CLASSIFICATION OF SOILS ON SLOPES OF VARYING ORIENTATIONS IN UMUAHIA AREA OF ABIA STATE, SOUTHEASTERN NIGERIA

BY

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CERTIFICATION

I certify that this work "Classification of soils on slopes of varying orientations in Umuahia of Abia State, Southeastern Nigeria" was carried out by Aliba, Vera Ogechi (20124760618) in partial fulfillment for the award of the degree of Master of Science (M.Sc) in Soil Survey and Land use planning in the Department of Soil Science and Technology of the Federal University of Technology, Owerri.

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DEDICATION

This thesis is dedicated to the Blessed Trinity and the Blessed Virgin Mary.

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ABSTRACT

Slope aspect affects soil properties. The study characterized and classified soils on slopes of varying orientations in Umudike (East-lying Toposequence) and Itu (West-lying Toposequence), both in Olokoro Umuahia, southeastern Nigeria. Transect soil sampling technique was employed in locating threedistinct positions, namely summit, midslope and footslopealong each of the toposequences at the East and West-lying orientations. A profile pit wasdug at the most representative points of the toposequences in each of the two locations and the soil profiles were described in situ, following the FAO guidelines. Soil samples were collected from each pedon based on the horizon differentiations and subjected to routine laboratory analyses. The soils were classified using the USDA Soil Taxonomy and correlated with the FAO World Reference Base. Data obtained weresubjected to statistical analysis (coefficient of variability and correlation) using the Genstat computerpackage. Results showed thatsoils of the East-lying slope were predominantly sandy-clay loam at the summit but sandy clay at the mid and footslopes, while in the West-lying slope, the texture was dominantly sandy-clay loam at both the summit and midslope but prominently sandy loam at the footslope. Soils of East-lying slope had very dark grayish brown (10YR3/2) moist to strong brown (7.5YR5/8)moist,dark brown (7.5R3/2) to strong brown (7.5YR5/8) moist,dark gray (5YR4/1) to reddish yellow(7.5R6/8) moist colours at the summit,midslope and footslope respectively, while that of the West-lying toposequence varied from brown (7.5YR4/2) moist to yellowish colour (5YR5/6), very dark grey (7.5YR3/1) moist to yellowish red (5YR5/8),very dark grayish brown (10YR3/2) moist to reddish yellow (5YR6/6) moist colours at the summit,midslope and footslope, respectively.The weathering intensity of the soils varied from moderate to high with silt-clay ratios ranging from 0.04-0.93, 0.04-1.26 and 0.04-0.66 at the summit, midslope and footslope respectively,in the East-lying toposequence and from 0.04-070, 0.27-1.59 and 0.14-1.08 atthe summit, midslope and footsloperespectively,in the West-lying toposequence. Bulk densities of soils increased with depth with mean values of 1.36 gcm^{-3}, 1.32 g cm^{-3}, and 1.34 g cm^{-3} recorded at the summit, midslope and footslope respectively,in the East-lying toposequence and 1.37 g cm^{-3}, 1.33 g $cm^{-3}$and 1.32 g cm^{-3}at the summit, midslope and footslope respectively, in the West lying toposequence. High variation (CV>35%) was noted in Ksat in the profiles of the toposequences, with values of Ksat ranging from 0.3-1.11 cm hr^{-1}, 0.19-1.96 cm $hr^{-1}$and 0.15-1.47 cm hr^{-1}at the summit, midslope and footslope, respectively in the West-lying toposequence whereas in the

East-lying toposequence,the values ranged from 0.18-2 cm hr^{-1}, 0.11-1.97 cm hr^{-1} and 0.12-1.48 cm hr^{-1} at the summit, midslope and footslope, respectively. Soil pH was very strongly acidic (4.58-4.78) in the East-lying toposequence but varied from very strongly acidic to strongly acidic (4.52-5.30), in the west lying toposequence. Organicmatter concentration was generally higher at the epipedons and ranged from (26.44to 23.36) $gkg^{-1}$and (30.64to 18.9) gkg^{-1}in soils of the East-lying and West-lying slopes, respectively. Effective cation exchange capacityvaried from (8.63- 13.79) $cmolkg^{-1}$in the East-lying toposequence and (10.42- 16.31) $cmolkg^{-1}$in the West – lying toposequence. Soils of East-lying toposequence were classified as Grossarenic Paleudalfs, Typic Paleudalfs and Arenic Hapludalfs Typic (USDA) atthe summit, midslope and footslope, respectively and correlated with Mollic Luvisols of the World Reference Base (WRB) whereas the soils of West-lying slope were classified as Arenic Glossudalfs, Typic Paleudalfs and Typic Ferrudalfs (USDA) at the summit, midslope and footslope, respectively which correlate to Haplic Albeluvisols of the WRB (FAO) legend.

CHAPTER ONE

Introduction

1.1 Background of study

Soil is an important component in man's total stock ofnatural resources and it regulates food production (Buol *et al*., 2003). A key feature of the soil is the variation in its properties (Mulla and McBratney, 2001). According to Lark and Wheeler (2000), variation in soil properties has long been known and has been the subject of much research. One of the contributors to variation is slope as its attributes vary. As the landscape is undulating, soil characteristics at differenttopographic positions differ. According to Mulla and McBratney (2001), variability in soil properties at the series level is often caused by small changes in topography that affect the transport and storage of water across and within the soil profile.

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

Variations in soil properties are important because they are responsible for differences in management systems designedto serve the end of productivity andconservation (Aduloju and Tetengi, 2011).The study and understanding of soil properties and their distribution over an area has proved useful for the development of soil management plan for efficient utilization of limited soil resources and agro-technology transfer (Buol *et al*., 2003). In Nigeria, many works on relationship between landscapepositions and soil properties were documented (Annan-Afful *et al.,* 2004; Abe *et al.,* 2009). For instance, (Ogban *et al.*, 1999) deduced that nutrient status and soil properties are relatedto topography of the land area. Also, Osodeke *et al.*(2005) reported differencesin quantity and forms of sesquioxides as influenced by geomorphic positions. They observed that the soils of theprofiles at higher slopes were dominated by the crystalline forms of iron (Fe) and aluminum (Al)-oxides while the soilsof the valley bottom were dominated by the amorphous forms of Fe and Al. Elsewhere, (Osodeke and Osondu, 2006) observed a wide variation inphosphorus (P) distribution along a toposequence insoutheastern Nigeria; where total P was found to be highest atthe upper slope and lowest at the middle slope.

1.2 Problem Statement

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

1.3 Justification of Study

Olokoro is an agrarian community in Umuahia south local government area of Abia state.The area is dominated with commercial farmers dealing on both small and large scale productions of several staple crops such as cassava, yam andmaize, and tree crops likeoil palm, among others. To increase agricultural production in the area, there is need to understand the characteristics of the soils. However, there exist only a limited data on soils of Olokoro community. Although slope orientation is important in the development of soils, the positionof a soil on a slope has also been found to affect the properties of soils.Previous studies such as Nuga *et al*. (2006), classified soils along a toposequence in Olokoro area, but did not consider the orientation of the slope. In light of the above, an in-depth knowledge of the characteristics and taxonomical classification of soils on varying slope orientations and positions in the area is paramount, as this would helpin the proper usage and management of the soil resources based on their potentials and limitations, thereby maximizing crop production in the area.

1.4 Objectives of the study

The major objective of this study was to classify soils on slopes of varying orientation in Olokoro,Umuahia, southeastern Nigeria using USDA Soil Taxonomy and FAO World Reference Base.

Specific objectives include to:

i. determine the physical and chemical properties of the soils
ii. classify the soils using USDA Soil Taxonomy and correlate same with FAO World Reference Base
iii. estimate degree of variation existing in soil properties within and between the studied toposequences based on the slope aspect
iv. establish relationship among the properties of the topounits using simple linear correlation.

1.5 Scope of Study

This study is limited to Itu West-lying and Umudike East-lying Toposequence in Olokoro area of Umuahia, Abia State Nigieria.

