^1E.

Note: weakly developed horizons soil formed from Aeolian-colluvial sandy material. Large burrows as a result of biological activities observed at the surface between10-25cm.

Plate 3: Pedon 3 (Typic Endoaquents). It is located on Latitude $13^0 14'$ North and Long. $05^0 13'$ East.
Note: deep soil, loamy materials with weak developed horizon

The Chemical Properties of the Soils
Soil reaction (pH)

Soil pH values in the summit ranged from 5.3 to 5.4 for the shoulder, 0.1 to 0.2 and 6.5 to 6.7 for the foot slope. The soils of the summit and shoulder were slightly acidic than those of the foot slope. The pH of the soils varied irregularly with depth showing a decrease in values at the subsurface compared to those of the surface. Similar results were reported by Yakubu, Ojanuga and Noma (2011) in the Kalambaina area of Sokoto State and by Esu (1982) in Zaria area. Agbu (1982) reported that low acidity in sokoto area is as a result of high base status with very little organic matter content in the soils. The pH value at times increases with the depth as noted by Yakubu and Ojanuga (2011) and Sharu, Yakubu, Noma and Tsafe (2013) who reported that the average pH values of the soils are 7.7, 7.1 and 7.0 which indicates acidity of the soil around humid regions. While, Akamigbo and Igwe (1990) who noted that low acidity result is observed in soils around humid regions due to soil erosion that is liable for the low to high calcium and magnesium contents of the soil.

Organic carbon
In the soils of the summit, organic carbon content ranged from 0.57 to 0.64%, it ranges from 0.29 to 0.14% for soils of the shoulder and 1.61 to 4.87% for the soils of the foot slope respectively. The organic carbon in the soil of the foot slope were relatively higher than those of the summit and shoulder. The high organic carbon in the foot slope may be attributed to agricultural activities in the area, such as the addition of organic manure. Food and Agricultural Organisation (FAO) (2006) reported a similar trend in organic carbon distribution in all the soils of uplands in the Sokoto-Rima Basin. In addition, Agbu and Ojanuga (1989) stated that low organic matter content in soils of Sokoto area could be due to rapid decomposition of organic materials accompanied by sparse vegetation and the hot semi-arid climate.

Total nitrogen (TN)
The total nitrogen value in the soils of the summit were in the range of 0.07 to 0.08g/kg^{-1}, while the value in the shoulder ranged from 0.05g/kg^{-1} to 0.08g/kg^{-1} (0.07g/kg^{-1}average), 0.08 to 0.34g/kg^{-1} (0.21g/kg^{-1} average) in the foot slope. Esu (1991) classified savannah soils into low, medium and high N fertility classes with N limits as <0.15. With this rating, therefore the soils could be regarded as low in nitrogen. The low N values recorded in all the pedons may be due to rapid decomposition of organic materials in the area. Nitrogen is a mobile element and can easily be lost in the soil through leaching, erosion and quick mineralization (Arunah, *Chiezey and Aliyu*, 2007).

Available phosphorus (AP)
Available phosphorus ranged from 1.0 to 1.03Mgkg^{-1} (1.02mgkg^{-1} average) in the summit while the average value in the shoulder is 1.01Mgkg^{-1} and 1.22Mgkg^{-1} in the foot slope. Generally, the soils could be rated as having low available phosphorus as reported by Esu, (1991) that soils with available P values<10 are low, 10-20 medium, and >20 high. The values are comparable with the values reported by Ohaeri and Eshett (2011). The loss of phosphorus is commonly owing to its elimination by the crops as posit by (Enwezor, Ohiri, Opuwaribo and Udo, 1990). Phosphorus react in acidic soils to produce an insoluble compound such as Fe3+, Al3+, and Mg2+

Electrical conductivity (EC)
The values of EC ranged from 0.215 to 0.256 dSm^{-1} for summit, 0.262 to 0.317dSm^{-1} for shoulder, and 0.235 to 0.25800.247dSm^{-1} for foot slope. This implied that the soils are non-saline as shown by an EC of less than 2dSm^{-1} according to limits set by Schoeneberger *et al.* (2002). The very low EC values are indication that there are little soluble salts in the soils.