CHAPTER TWO

2.0 Literature Review

2.1 Processes of soil development

Soil is a product of interaction between climate, parent material, relief and organismover a period of time. Its formation involves complex pedogenic processes (Boul *et al*., 1997) such as addition, losses, translocation, and transformation. While climateand organisms actively influence soil formation, Onweremadu and Mbah (2009) observed that topography indirectly affected the rates ofpedogenesis and distribution of soil nutrients. A large number of processes are responsible for formation of soils (Pidway, 2006). Thepedogenic processes, which represent collectively the physical, chemical andbiological processes in soil, determine the characteristics of the resulting soil.According to Anderson (1997), pedogenesis is concerned with the process thatdetermines the morphologically significant properties, such as horizons of clays orsesquioxide enrichment and leached horizons. It also influences the functionalproperties of soil, such as the ability to retain and recycle nutrients, the environmentfor soil micro flora, and the medium presented to a developing root. Boul *et al*. (1997) considered soils to be formed by basic processes of addition, removal, transformation and transfer after an initial step of parent material deposition. For a particular soil, the relative importance of these processes varies and the result is the variety of profilesseen in any landscape.

2.1.1 Distribution of soil properties in landscapes

Soil preserves a record of landscape evolution and climate that can be interpreted by quantifying numerous chemical and physical properties accumulated in soil profiles (Khomo, 2008). Weathering intensityis a soil process that indexes the degree to which soil mineral chemistries diverge from the chemistry of soil's parent material, which can either be the underlying rock, exogenous material such as dust, or a combination (Khomo, 2008). Departures of soil from parent material composition are a function of how appreciably soil has evolved away from its starting material. The divergence of soil from its mineral precursors in parent material is mediated by soil forming factors such as climate and topography which vary geographically (Jenny, 1941), and serve to modify the intensity of soil forming processes, such as chemical weathering and leaching (Bridges, 1978). Consequently, weathering extent and the emergence of unique soil properties will vary spatially in landscapes by geographic location.

Hillslopes are a convenient scale to view locally interacting factors and processes that impinge on soil formation because they are delimited by a hillcrest and a basal stream. Beyond the boundaries demarcated by crests and streams, hydrological connectivity ceases. The predictable relationship among soils that make up a hydrologically connected hillslope is defined as a catena (Milne, 1935). A catena is a series of physically, chemically and morphologically distinct soils on a hillslope linked by topographically mediated transfers of material. Since effective moisture, slope length and hillslope relief control the amount of water and mass transmitted through catenas.

2.1.2 The nature of soil

The nature of soil requires multidisciplinary research for a full comprehension of its complexity, and there has been recent advocacy for such approaches (Brantley *et al.*, 2007). Fragmentary views will always fail to garner overarching understanding of soil complexity and will thereby limit integrated views on how soil develops and is spatially arranged in landscapes. The disciplinary framework in this study therefore spans soil science, geomorphology and geology to more effectively probe and explain complexities in soil landscapes. Soil is complex because it forms at the boundary of the lithosphere, atmosphere, hydrosphere and biosphere (Brady and Weil, 2004), the interface recently termed the Critical Zone, due to its importance for the functioning of terrestrial ecosystems (Chorover *et al.*, 2007). Soil is a multiphase mixture of solids derived from primary minerals in the lithosphere; gases unique from and continuous with the atmosphere; water containing dissolved and suspended material; and organisms and their by-products. Soil complexity can hence best be understood in the context of geological material open to spatially heterogeneous biological, hydrological and geochemical exchanges at the Earth's surface. Inputs to soil are via addition of organic matter, rain water, rock-derived minerals, plus atmospheric deposition of gaseous and particulate matter. Outputs from soil occur by physical erosion, leaching of solutes and colloids, incorporation of soil constituents into biomass and emission of volatiles to the atmosphere. Therefore, the complex nature of soil requires many cross-disciplinary excursions including an appreciation of the geological inheritance of soil and the role that geomorphic setting plays in determining water flow through soil landscapes.

2.1.3 Scales of soil variation

There are various scales at which patterns in soil property distribution emerge in landscapes. Variations span microscopic (micrometers) to vast regional (square kilometers) scales. To yield pedological utility, an investigation must take place at scales commensurate with the spatial domains of pedological pattern. In this study, research questions pertain to changes in weathering and soil properties on catenas as influenced by differences in climate and topography. Therefore, the spatial domain encompasses scales where topographic and climatic variations are expressed in soil properties. Consequently, the study's spatial domains are: (1) the study area at the broadest scale for which climate varies; (2) the drainage network at which scale hillslope relief varies *viz.* high and low relief hillslopes in the upper and lower reaches of drainage networks respectively; (3) the catena for which there is rising. Contributing area with increased distance from crest; (4) the pedon in which soil properties and weathering vary with depth and (5) the soil horizon at the smallest scale which demarcates the unit for measuring soil properties in the study(Brady and Weil, 2004).

2.1.4 Organization of soil

A soil profile is composed of near-horizontal layers (horizons) distributed vertically from the soil surface to rock or sediment, a differentiation driven by vertical penetration of biotic products and percolation of water. Thus, the gradual transition from soil to rock coincides with lower concentrations of clay and organic matter and more gravel to cobble size rock material. Not all soil processes lead to strong horizonation (Brady and Weil, 2004). For example, horizons can be destroyed by biological mixing; too much water flowing through a soil can lead to uniformly leached horizons and limited water flux can arrest soil formation leading to indistinct horizon development.

An individual soil profile lies in a mosaic of others indexed by a measure referencing its location between a crest and basal stream *e.g.* distance from crest or upslope contributing area. A single catena is part of a drainage network of streams ranging from small depressions in headwaters to progressively larger channels downstream. In the context of hydrological fluxes along hillslopes, catena properties vary with topographic attributes such as slope gradient, relief, catchment size, *etc*. The soil landscape thus cascades in scale from a horizon, to a soil profile, to a series of profiles coalescing into pattern at the catena scale, to a spectrum of catenas abutting streams at bigger scales and to drainage networks in different climate zones (Brady and Weil, 2004).

2.1.5 Soil differentiation

Horizon properties themselves suggest mechanisms for profile differentiation through intra-profile processes. These inter-horizon processes operate vertically from surface soil to rock in response to infiltrating water. Gravity induces water to percolate through the soil skeleton bearing a load of dissolved and colloidal material, which are removed from near-surface horizons and re-deposited as plasma at depth resulting in horizonation or soil profile differentiation (Birru, 2003). The pattern of soil profiles down a catena likewise is linked by downslope water flow that redistributes mass as solution or colloidal flow. The degree to which a soil profile or catena are differentiated from the source-rock is a function of soil forming processes and pedological state factors, which are scale dependent. For example, at the hillslope scale, geology is generally uniform from crest to base, but at larger scales, geology shapes weathering and soil properties on geo-topographic platforms in landscapes (Brady and Weil, 2004).

2.2 Soil landform relationships

Many of the differences in soils that vary with topography are due to some combinations of microclimate, pedogenesis and geological processes. In a given geographical locationthe landform, indirectly control most of the soil forming processes. Erosion processes aremore intensive on the steeper slopes and convex land form; accumulation processes areconcentrated on the flatter areas and concave landforms (Weigel, 1986). The same author described that due to the longer periods of high soil moisture, weathering processes aremuch more intensive in flatter and concave areas.The most obvious relationship of soil properties to landform/topography probablyoccurs in humid regions where soils on nearly level areas reflect to have thicker solumthan on sloppy land (Boul *et al*., 2003). Slope orientation can also greatly affect soilorganic carbon distribution with depth, the presence or absence of an E horizon, pH andpresence of exchangeable bases. Soils on the uplands commonly are well drained,whereas those in depressions are poorly drained and rich in clay and organic matter, withsigns of various degrees of gleying (Belay, 1998). As a result of complexity of soil forming factors such as climate, geology andtopographic factors, soils with diverse characteristics develop in various partsof a country (Mitiku, 1987). According to the same author, the major soils Leptosols,Nitisols, Cambisols and Vertisols cover 16, 12, 11.5 and 10%, respectively, of the totalarea. TheVertisols commonly occur in poorly drained lower topographic positions, whereas the Nitisols occurred on better drained, higher topography areas.