Table 4. Chemical properties of the soils of Dundaye District

Pedon	Horizon	Depth (cm)	pH (1:1) (H_2O)	OC (%)	OM (%)	Total N (%)	Available P (%)	SAR	Esp (%)	EC (dSm^{-1})	Ca	Mg	K	Na	CEC	Extractable Acidity Al^{3+}	H^+	B.S %
											→ Cmol/kg^{-1} ←							
							Typic Haplustepts (Summit)											
	Ap	0-15	6.6	0.299	0.52	0.08	1.04	4.33	15.80	0.199	0.35	0.25	0.59	0.65	4.12	1.4	0.9	57
1	AC	15-27	5.1	0.299	0.52	0.07	1.03	4.70	15.70	0.211	0.35	0.20	0.62	0.65	4.14	1.2	0.7	54
	C1	27-39	5.0	0.339	0.59	0.07	1.00	4.07	15.90	0.230	0.35	0.20	0.56	0.65	4.08	1.2	0.7	54
	C2	39-58$^+$	4.9	0.379	0.66	0.07	1.00	4.15	13.97	0.218	0.30	0.25	0.51	0.57	4.08	1.2	0.7	51
		WA	**5.40**	**0.329**	**0.57**	**0.07**	**1.02**	**4.16**	**15.3**	**0.215**	**0.34**	**0.23**	**0.57**	**0.63**	**4.11**	**1.23**	**0.75**	**54**
	Ap	0-23	5.6	0.339	0.59	0.08	1.06	3.71	15.3	0.237	0.40	0.30	0.64	0.65	4.26	1.4	1.0	61
2	AC	23-47	5.1	0.339	0.59	0.06	1.05	4.07	14.3	0.237	0.35	0.25	0.59	0.61	4.26	1.3	1.0	58
	C1	47-78	5 .0	0.379	0.66	0.06	1.01	4.07	14.9	0.262	0.35	0.25	0.54	0.61	4.10	1.1	0.7	59
	C2	78-97$^+$	5.3	0.419	0.72	0.06	1.99	3.78	12.9	0.237	0.35	0.20	0.54	0.52	4.04	1.1	0.7	57
		WA	**5.25**	**0.360**	**0.64**	**0.07**	**1.03**	**3.91**	**14.4**	**0.256**	**0.36**	**0.20**	**0.58**	**0.59**	**5.19**	**1.23**	**0.85**	**58**
							Vermic Ustorthents(Shoulder)											
	Ap	0-24	5.1	0.100	0.17	0.07	1.09	3.73	14.4	0.288	0.40	0.35	0.69	0.7	4.86	1.2	0.8	53
3	AC	24-76	5.1	0.259	0.45	0.04	1.02	2.08	8.05	0.307	0.25	0.50	0.64	0.39	4.84	1.2	0.7	50
	C1	76-122	5.1	0.180	0.31	0.04	0.98	2.40	8.13	0.326	0.25	0.40	0.54	0.39	4.80	1.0	0.7	47
	C2	122-175$^+$	5.2	0.200	0.21	0.03	0.96	2.40	8.13	0.346	0.25	0.40	0.54	0.39	4.80	1.0	0.7	47
		WA	**5.13**	**0.185**	**0.29**	**0.05**	**1.01**	**2.65**	**9.68**	**0.317**	**0.29**	**0.41**	**0.61**	**0.47**	**2.41**	**1.10**	**0.73**	**49**
	Ap	0-40	5.4	0.100	0.17	0.08	0.97	3.11	14.2	0.249	0.35	0.55	0.64	0.70	4.92	1.4	0.1	65
4	AC	40-80	5.4	0.100	0.17	0.07	0.99	4.44	8.81	0.262	0.25	0.25	0.67	0.43	4.88	1.3	0.1	61
	C1	80-158	5.2	0.040	0.07	0.06	1.04	3.12	8.05	0.243	0.25	0.25	0.67	0.39	4.84	1.1	0.7	59
	C2	158-199$^+$	5.7	0.080	0.14	0.06	1.02	3.47	8.05	0.294	0.25	0.25	0.62	0.39	4.84	1.1	0.7	59
		WA	**5.43**	**0.080**	**0.14**	**0.08**	**1.01**	**3.53**	**9.78**	**0.262**	**0.28**	**0.28**	**0.65**	**0.48**	**4.89**	**1.23**	**0.85**	**61**

Table 4 Continued.