2.3 Controls on weathering and soil properties by parent material and topography

The intensity of material fluxes across toposequence depends on parent material and topography which are in turn ultimately shaped by tectonic activity. Variation in tectonic forcing on continents leads to geo-tectonic soil provinces distinguished by dominant lithospheric material, seismicity, volcanism and topography (Paton *et al*., 1995). Thick soil develops on continental plate centres characterized by low seismicity, low volcanism, gentle topography and granitic rock. In the absence of significant geothermal control, topography and rock type emerge as major thrusts on pedogenesis and soil landscape evolution.

2.3.1 Parent material control

Parent material is the raw input of primary minerals for pedogenesis at time zero (Schaetzl and Anderson, 2005). The parent material of a soil may be rock, dust, alluvium or another soil. A soil inherits its parent material's primary minerals, chemistry and physical properties. These parent material attributes become initial soil properties until the soil is divorced from its genetic origin by soil forming processes. For example, coarse-grained granite produces an initially coarse-grained soil. However, mobilization and illuviation of plasma may modify a downslope soil's granitic inheritance by supplementing it with material from upslope. Felsic landscapes exemplify the discrepancy between soil and parent material far more than other geo-terrains. If downslope illuviation occurs on a mafic catena, for example, extra plasma downslope will not result in a sharp texture contrast because the soil was clay-rich to begin with. In granite, by contrast, a coarse matrix aids relatively unimpeded movement of plasma through pores down soil profiles and laterally across catenas. Therefore granitic landscapes are ideal for studying catena or differentiation in various factorial contexts because potential clay augmentation is most readily identified in coarse-grained lithologies (Brady and Weil, 2004). But within granite itself, soil development is nuanced by internal heterogeneity in rock composition which alters the degree of catena differentiation. Rock variation is pervasive in landscapes and occurs even in apparently uniform stretches. Often, landscapes are in reality compositionally heterogeneous at scales too fine for most geological maps.

2.3.2 Topographic control

Topography has a strong influence on soil development.Soils on the side of hills tend to be shallow due to erosional losses. Soils on the top of hills tend to be deep, but lighter in colour due to leaching losses. Soils in the valleys tend to be deeper, darker and contain more horizons.This is due to increased material deposition from hillside erosion, material accumulation from downward leaching from the tops of hills, and the collection of greater quantities of water in the low lying areas.

Scholten *et al*. (1997) showed that soils in high-lying ground are rich in resistant K-feldspar relative to easily weathered plagioclase. Therefore, geology plays a crucial role in topographic development and acts as a template for catena differentiation. Once established, topography is a passive soil forming factor, modifying weathering and soil properties indirectly via its influence on water and mass movements (Jenny, 1941). Topographic variation can be viewed at many scales; ranging from the contrast between inland plateaus and coastal escarpments; to variation in the relief of a drainage network's stream-catena systems and to the topographic contrasts on a hillslope between crest and toeslope. Geomorphic changes along the cross section of a hillslope induce material transfers down gradients of decreasing potential energy from high to low ground, whether liquid, solute, plasma or solid. Therefore in addition to the genetic link that a soil has with its underlying parent material, the soil can also have a hydrological link with an upslope soil through material redistribution mediated by topography (Jenny, 1941).

Geo-topographically controlled variation in soil properties on hillslopes forms regular and repeated catena patterns from crest to toeslope (Milne, 1935). Greene (1947) saw the catena's resemblance to a soil profile rotated to its side in how soils down a profile or catena are hydrologically connected. Milne (1935) acknowledged the veracity of geologic variation in landscapes and suggested there should be catenas developed on uniform parent and those traversing various geologies. He attributed catena differentiation to translocation of plasma and solutes, as well as particulate transport by soil erosion. Thus, unlike most of his North American contemporaries, who viewed the soil-topography relationship as a curious modifier of climatic control. Milne also recognized the geomorphic process of erosion as central to pedogenesis (Brown, 2006). Far from being surrogate to climate in controlling weathering and soil properties, topography and geology are the template upon which climate acts (Khomo, 2008).

2.4 Soil characterization and classification

The type of soil formed under a particular set of environment is a function of the parent materialand time. In order to accurately classify a soil and make recommendations for utilitarianpurposes, soils occupying any particular agro-ecological zone must be properlycharacterized (Brady 1990; Esu 2005). Information on the kinds of soils in an areais obtained through soil survey activities. Soil physico-chemical properties and micronutrients vary in their contents from soil tosoil and from one parent material to the other. The purpose of soil classification is to organize our knowledge that the properties of soilbe remembered and their relationships may be understood most easily for specificobjectives. Accordingly, the presence or absence of specific diagnostic horizons, properties and materials were used to distinguish soil units and subunits as given in theemployed classification system (FAO/WRB, 2006). Several approaches and classification schemes exists in various countries in the world like USSR, Australian, Canadian, South African, etc, and most havebeen on a national basis (Foth, 1990).

The classification schemes differ because they are based on different appreciation of soil formation, use different criteria, and different hierarchical sub-divisions (Landon, 1991; Buol *et al.*, 2003). According to FAO (1991), modern classification systems classify soils based onquantitative characteristics defined as diagnostic horizons, properties and materialsbecause the properties that result from soil processes are more easily quantifiable thanprocess of soil development. Its working materials are the description, characterizationand interpretation of soil profiles, soil bodies and pattern of soils (SSDS, 2000).Therefore, soil genesis study is dependent upon the supportive and correlative activitiesof soil morphology, characterization and soil geology. Basically, soil classification iscarried out with the help of field mapping, observation of soil profile and use oflaboratory analysis (Buol *et al*., 2003).

The USDA Soil Taxonomy (Soil Survey Staff, 1975, 1999) and the FAO-UNESCO SoilClassification System (FAO, 2001) are the two most used classification systems in Nigeria (Esu,
1999). For instance, Nuga *et al*.(2006) classified the soils crest, upper slope and middle slope along a toposequence in Ikwuano Local Government Area, Umuahia Abia state as typic kandiudalfs while soils of the valley bottom was classified as typic kandiaquultsaccordingto the USDA (Soil Survey Staff, 2003) systems. The soils of tropical Nigeria were mostly Alfisols and Ultisols, with respect to such criterianas nature of the epipedon, diagnostic master horizon, the cation exchange capacity, percentagebase saturation, organic carbon content, soil drainage characteristics, soil temperature, moisture regimes and soil colour. Esu and Akpan-Idiok (2010) characterized the morphological and physico-chemical properties of alluvial soils and classified them according to the USDA SoilTaxonomy System (Soil Survey Staff, 1999) and the FAO/UNESCO/ISRIC World Reference Base for Soil Resources (WRB) Classification System (FAO, 2001). The soils met the requirement as Entisols and Vertisols.

The mineralogical analyses carried out on the clay fractions from the horizons of Nsukka soilseries (Akamigbo and Igwe, 1990) showed that the dominant clay minerals are kaolinite andquartz; and the classifications according to Soil Taxonomy and FAO/UNESCO Soil Legend areUltisols and either Acrisols or Nitisols. The characteristics of Umuahia soils include their sandyloam textural class, considerably high sand and moderate clay fraction formed from false-beddedsandstone (Orajaka, 1975) and acidic reaction, associated with low activity clays, highlydegraded and leached profiles; which Akamigbo and Asadu (1983) described as deeply weathered soils mostly derived from the residual of sedimentary materials. The CEC of the soilsare generally low (Asadu, 1990) as well as low exchangeable bases. Akamigbo andAsadu (1983) reported these intrinsic properties as dependent on the parent materials of the soils.The soils of Umuahia in Southeastern Nigeria havegenerally been derived from the residua (disintegrated rock materials) of either false-beddedsandstone or upper-coal measures (Asadu, 1990), which give rise to sandy soils. These soils are low in inherent fertility and are subjected to high temperature and rainfall of high intensity (Asadu *et al.*, 2010). Nigerian soilsderived from basic rocks have higher content of micronutrients than those derived from acidrocks (Chude *et al.,* 1993). It is not so much abundance or the total content of these micronutrientelements as the availability that is crucial to plant growth, since micronutrients in most soils are ordinarily insoluble and are not easily available to plants.