Pedon	Horizon	Depth (cm)	pH (1:1) H_2O	OC (%)	OM (%)	Total N (%)	Available P (%)	SAR	Esp (%)	EC (dSm^{-1})	Ca	Mg	K	Na	CEC	Extractable Acidity H^+	AL^{3+}	B.S %
											→ Cmol/kg $^{-1}$ ←							
							Typic Endoaquents (Foot Slope)											
5	Ap	0-24	6.2	0.838	1.45	1.11	1.30	3.83	15.1	0.237	0 .60	0.35	0.92	0.91	6.02	1.6	0.8	64
	AC	24-61	6.3	0.838	1.45	0.09	1.21	4.04	5.1	0.230	0.55	0.35	0.87	0.91	6.02	1.5	0.7	61
	C1	61-103	6.8	0.898	1.55	0.09	1.22	3.69	14.4	0.250	0.55	0.35	0.82	0.83	5.76	1.5	0.7	64
	C2	103-145+	6.8	0.958	1.66	0.08	1.19	5.11	14.5	0.224	0.50	0.15	0.79	0.83	5.72	1.4	0.6	59
		WA	**6.52**	**0.883**	**4.87**	**0.34**	**1.23**	**4.17**	**14.8**	**0.235**	**0.55**	**0.30**	**0.85**	**0.87**	**5.88**	**1.50**	**0.70**	**62**
6	Ap	0-38	6.5	0.878	1.52	0.08	1.23	4.71	16.5	0.269	0.70	0.15	1.10	1.00	6.06	1.6	0.6	65
	AC	38-75	6.2	0.898	1.55	0.08	1.21	5.00	16.9	0.250	0.70	0.10	1.05	1.00	5.92	1.6	0.6	64
	Cg1	75-106	7.2	0.958	1.66	0.07	1.20	4.35	15.3	0.230	0.60	0.20	0.97	0.87	5.70	1.5	0.7	60
	Cg2	106-162+	6.7	0.998	1.73	0.07	1.18	5.35	15.4	0.243	0.55	0.10	0.92	0.87	5.66	1.5	0.7	60
		WA	**6.65**	**0.933**	**1.62**	**0.08**	**1.21**	**4.85**	**16.0**	**0.258**	**0.64**	**0.14**	**1.01**	**0.94**	**5.80**	**0.65**	**1.55**	**62.3**

B.S= Base Saturation , OC=organic carbon, OM=organic matter, SAR=sodium adsorption ratio, ESP=exchangeable sodium percentage, EC=Electrical conductivity, WA=Weighted Average

Exchangeable sodium percentage (ESP) and sodium adsorption ratio.

The average values of exchangeable sodium percentage (ESP) in all the three pedons were 9.73%;14.85% and 15.4% for soils of the summit, shoulder and foot slope respectively. The ESP in the summit and shoulder pedons were below 15% which is the critical limit for sodicity except foot slope that is relatively higher (Brady and Weil, 2002). The Sodium Adsorption Ratio in all the pedons were below the threshold value of 13 for sodic soils. Similar results were obtained by Yakubu *et al.* (2011) while assessing soil and water quality for irrigation in Sanyinna area of Sokoto, Nigeria.

From the results of the morphological, physical and chemicals properties of the soils, it is evident that, these soils were formed from the operations of pedogenic process. Field observation revealed that the soils were formed due to aeolian deposits as well as the influence of topography on the soil surface. The resistant layers had indurated plinthite surfaces formed most probably during early tertiary humid tropical climate. A substantial portion of the summit is covered with ironstones which filled surface and subsurface horizons.

Implication of Dundaye soil on crop production in the study area

The soil of the study area is generally sandy and low in fertility. Sandy soil is good for the cultivation of legumes such as beans, ground nuts and soybeans. The bulk density of the soil of the summit are favorable for crop production, especially grain crops such as millet, sorghum and rice. Maize can also be cultivated with the aid of irrigation. The shoulder and foot slopes of the characterized soils may impair root penetration and water percolation, hence, the need for effective maintenance of the soil. In maintaining soil fertility, the farmer is mainly concerned with keeping the soil at a satisfactory physical condition and maintaining the nutrient supply at a desired level. A fertile soil must be in a physical condition that is favourable for root growth. Thus, cultivation to break down the soil aggregates must be done. This important practice will accelerate the decomposition of organic matter which when present, aids in promoting the porosity and granulation of the soil. Maintaining good soil structure and providing good vegetative cover or mulching, together with minimal, timely and systematic cultivation also help to maintain soil fertility (National Open University of Nigeria, 2013).