Soils are the bases for most development projects. In order to ensure that the soil is put to themost appropriate and sustainable use, there is every need for characterization and classificationof the soil. Soil characterization, soil classification and soil mapping provide a powerful resourcefor the benefit of mankind, especially in the area of food security and environmentalsustainability (Esu, 2005). According to Ajiboye and Ogunwale (2010), earlier studies conducted on the soils of various regions of Nigeria and subsequent classifications were based majorly onthe soil parent materials at the higher category classes. Soil classification study is a major building block for understanding the soil, classifying it and getting the best understanding of the environment.

2.4.1 Major problems in soil classification

All soil scientists dealing with soil classification know that there is very seldom a complete agreement on the name for a soil profile among colleagues, even when consulting the same handbook and the same data base about site, profile and analytical data. For example, the classification of 6 profiles of Mozambique by an international panel of 12 soil experts provided for each pedon on average 8 different names at the subgroup level of ST (Kauffmann, 1987). At the order level some soils received 4 different names, ranging, for example, from Oxisol to Mollisol, Ultisol and Alfisol. We can agree with Kauffman (1987) when he stated that the large differences for same profiles cannot be allowed in any taxonomic system”. The excellent excursion organised during the International Symposium on Soil Classification 2001 in Hungary (Anonymous, 2001), attended by a set of world specialists in soil classification, and illustrated once more the disagreement among scientists when providing names to the visited profiles. Unfortunately the discrepancies do not always concern minor details. This situation is one of the major reasons why soil classification has poor reputation in the discipline of soil science. Students should not only be informed about this status, they should also learn about the reasons behind it. At least three aspects must be distinguished here.

- Quality of the handbooks.
- Quality of the soil databases.
- Soil scientists usually proceed too fast when classifying soils.

2.5 Concept of soil toposequence

Catena" (Milne, 1935) or toposequence (Juo and Moorman, 1981)) refers to a succession of sites from crest to a valley bottom, which contains a range of soil profiles that are representative of the landscape and soils. The topographical features of a landscape are vital in understanding soil forming processes and modification of soil profile development. Consequently, understanding the roles of topography in a landscape will help in assessing productive values of soils and most importantly, in developing strategies for its conservation (Blum, 2013).

A toposequence is a sequence of related soils from the hill top to the valley floor. Most pedologists have recognized the influence of topography on soil properties (Moorman, 1981; Akamigbo and Asadu, 1986). Different results have been obtainedfrom toposequence studies of different areas. Topography may bring about thedifference in soil properties of some related soils. This sequence is referred to as atoposequence (Brady, 1974). Toposequences have beenused by many pedologists to characterize soils (Akamigbo and Asadu, 1986).According to Akamigbo and Asadu (1986), in the study carried out at Opanda, Eha-Amufu, and Nkpologu, topography in combination with other soil forming factors affected the depth or thickness of soil solum, particle size distribution, organic mattercontent, cation exchange capacity, total exchangeable bases and exchangeable acidity.

Ruhe (1960) identified 5 major soil positions on a typical toposequence in Iowa, USA; summit, shoulder, backslope, footslope, and toeslope. This toposequence pattern of landscape is very common inmany parts of West Africa (Van Staveren and Stoop, 1985; Ouattara, 1990; Doumbia, 1990). Increasing population pressure expanded farming from gently sloping surfaces inthe highlands to steeper slopes and marginal lands in Ethiopia (Azene, 1997; Demel, 2001) which inturn have brought disturbance to the ecosystems, particularly as soils are the determinantfactors of agricultural production and productivity. Soil frequently occurs in a well defined and fairly regular sequence (Smyth andMontgomery, 1962) thus, soil properties (morphological, physical and chemical) and the potentials for crop production often vary from crest to the valley bottom due to difference in soil types. Odenerho (1980) observed that the distribution of individual soil series on a toposequence as well as the spatial distribution of the toposequence itself haveconsiderable influence on the land use pattern of an area.

Stoop (1987) observed a high degree of variability in crops stands and lowaverage productivity on the West African landscape and noted that crop yield tends todecrease from fertile valley bottom soil to generally infertile up lands. In spite of these reported variability in soil properties and crops yield along the toposequence,recommendation for agronomic practices are often made to farmers without due consideration for specific topographic locations that might influence the management options such as fertilizer rate and types, tillage operations and herbicides application (Oluwatosin *et al.*, 2001). This brings about sharp variations in crop yield. Moorman *et al*. (1981) noted that an understanding of the basic soil properties is essential for developing soil management practices that will maintain the productive potential of a soil.

Slope is one of the important factors of universal soil lossequation. Its geometry, such as slope angle, length andcurvature influence runoff, drainage, and soil erosion (Aandahl, 1949) causing a significant difference in soilphysico-chemical properties (Brubaker *et al.*, 1993). Nejad and Nejad (1997) reported the effect of topography on soil genesis and development of soils and observed thatslope gradient and slope length had direct and indirecteffect on calcification, mineralization and soil physical andchemical properties.The slope can be divided into sections which are commonly referredto as the ridge, crest, slope and toeslope. Steeper slopesections tend to be freely drained, while at the bottom of slopes (toeslopearea) there is usually a higher moisture content due to poor drainage(Ritter 1986). Toeslope soils are not only higher in moisture content, but arealso known to be richer in clay and organic matter (Birkeland, 1984).

Soil properties on atoposequence differ due to degree of wind and rainfallerosion, transport and deposition of particle components ofthe soil (Krasilnikov *et al.*, 2005). Pedogenic processes acting on soil properties affectthe geomorphic features and differentiate the soils by theirlocation within the toposequence (Huggett, 1975; Ovalles and Collins, 1986). Because soils are an integral part of the land surface, any variations in the geomorphic processes influence the pedogenic processes (Young and Hammer, 2000; Brunner *et al.*, 2004) so soil surveys can find the relationship between topography and different soils. Topography is also linked to many ecologicalcharacteristics through its influence on both soil moisture and soil chemistry (Hattar *et al.*, 2010).

Studies have shown that the extent of variability in soil properties may be significant even for a simple change in topography (Uehera *et al.*, 1985). Consequently, soils on hill slopes exhibits remarkable difference in properties from those on the summits because of percolating water which tends to move laterally across a profile instead of vertically (Russel, 1967). According to (Glassman *et al.*, 1980) water velocity on a slope affect deposition of materials in suspension, sand drops out of suspension first, while clay size particles can be carried further away from the base of the slope before they are deposited. This kind geological sorting brings about variation in soil in relation to landscape. Some researchers have related some soilchemical and mineralogical properties to the slopesteepness, length curvature and the relative location withina toposequence (Gessler *et al.*, 2000; Johnson *et al.*, 2000) and others related the topography with hydrological variation by introducing the topographicwetness index (Beven and Kirkby, 1979). The topography of an area can affect the microclimate, soil formation, parent material and hydrological and geological processes, which in turn effect soil processes (Birkeland 1984). Topographic factors such as the orientation of the hillslope and thesteepness of the slope affect the microclimate, vegetation establishment, water movement, and erosion (Birkeland 1984).

2.5.1 Soil property distribution along toposequence in different contexts

Soil texture, structure and colour are three of the more self-evident soil properties easily perceived in the field or in hand samples. Soil texture depends on the relative abundances of sand (2.0-0.05 mm), silt (0.05-0.002 mm) and clay (<0.002 mm) sized particles. The size distribution of particles is originally inherited from parent material and subsequently modified by atmospherically derived dust and chemical weathering, leading to a slow and progressive skewing of the size distribution toward smaller particles. Superimposed on these determinants of soil texture are redistribution processes whereby clays are removed from upper and to lower horizons or from catena apices to low lands (Khomo, 2008). Texture contrasts among soil horizons generally reflect differences in pedogenic processes (Bridges, 1978), but may also denote biological, geological or geomorphic discontinuities (Schaetzl and Anderson, 2005). For example, bioturbation by macrofaunal agitation of soil may obliterate any horizons resulting in homogenization of texture. Also, mining of fine soil from deep horizons by mesofauna such as termites can also produce a texture contrast in soil (Jones, 1990). In yet other situations, a lithological discontinuity as exists in layered sedimentary rock can be inherited by a soil resulting in texture contrast(Khomo, 2008).

As with texture, systematic changes in soil structure attest to differentiation down a soil profile or along a catena. Structure encapsulates size, shape and integrity of individual soil aggregates. Structure can range from small granules that disintegrate on touch to hard blocks depending on the carbon content and soil texture (Schoeneberger, 1998). High concentrations of organic matter promote granular structure whereas blocky structure reflects high clay with less organic matter (Chikezie *et al*., 2010). Since clay tends to accumulate in the distal ends of catenas, strong, blocky structures are common in downslope positions (Khomo, 2008). Colour is a compound soil property due to relative amounts of soil components such as organic matter, iron oxides, salts such as calcium carbonates and primary minerals. The important colorants in soil are dark brown to black organic matter, red to yellow iron oxides, and whitish salts. By contrast, primary minerals have subdued colours that are only evident under conditions which suppress the more colourful soil components (Khomo, 2008). Overall, soil colour is a balance between the amount of organic matter and the abundance and extent of grain coating by various species of oxidized iron or calcium carbonate. Therefore, parts of a granitic catena with abundant primary minerals in an unweathered state will have the light colours of quartz and feldspar whereas downslope, where organic matter and iron oxides accumulate, soils commonly have darker colours. Soils that lie near water seeps along catenas where redox processes are common have light colours that betray the absence of oxidized iron (Khomo, 2008). All soil properties have a systematic landscape distribution under factorial (Jenny, 1941) and process domains (Bridges, 1978) specific to the soil’s location. If the factors and processes of soil formation are known, weathering and soil properties can be explained (Jenny, 1941).

2.6. Soil morphological properties

2.6.1 Soil depth

Soil depth has strong relation with weathering rate, soil erosion, topography and other soil properties like hardpan, platy structures, stratified layers, salt accumulation and the like (Rai, 2002). Mostly, the depth of the soils is influenced by the relief (Mesfin, 1998). Soils on gentle slopes have thicker depth than those of sloppy lands (Bono and Seiler, 1984; Belay, 2000; Engdawork, 2002). The soil thickness increases down the slope and the depth of the solum ranged from 18 cm on the summit to over 200 cm at the toeslope (Mebit, 2006). Mostly, the depth of the soils is influenced by the relief (Mesfin, 1998). Sheleme (2011) found out that convex crest and depression had deeper and darker surface layers as compared to the others. These might be attributed to relatively low removal of surface soil by water erosion at the convex crest (plain with 2% slope), and continuous deposition of soil material in the depression. On a toposequence derived from coarse-grained Pegmatites in a tropical region, Delta State, Nigeria, Egbuchua (2014) observed that soil depth increased progressively along the slope positions. The crest and upper-slopes were deep up to 140 cm. The lower and valley bottom slopes were shallow (60-80 cm depth) because of high water table. The shallow depth observed in the lower/valley bottom slope positions could be attributed to water erosion effects along the slope as some materials could be eroded from the crest and upper slopes downward thereby decreasing the thickness of the solum (Egbuchua, 2014).

2.6.2 Soil colour

According to Mohammed *et al.* (2005), soil colour characteristics showed a gradient pattern of variation from dark in slope summit uncultivated soils through brown in foot slope, to black and/or dark brown in toe slope cultivated soils. In a similar way, Belay (1997) identified the colour variation in Watiya catchment of Wello, Ethiopia, that the soil color marked down slope increases in hue and decreases in chroma reflecting the effects of reduced drainage. The poorly drained uncultivated Vertisols on the lower toe slope were black (10YR 2/1) while the well drained cultivated upper toe slope soils were dark brown (10YR 3/3). Belay (1996) attributed the

more or less uniform dark color which characterized the A horizon to depths of more than 120 cm to pedoturbation and mixing of organic matter enriched surface soils in an alkaline environment.Nwaka (2000),attributed the uniform dark colour of Vertisols of a plain in Borno State to a high content of humin, a group of humic acid that is dark but has low organic carbon content, thus making the soils low in organic matter, with the dark colour of the soils not withjstanding. According to Abayneh (2001), the value and chroma of the soils of Raya Valley are lower (mainly 2/1) in the valley bottom than in the alluvial plains (mainly 3/2). This is primarily due to the relatively higher organic matter content of the soils of the valley bottom.
Organic matter, water content and the presence and oxidation states of iron and manganese oxides influence soil color. Egbuchua (2014) found that the morphological features of soils ona toposequence derived from coarse-grained Pegmatites in a tropical region, Delta State, Nigeriavaried, the soil colours differed from the crest, upper and middle-slope positions and are characterized by a Hue of 5YR yellowish red. The lower and valley bottom slope positions have 7.5 YR and 10 YR reddish, yellow and grayish colour sequence as evidence of water saturation at some period of the year thereby signifying poor drainage conditions. The observed change in soil colour along the toposequence was as a result of the influence of topography on micro-climate (Egbuchua, 2014).

Soils on hilly slopes are usually characterized by coarse textured and are lighter in color while soils at lower slopes are fine in texture and darker in color due to the removal of organic matter and finer soil particles from the upper slopes in the case of the former, and their deposition at the lower slopes in the case of the latter (Sopher and Baird, 1982). In a study done by Obasi *et al.* (2011) on soils of a forest-savanna mosaic on aridge at Afikpo, Southeastern Nigeria, the south facing slope (SFS) soil colour ranged from dark reddish brown (2.5 YR 3/2) moist to orange (7.5 YR 6/8) moist at the crest. At the midslope, colour graded from yellowish brown (10 YR 5/2) to lightyellowish orange (10 YR 6/6) down the profile while the footslope was dark brown (10 YR 3/3) at the topmosthorizon to yellowish brown (7.5 YR 5/8) at the lowest horizon of the profile. North facing slope (NFS) colourswere as follow; crest was brown (7.5 YR 4/4) at the topmost horizon and orange (2.5 YR 6/8) at the lowesthorizon of the profile. Midslope; dark brown (7.5 YR 3/3) to yellow orange (7.5 YR 8/8) while the footslopegraded from grayish yellow brown (10

YR 6/6) to dull yellow orange (10 YR 6/4) (Obasi *et al.*, 2011).Generally, the colour indicated that virtually all the pedons showed a sign of eluviation in which sesquioxides,carbonates, and or clay minerals have been leached out except at the foot of NFS where aquic condition wasencountered. The grayish yellow brown colour suggests that the footslope is of less inherent productivity resultingfrom previous condition of restricted drainage (Ibanga, 2006).

2.6.3 Soil structure and consistence

The individual soil particles are not usually randomly arranged in field soils but are combinedto form secondary soil particles called aggregates or peds (Scott, 2000). An aggregate is agroup of primary soil particles (sand, silt and clay) that cohere to each other more stronglythan to other surrounding soil particles (Sanchez, 1997). According to the same authors, a pedis a unit of soil structure formed by natural processes, in contrast to a clod, which is formedartificially. This implies that two soils with the same texture may have distinctly different soilphysical properties and behaviors because the particles are arranged in different ways. Theprimary particles are bound together into aggregates by colloidal substances such as OM, clay, metallic oxides, and carbonates. Soil structure is, therefore, defined as the size, shape, andarrangement of aggregates of the soil (Scott, 2000).The nature, size, and distribution of natural aggregates of soil play a very important role indetermining such soil physical conditions and characteristics as pore space, water retention andmovement, infiltration, porosity and aeration, heat transfer, strength and erodibility (Hillel,2004). Furthermore, as soil structure influences the mechanical properties of the soil, it mayalso affect such disparate phenomena as germination, root growth, tillage and overland traffic.Management practices such as cultivation, plowing, irrigation, drainage, cropping, liming, andmanuring operations directly influence soil structure.