The soil of the study area was characterized as low in nitrogen, phosphorus and non-saline in nature. The alternation of legumes and non-legumes or the use of legumes in rotation would help to maintain and balance the soil fertility. This is because the residues of such crops as groundnuts and soya beans improve the nitrogen content of the soil through their ability to fix nitrogen in their roots. Moreover, with the incorporation of the plant residues left on the field into the soil, improves aeration, soil structure and water-holding capacity of the soil.

The farmers in the study area can also practice other viable methods of maintaining the soil fertility. Maintaining good soil structure and providing good vegetative cover or mulching, together with minimal, timely and systematic cultivation also help to maintain soil fertility. The fertility of the soil must be maintained, and this could be done effectively by crop rotation, cover cropping, green manuring, application of compost and farmyard manure as well as proper land use (National Open University of Nigeria, 2013)

CONCLUSION

This study has characterized and classified soils along a toposequence and its implications on crop production in Dundaye district of Sokoto, Nigeria. From the findings the following conclusions could be drawn: topography played a major role in influencing soil characteristics and distribution in the study area; the bulk density of the soil of the summit are favorable for crop production, especially grain crops; landscape position was found to have influenced both on the morphological and physical properties of the soils as indicated by the differences in soil properties between soils of the summit, shoulder and foot slope; relatively high bulk density values of the surface and subsurface horizons in the pedons was reported; bulk density values between 1.6 and 1.7 Mg/m^3 and above was reported and have been described as unfavorable values for crop production; silt/clay ratios were generally higher in summit and foot slope than the shoulder in the surface horizons and decreased with increase in depth; The organic carbon in the soil of the foot slope were relatively higher than those of the summit and shoulder; the soils could be regarded as low in nitrogen; the soils could be rated as having low available phosphorus; the soils are non-saline. This study will go a long way to supporting researchers, farmers and agriculturist who will want to embark on massive agricultural production in Sokoto State, Nigeria and the world at large

Recommendations

Based on the results of the study, the following recommendations were drawn:

1. The low fertility status of the soils of Dundaye District can be brought to better use for agriculture by increasing the organic matter level through incorporation of organic residues such as farmyard manure, plant residues, and household refuse.
2. For sustainable crop production, there is need for guided inorganic fertilizer use and improved management practices in the area that will effectively minimize erosion and enhance and maintain soil quality and productivity.
3. Afforestation could help to provide cover to the soil against erosion.

REFERENCES

Abubakar, M. G. (2006). An Investigation of Ground Water Potential of Gada Town, Sokoto State Using Vertical Electrical Sounding. An unpublished Msc. thesis, Department of Geography, Ahmadu Bello University, Zaria, Nigeria.

Agbu, P. A. (1982). Reconnaissance soil survey of part of Dange Area of Sokoto State, Nigeria. Unpublished M.Sc. thesis submitted to Dept of soil science A.B.U Zaria, Nigeria pp 132.

Agbu, P. A. and A.G. Ojanuga, (1989). Properties and Classification of Soils of Dange Area of Sokoto State Nigeria. *Samaru J. of Agric Res*.6:37-47.

Akamigbo, F. O. R and Igwe CA (1990). Morphology Geography Genesis and Taxonomy of three Soil Series in Eastern Nigeria. Samaru Journal of Agricultural Research 7: 33-48.

Akamigbo, F. O. R. (1999). Influence of Land use on Soil Properties of the Humid Tropical Regions, 23 – 27.

Arunah, U. L., U. F. Chiezey and, L. Aliyu, (2007). Effect of Nitrogen Fertilizer and Poultry Manure on Growth Attributes of two Sorghum Varieties. In: E. O Uyovbisere, S. A. Yusuf, J. O. Ogunwale, L. Aliyu S. A. Ojeniyi(eds). Soil and water management of wetland soils. Proceedings of the 31st annual conf. of the SSSN A.B.U, Zaria, Nigeria Nov.13th to 17th. 2006.

Ashaye, T. I. (1969). Sesquioxide Status and Particle Size Distribution in Twelve Nigeria Soils Derived from Sandstones. *African Soils* 1:85-95.

Blake, G.R; and K. H. Hartge, (1986). Bulk density: In: Klute A. (ed). Methods of Soil Analysis. Monograph No 9. American Society of Agronomy. Madison, Wisconsin, USA pp 197

Brady, N. C and R. R Weil (2002). *The Nature and Properties of Soils.* 13th Edition. Singapore, Pearson Education. Pp 976.