The soils at the foot slope had strong to moderate, fine to medium, subangular blocky structure on the surface that changed to moderate to strong, medium to coarse angular blocky in the subsurface horizons (Mohammed *et al.*, 2005). According to the same authors, the toeslope soils dominantly consisted of strong to very strong, medium subangular blocky on the surface and very strong, coarse to very coarse angular blocky in the subsurface horizons. The structure of the soil along the toposequence exhibited wide variability. The structure of the soil at the summit areas was weak to moderate, fine to medium, crumb while that of the soil at the toeslope was moderate to very strong, fine to very coarse blocky structure at the surface (Mebit, 2006). The weak strength of the structure in the horizons might be due to the relatively high OM and low clay content of the soils which is suitable for agriculture because it is easy for plowing. In the subsurface horizons soil structure changed to blocky with subangular variants with slight variation in grade and size (Demelash, 2010). The strong structure in the soils could be attributed to the high clay content. According to Gokhan and Ertugrul, (2012) the high clay content in soils brings out excessive shrink-swell actions during drying and wetting cycles. This might be the one reason for the observed cracks in the soils.

According to Mebit (2006), dry soil consistency was different along the toposequence. The summit area had soft to slightly hard, whereas the toeslope had slightly hard to very hard consistence. Although consistency is an inherent soil characteristic and a reflection of the particle size composition of the soil, variations in clay and organic matter contents at the upper elevations changed stickiness and plasticity of the surface soil layers along the topsequence of the study area. As indicated by Demelash (2010) change in consistence characteristics from the surface to the subsurface horizons reflects high contents of clay and low contents of OM of the subsurface horizons. Mahajan *et al*. (2007) indicated that the soil consistence exhibited varying behavior i.e. firm, friable, and very friable to loose. On a toposequence derived from coarse-grained Pegmatites in a tropical region, Delta State, Nigeria, Egbuchua (2014) found loose and friable consistency at the upper slope, slightly hard and sticky at the midslope and firm and slightly plastic at the valley bottom.

2.7 Soil physical properties

2.7.1 Soil texture

The soil solid phase as a whole can be characterized in terms of the relative proportions of itsparticle size groups called soil separates. The relative size range of the soil particles isexpressed by the term texture, which, qualitatively, refers to the fineness or coarseness of thesoil. Quantitatively, it refers to the relative proportions of the different particle size fractions,specifically referred to as sand, silt and clay (with organic and cementing materials removed)(Chaudhary, 2002; Hillel, 2004).Soil texture affects a number of physical and chemical properties of soils including infiltrationand retention of water, soil aeration, absorption of nutrients, microbial activities, tillage andirrigation practices (Sanchez, 1976; Gupta, 2004). Sandy soils have low water and nutrientholding capacity, low OM content, little or no swelling and shrinkage capacity and high leaching ofnutrients and pollutants (FAO, 1998). On the other hand, clayey soils have high nutrient andwater holding capacity, poor aeration, very slow drainage unless cracked, high to medium OMand relatively high swelling and shrinkage properties compared to the sandy soils (Ranst,1991; FAO, 1998). It is also an indicator of some other related soil features such as type ofparent material, homogeneity and heterogeneity within the profile, migration of clay andintensity of weathering of soil material or age of soil (Lilienfein *et al*., 2000).

Soil texture is one of the inherent soil physical properties less affected by management. Therate of increase in stickiness or ability to mould as the moisture content increases depends onthe content of silt and clay, the degree to which the clay particles are bound together into stablegranules and the OM content of the soil (Hillel, 2004). Over a very long period, geologic andpedogenic processes such as erosion, deposition, eluviation, illuviation and weathering canchange the textures of various soil horizons (Brady and Weil, 2004).Although soil texture is considered as a permanent property, Wakene (2001) indicated thatmanagement systems may contribute indirectly to changes in particle size distributionparticularly in the surface horizons as a result of clay removal through sheet and rill erosion,and mixing up of soils of the surface and subsurface horizons during mechanical tillageactivities. Research results on soils of the Jello micro-catchments in West Hararghe areas ofOromia Region, Eastern Ethiopia showed that textural class varied with positions of soils in the landscape(Mohammed *et al*., 2005).

According to Samuel (2006), the texture of the surface soil at the back slope profile was sandy loam in back slope areas at which sand was the dominant soil separate (61%), whereas it was clay in texture throughout the profile except loam soil texture (23% clay) occurred at the depth of 131-194 cm of the foot hill slope soil. However, textural classes of the surface horizons were clay for all the landforms except for the backslope, which was clay loam. Clay percentage increased and sand decreased from the summit area to the toeslope. Although texture is an inherent soil property, slope may contribute directly to the change in particle size distribution particularly in the summit area as a result of clay removal through erosion and deposition at the toeslope (Mebit, 2006).

Soils assume increasingly heavier texture from the crest down to the toe slope (Belay, 1997). The soil textural class varies with positions of soils in the landscape. It ranges from silt clay loam in the upper slopes to clayey in the lower slope positions; suggesting that amount of clay increases down slope (Mohammed *et al.,* 2005). The Vertisols in the lower toe slopes are much heavier than those on the upper parts and this is mainly attributed to the relatively finer texture of the fresh alluvium reaching the slope positions and itsmore intense weathering due to higher moisture supply at the site (Belay, 1996). Beshir*et al*. (2015)showed that sand, silt and clay fractions differed significantly along three slopes, land use types and both soil depths along a toposequence in Gilgel Gibe Catchment in Nadda Assendabo Watershed, Southwest Ethiopia. According to Glassman *et al*. (1980) water velocity on a slope affect deposition of materials in suspension, sand drops out of suspension first, while clay size particles can be carried further away from the base of the slope before they are deposited.

2.7.2 Bulk and particle densities

Bulk density is a measure of the weight of the soil per unit volume, usually given on an ovendry basis (Ranst, 1991). The volume includes both solids and pores. Bulk density values areimportant in quantitative studies, such as in calculating the volumetric water content, totalporosity, mass of soil per unit area per unit depth and to indicate whether a given soil is toocompact for root penetration or not.Variation in bulk density is attributable to the variation in the relative proportion and specificgravity of solid organic and inorganic particles and to the porosity of the soil. Consequently,bulk density of soils is influenced by soil texture, structure, OM content and soil managementpractices. The bulk density of granulated clay surface soils will commonly be in the range of1.0 to 1.3 g cm^{-3} while that of coarse-textured surface soils will usually be in the range of 1.3to 1.8 g cm^{-3}(Hillel, 2004). The greater development of structure in the fine-textured surfacesoils and relatively higher OM content accounts for their lower bulk density as compared tothe more sandy soils with less structural differentiation (Sanchez, 1976). Low bulk densityvalues (generally below 1.3 g cm^{-3}) indicate a porous soil condition (FAO, 2006). Increase inOM lowers bulk density while compaction increases bulk density. In swelling soils, bulkdensity decreases with increase in moisture content and vice versa. Bulk density is generallyhigher in lower profile layers (Chaudhary, 2002). The density of OM is very low as comparedto the mineral soil and hence higher organic matter content results in lower density. Moreover,higher compaction due to the weight of the overlying layers also increases the bulk density ofthe subsurface layers (Shiferaw, 2004).

The fact that the bulk density is lower at the surface than the under-lying horizons observed in the toeslope and lower footslope area soils were in agreement with the established fact that bulk density is lowest at the surface due to high organic matter content (Mebit, 2006; Samuel, 2006). According to the same author, in the toeslope, lower footslope and upper footslope areas, bulk density increased with depth. According to Ahmed (2002), bulk density showed greater variation with profile depth and higher bulk density was obtained at the sub-soil horizons under all the elevation zones and land use types. According to Malo *et al*. (1974), there is also an abrupt decrease in bulk density values at the footslope and toeslope positions caused by increased amounts of organic matter and fine particles. There is alsoan abrupt decrease in bulk density values at the footslope and toeslope positions caused byincreased amounts of organic matter and fine particles (Malo *et al*., 1974).

According to Mebit (2006), the highest particle density (3.08 g cm^{-3}) was recorded at the surface horizon of the lower footslope whilst the lowest (2.70 g cm^{-3}) was observed at the surface horizon of the backslope. The highest particle density at the surface horizon of the lower footslope might be due to the presence of low organic matter. Whereas, the lowest particle density in the backslope may be attributed to the relatively higher organic carbon content than in the soil under the other slope gradient. In most mineral soils, the mean particle density varies from 2.6 to 2.75 g cm^{-3} since they are largely composed of quartz, feldspar, micas, and the colloidal silicates (Hillel, 1980). According to Ahmed (2002), the surface soil layers possessed lower particle density values than the subsoil horizons and the highest particle density (2.93 g cm^{-3}) was obtained at the subsoil horizon (57-95 cm depth) in grazing land soils of the middle elevation. The mean bulk density for the crest/upper slopes, middle-slope and lower/valley bottom slopes were 1.20 gcm^{-3}, 0.79 gcm^{-3} and 0.47 gcm^{-3} and coefficient of variations of 19.30%, 11.47% and 14.65% in that order respectively was reported by Egbuchua (2014) on a toposequence derived from coarse-grained Pegmatites in a tropical region, Delta State, Nigeria.

2.7.3 Soil porosity

Porosity, defined as the ratio of total volume of pore spaces to the total volume of soil, is anindex of the relative pore space in the soil. For soils with the same particle density, the lower the bulk density, the higher is the percent pore space (total porosity). Total porosity of soil usually lies between 30% (in compacted subsoil) to 70% **(**in well-aggregated, high-OM surfacesoils**) (**Brady and Weil, 2004) and may be used as a very general indication of the degree ofcompaction in a soil in the same way as bulk density is used. As is the case with bulk density, management exerts a decisive influence on the pore space of soils (Brady and Weil, 2004). Coarse-textured soils tend to be less porous than fine-textured soils, though the mean size of individual pores is greater in the former than in the latter (Hillel, 2004). Sands with a total pore space of less than about 40% are liable to restrict root growth due to excessive strength whilst in clay soils limiting total porosities are higher, and less than 50% can be taken as the corresponding value (Landon, 1991).

The decrease in OM and increase in clay that occur with depth in many profiles are associated with a shift from macro pores to micro pores (Brady andWeil, 2004). In contrast to macro pores, micro pores are usually filled with water in the field soils. Even if not water filled, they are too small to permit much air movement. Fine textured soils, especially those without a stable granular structure may have a dominance of micropores, thus allowing relatively slow gas and water movement, despite the relatively large volume of total pore spaces (Chaudhary, 2002). Mebit (2006) reported that the high total porosity was the reflection of high organic matter content along the toposequence of Woreta agricultural research farm.

Similarly, Wakene (2001) reported that the low total porosity was the reflection of the low organic matter content and the high bulk density that was imposed by the use of heavy farm machinery for tillage activity and intense grazing of the fallow land The pore spaces exist because of the particle and the disturbance including those due to roots, soil animals, swelling, cracking on shrinking and tillage that alter the spacing of aggregates or particles (Rose *et al*., 1996). Considering only the surface soil layers, the lowest total porosity (55.07%) was observed on the toe slope, followed by (58.77%) the lower footslope, and the highest total porosity (66.07%) was observed at the 0-25 cm depth of the Mollic Leptosols of the backslope area (Mebit, 2006). Considering the topsoil layers, total porosity was relatively higher (64%) in the foot hill slope soil than in the back slope soil (53%) at the Adi-silky study site (Samuel, 2006). The higher values of total porosity corresponded to the higher amount of organic matter contents and lower bulk density values as reported by Mohammed (2003) and Wakene(2001). Egbuchua (2014) observed that the crest/upper soils developed on a toposequence derived from coarse-grained Pegmatites in a tropical region, Delta State, Nigeria have lower total porosity with mean values of 48.45%, while the lower/valley bottom slopes have mean total porosity of 59.85%. Total porosity was found to decrease with depth of profile and it is closely related to organic matter content, clay accumulation and the activities of earthworms and other macro-animals in the soil system. Total porosity has also an inverse relationship with bulk density (Egbuchua, 2014).

2.7.4 Soil water content and retention characteristics

Soil water enhances various soil physicochemical reactions and supplies essential nutrients for plants and animals including micro and macro organisms residing in soils in order that they can carry out their own activities (Havlin *et al.,* 2002; Brady and Weil, 2004). The portion of stored soil water that can readily be absorbed by plants is said to be available water. According to Mebit (2006) soil water retention at field capacity (FC) and permanent wilting point (PWP) increased with depth for the soils in the toe slope, lower footslope and upper footslope areas. The increases of these three components of soil moisture holding capacity of soils with depth may be due to the increasing values of clay content with profile depth observed in these soil pedons along the toposequence. Variation in topography, land use and soil attribute all affect the distribution of soil moisture (Ahmed, 2002; Brady and Weil, 2004).

As described by Samuel (2006), the three soil moisture characteristics (FC, PWP and AWC) consistently increased with decreasing elevation. According to the same author, the water content held at field capacity and permanent wilting point as well as the available water holding capacity of the back slope soil was lowest at the subsoil horizon, whereas relatively the lowest values of these three soil moisture characteristics were observed in the surface horizons of the foot hill slope soil and at FC and at AWC of the cultivated land of lower footslope at the Keyih-amed/Adi-adla site. Soils at the footslope and toeslope positions are relatively more moist and receive material from upslope positions via both run-off and leaching (Walker *et al*., 1968). Soil moisture content is affected by the slope and aspect in the landscape (Daniels *et al*., 1987). According to Igwe (2003), moisture content was higher in the upper layer than in the lower layer, which may be due to the combined retention capabilities of organic matter and clay on top soil. Soils at the footslope and toeslope positions are relatively more moist and receive material from up slope positions via both run-off and leaching (Walker *et al*., 1968).

2.8 Soil chemical properties

2.8.1 Soil pH and electrical conductivity

Soil reaction (pH) is a measure of the concentration of H^+ ions in the soil solution or in otherwords a measure of acidity or alkalinity of a soil. It is the simplest and the most important chemical parameter measured in soils. It has vital role in determining several chemical reactions and in influencing plant growth by affecting the activity of soil microorganisms and altering the solubility and availability of most of the essential plant nutrients and particularly the micronutrients such as Fe, Zn, Cu and Mn (Miller and Gardiner, 2001).Soil reaction affects nutrient availability and toxicity, microbial activity, and root growth. Thus, it is one of the most important chemical characteristics of the soil solution because both higher plants and microorganisms respond so markedly to their chemical environment. Descriptive terms commonly associated with certain ranges in pH are extremely acidic (pH <4.5), very strongly acidic (pH 4.5-5.0), strongly acidic (pH 5.1-5.5), moderately acidic (pH5.6-6.0), slightly acid (pH 6.1-6.5), neutral (pH 6.6-7.3), slightly alkaline (pH 7.4-7.8),moderately alkaline (pH 7.9-8.4), strongly alkaline (pH 8.5-9.0), and very strongly alkaline(pH > 9.1) (Foth and Ellis, 1997).The degree and nature of soil reaction are influenced by different anthropogenic and natural activities including leaching of exchangeable bases, acidrains, decomposition of organic materials, application of commercial fertilizers and otherfarming practices (Brady and Weil, 2004; Havlin *et al.,* 2002).

Soil reaction (pH) is mostly related to the nature of the parent material, climate, organic matter and topographic situations (Tamirat, 1992). Soil organic matter, or humus, contains reactive carboxylic and phenolic hydroxyl groups that behave as weak acids releasing H^+ to the soil solution. As described by Mebit (2006), the highest pH (H_2O) value (5.7) was observed on the Mollic Leptosols of the backslope followed by the same soil unit of the summit area (pH=5.6) when the surface horizons were considered. This is due to the higher buffering capacity attributed to the relatively higher organic matter content of the areas. As reported by Tadesse (2002) and Solomon (2006) in the middle and high altitude areas, pH of the soil decreases with depth of the soil. Soil pH increased with depth of soil profile and relatively high pH was observed at subsoil horizons in Alfisols of Bako area (Wakene, 2001) and Mount Chilallo

(Ahmed, 2002) and in Vertisols of the central highlands of Ethiopia (Tamirat, 1992). The soils in high altitude and those with higher slopes had low pH values, probably suggesting the washing out of solutes from these parts (Abayneh, 2001; Mohammed *et al*., 2005).