Brady, N. C. and R.R Weil, (1999). *The Nature and Properties of Soils.* 12th ed. Prentice Hall.881pp.

Bray, R. H and Kurtz, L. T. (1945). Determination of Total Organic and available forms of phosphorus in soils. *Soil science* 59;39-46

Bremner, M. J. (1965). Total Nitrogen: In: C. A. Black (ed). Methods of Soil Analyses Part 1. *American Society of Agronomy Monograph* NO. 9 371-373

Daniels, R. B, E. E, Gamble and J. G. Cady, (1970) Some Relations among Coastal Plain Soils and Geomorphic surfaces in North Carolina. Soil Sci Soc. Am. Proc.34:648-653.

Davis, G. (1982). Rainfall and Temperature. In: Abdu, P.S. and Swindell, K. (Eds.) Sokoto State in Maps: An Atlas of Physical and Human Resources. Ibadan: Ibadan University Press.

De Geus J. G. (1973). Fertilizer Guide for the Tropics and Subtropics. Ed.2, p.774.

Desanker, P. and Magadza, C. (2001). *Climate Change 2001 Impacts, Adaptation, and Vulnerability*. IPCC, Cambridge University Press. Contribution of working group II. 494-499, 517-524.

Dwyer, S. A., Ghannoum, O., Nicotra, A., and Caemmerer, S. V. (2006). High Temperature Acclimation of C4 Photosynthesis. Research School of Biological Sciences and School of Botany and Zoology, Australian National University, Western Sydney, South Penrith DC; Australia

Enwezor, W. O, Ohiri A. C, Opuwaribo, E. E and Udo, E. J. (1990). Literature Review on Soil Fertility Investigation in Nigeria. Federal ministry of Agriculture and Natural Resources Lagos.

Esu, I. E. (1982). Evaluation of Soils for Irrigation in Kaduna Area of Nigeria. Unpublished PhD thesis Dept. of Soil Science, A.B.U, Zaria,305pp.

Esu, I. E. (1991). Soil Characterization, Classification and Survey, Professor of Soil Science, University of Calabar Nigeria.

FAO (Food and Agricultural Organization) (2006), Guideline for Social Description, 4th ed, Rome.

Gee G.W., Bauder, J.N. (1979) Particle Size Analysis by Hydrometric Method; A Simplified Method for Routine Textural Analysis and Sensitivity Test of Mineral Parameters, Soil Science Society, American Journal, 43:1004-1007.

Gerrard, A.J. (1981). Hillslope Profile Analysis. *Area* 10,129-130.

Idoga, S; I. J. Ibanga, and W.B. Malgwi (2006). Variation in Soil Morphological and Physical Properties and their Management Implications on a Toposequence in Samaru area, Nigeria 19-25. In proceedings of the 31st Annual conf. SSS of Nigeria. Ahmadu Bello University Zaria, Nigeria. NOV 13-17

Jimoh, A. I., A. L. Mbaya, D. Akande, D. T. Agaku, S. Haruna (2020). Impact of Toposequence on Soil Properties and Classification in Zaria, Kaduna State, northern Guinea Savanna, Nigeria. EQA - International Journal of Environmental Quality ISSN 2281-4485 - Vol. 38 (2020): 48-58 Journal homepage: https://eqa.unibo.it/

Michael, J. and Wild, A. (1975). Soils of the West Africa Savanna, technical communication No 55 commonwealth Bureau of soils Harpenden, 218.

Jones. J. B. (2001). Laboratory Guide for Conducting Soil Tests and Plant Analysis. CRC PRESS LLC.363PP.

Lal, R. (1980). Physical and Mechanical Characteristics of Alfisols and Ultisols With Reference to Soil in Tropics. In: B.K.G. Theng (Ed). Soils with variable charge. New Zealand Society of Soli Science, pp253-279.

Mclean, E. O (1982). Soil pH and Requirement. In page *et al*., (eds), part 2 second edition. Chemical and microbiological properties. Agron .NO 9 Am SOC Agron, Madison USA, 199-224.

Medugu, N. I., Majid, R. M. and Choji, I. D. (2008). A Comprehensive Approach to Drought and Desertification in Nigeria: A brief evaluation of government policies. Management of Environmental Quality: An International Journal, 19(6): 690-704.

Morbeg, J. P and Esu, I. E. (1991). Characteristics and Composition of Nigeria Savanna Soils, *Geoderma* 48:113-129.

Nahusenay A., Kibebew K. (2016) Effects of Land use, Soil Depth and Topography on Soil Physicochemical Properties along the Toposequence at the Wadla Delanta Massif, Northcentral Highlands of Ethiopia. Environment and Pollution, 5(2):57-71. ISSN 1927-0909; E-ISSN 19270917.

Nelson D. W. and Sommers, L.E (1982) Total Organic Carbon and Organic Matter. Methods of soil analysis part II, 2nd Ed. Agron, Monogr, No. 9 ASA and SSSA. Madison, Wis. PP 961-1010

Nuga, B. O., Eluwa, N.C, Akinbola,G.E and Wokocha,C.C. (2006). Characterization and Classification of soils along a toposequence in Ikwano local Government area, of Abia State. *Agric Journal* 1(4):192-197.

Odjugo, P. A. O. (2010). General Overview of Climate Change Impacts in Nigeria, *Journal of Human Ecology*, 29(1), 47-55.

Ogunkunle, A. O and Onasanya, O.S. (1992) - Soil-landscape relationship in a forest zone in South Western Nigeria. *Samaru J. Agric, Res.* 9:19.33

Ohaeri, J. E and Eshett, E. T. (2011). Phosphorus Forms and Distribution in Selected Soils Formed Over Different Parent Materials in Abia State of Nigeria. Agro-science journal of Tropical Agriculture, Food, Environment and Extension, 10(3): 28-37.

Okusami, T. A; Rust, R. H and Jou, A. S. R. (1985). Characteristics and Classification of Some Soils Formed on post-cretaceous sediments in Southern Nigeria *Soil Science* 140:110-119

Olatunji, O. O. M. Ogunkunie, A.O and Tabi, A.O. (2007). Influence of Parent Material and Topography on some Soil Properties in South western Nigeria. *Nigerian Journal of Soil & Environmental Resources.* 7:1-6.

Oriako, P. A., Obineche, C. I., Ezechike, N. U. & Ezema, P. C. (2022). Assessment of Soil Physico-Chemical Properties on a Toposequence of an Erosion Site in Ikeduru, Southeastern Nigeria, Turkish Journal of Agricultural Engineering Research, 2022, 3(2), 292-3

National Open University of Nigeria (NOUN) (2013). Introduction to Pedology and Soil Classification (SST 301) Course guide. Available at www.nou.edu.ng

Sani, M. (2005). *The Geographical Study of Sokoto Central Market*. An unpublished Msc. Thesis presented in the Department of Geography, Usmanu Danfodio University, Sokoto, Nigeria.

Schultz, T. W. (1975). Report on Hadejia Irrigation Project, Lagos, Nigeria.

Sharu, M. B, Yakubu M, Noma SS and Tsafe A. I. (2013). Characterization and classification of soils on an agricultural landscape in Dingyadi District, Sokoto State, Nigeria. Nigerian Journal of Basic and Applied Science (June 2013), 21(2): 137-147.

Sheik, D. A. and Aliyu, M. (2017). Examining Sediment Accumulation in Goronyo Reservior, Sokoto State, Nigeria. *IOSR Journal of Humanities and Social Sciences (IOSR-JHSS), 22(8), 60-65.*

Somebroek, W. G and Zonneveld, I. S. (1971). Ancient Dune Fields and Fluviatile Deposits in the Rima - Sokoto River Basin (NW Nigeria). Soil Survey Paper No. 5, Netherlands Soil Survey Institute, Wageningen. 109pp.

Thomas, G. W. (1982). Exchangeable cations. In: M.F Thomas. Methods of soil Analysis, Part II, 2nd Agron. Monogr, No 9 ASA and SSSA. Madison, Wis. 149.157pp.

Van Wambeke A. R. (1962). Criteria for Classifying Tropical Soils by Age. *Journal of Soil Science* 13:124-132.

Yakubu, M., Ojanuga, A. G., and Noma, S. S. (2011). Soils on Different Geologic and Geomorphic surfaces in Sokoto Rima-plain, Nigeria. In M. K. A Adebayo, A.J. Odofin, A. O. Osunde, A Bala and S. O. Ojeniyi (Eds). Soil resources management, Global climate change and food security. Proceedings of the 35th annual conferences of SSN/Minna, Niger State, March 7th to 11th.