According to Mohammed (2003), the soil in high altitude and higher slopes had low pH values, probably suggesting the washing away of solutes and basic cations from these parts. Continuous cultivation practices, excessive precipitation, steepness of the topography and application of inorganic fertilizer could have attributed as some of the factors which are responsible for the reduction of pH in the soil. Mohammed (2005) also concluded that the lowest value of pH under the cultivated land could be due to the depletion of basic cations in crop harvest and leached to streams in runoff generated from accelerated erosions. Continuous cultivation practices, excessive precipitation, steepness of the topography and application of inorganic fertilizers could be ascribed as some of the factors which are responsible for the reduction of pH in the soil profiles at the middle and upper elevation zones (Mokwunye, 1978; Ahmed, 2002). The electrical conductivity (EC) measurement identifies soils, which are potentially saline (Okalebo *et al*., 2002). According to Demelash (2010), the values of EC recorded in the subsoil layers of the soil profiles along the toposequence, ranging from 0.02 dS m^{-1} at the high altitude area to 0.19 dS m-1 in the depression area, were not significantly different from that of the surface soil horizons. As indicated by Landon (1991), in the soil, the determination of the electrical conductivity serves to give an idea of the total quantity of soluble salts and the degree of salinity. The critical level of electrical conductivity of saturated soil paste extracts (EC) for most crops is 4 dS m^{-1}.

2.8.2 Organic matter

Soil organic matter (OM) arises from the debris of green plants, animal residues and excretathat are deposited on the surface and mixed to a variable extent with the mineral component (Hillel, 2004). Soil OM is defined as any living or dead plant and animal materials in the soiland it comprises a wide range of organic species such as humic substances, carbohydrates,proteins, and plant residues (Foth and Ellis, 1997). Humus is the substance left after soilorganisms have modified original organic materials to a rather stable group of decay products as is the colloidal remains of OM (Millar and Gardner, 2001). Havlin *et al.* (2002) has indicated that the distribution of OM in trees and ground cover is 38%, 9% in the forest floor and 53% in the soil including the roots plus the OM associated with soil particles. Soil O M originates from plant and animal residues, which are generally present in various stages of decomposition that is from fresh additions to well-decayed humus.In all forms of agricultural systems, whether traditional or modern, soil OM plays an essential role in sustaining crop production and preventing land degradation (Vance, 2000). Because of its positive influence on several soil processes, crop productivity and environmental quality, soil OM is often considered the single most important indicator of soil quality and sustainable land management (Roming *et al.*, 1995; Vance, 2000). Based on OM content, soils are characterized as mineral or organic. Mineral soils form most of our cultivated landand may contain from a mere trace to 20 to 30% OM, but organic soils contain 80% or more OM (Prasad and Power, 1997).

Higher soil organic matter contents were observed at the surface layers than sub-soil horizons in soil profiles opened at different sites (Abayneh, 2001; Mebit, 2006; Shimeles, 2006; Solomon, 2006). According to Ahmed (2002), the highest value of OM was found at the upper elevation under the virgin natural vegetation land soils. Belay (1996) stated that major differences were observed in the organic matter contents of the upper and lower toe slope areas. As reported by Abayneh (2001), soil OM depends on the rates of renewal (source) and loss (removal) of carbon from the soil and it decreases with depth of the soil. Altitude increases, OM content of the soil increases due to its low decomposition rates due to lower air as well as soil temperature with increasing altitude. Demelash (2010) states that higher OM content in the surface horizons of the low-lying areas could be related to its foot slope position. This position could allow the profile to receive OM from upper slope areas through processes of erosion and deposition. Generally low organic matter content which decreased with increase in depth was recorded by Nuga *et al.*(2008) in a toposequence in Ikwuano, Umuahia. On a slope position in toposequence under a *Tectona grandis* Plantation in Minna, Southern Guinea Savanna of Nigeria, Lawal *et al.* (2014) reported decreased OC concentration with decreased slope.Guo *et al.* (2006) found that Histosols have the highest SOC content at 140.1 kg m^{-3}, followed by Vertisols (14.7 kg m^{-3}) and Mollisols (13.5kg m^{-3}), with Alfisols having 7.5 kg m^{-3} and Inceptisols 8.9 kg m^{-3}. However, Inceptisols and Entisols had the greatest variability of SOC content among soil orders. Kern (1994) also found that the influence of soil moisture regimes varied among soil orders, but generally wet and cold groupings had greater SOC contents.

2.8.3 Total nitrogen

Nitrogen (N) is the fourth plant nutrient taken up by plants in greatest quantity next to carbon, oxygen and hydrogen, but it is one of the most deficient elements in the tropics for crop production and critical shortage of this nutrient brings significant grain/biomass yield reduction (Yihenew, 2002). Most Ethiopian black or dark grey soils are N-depleted and more than 50% of the cultivable lands are N-responsive soils (Mishra *et al*., 2004). Variation in contents of total N is closely related to contents of OM, which is its major source, and thus, the source of its variability (Mohammed *et al*., 2005). In general, in the surface soil layers, OM and total N increased with increasing elevations while in the subsoil horizons, the contents of these parameters do not reveal consistent relationship with elevation in the soils of the western slopes of mount Chilalo (Ahmed, 2002). Total N content of soils ranges from less than 0.02% in sub-soils of humid and sub-humid mineral soils to more than 2.5% in peat soils. Highly weathered soils of the humid and sub-humid tropics have too low total N due to leaching, and saline and sodic soils of arid and semi-arid regions are also poor (less than 0.01%) in their N content which is attributed to the generally very low biomass production and fast oxidation of OM in such climatic zones (Havlin *et al.,* 2002).

The contents of total N decreased with a decrease in altitude and down slope position (Mohammed *et al.,* 2005). The same authors reported that the highest (0.56%) content of total nitrogen corresponded to the profile having high value of organic matter content. The lowest amount of total nitrogen (0.04%) was recorded in the pedon which also had the lowest organic matter content (1.7%). Considering the surface soil layers, the highest total nitrogen (0.446%) was recorded under the Mollic Leptosol of the backslope, whereas, the lowest total nitrogen (0.12%) was recorded under the Dystric Nitisols of the lower footslope (Mebit, 2006). Such great variation could be attributed to the variation in the landuse system. Generally low total nitrogen content which decreased with increase in depth was recorded by Nuga *et al.*(2008)in a toposequence in Ikwuano, Umuahia. Oku *et al.*(2010) recorded total N level of 0.08 - 0.09, 0.04 - 0.12 and 0.08 - 0.14 % in crest, midslope and foot slope along an Udalf toposequence in the humid forest zone of Nigeria.

2.8.4 Available phosphorus

Phosphorus (P) is known as the master key to agriculture because lack of available P in thesoils limits the growth of both cultivated and uncultivated plants (Foth and Ellis, 1997). Following N, P has more wide spread influence on both natural and agricultural ecosystems than any other essential elements. Phosphorus is rarely found in the pure elemental form (P) in nature. It is chemically very reactive; thus, it is almost always found combined with other elements, especially oxygen, as $H_2PO_4^-$ or HPO_4^{2-}. These orthophosphate forms react quickly with Al, Ca, Fe, Mn, and other elements to form insoluble compounds that are only slowly available to plants. Phosphorus must be managed very carefully to maximize its availability to plants. Available soil P is derived from the weathering of a number of different minerals, but primarily from the chemical breakdown of apatite, which is composed largely of calcium phosphate (Brady and Weil, 2004).

Most P compounds formed in the soil are insoluble and are not readily available to plants.Relatively small quantities of the orthophosphate forms are present and can be taken up by plant roots. The soluble orthophosphates (HPO_4^{2-} and $H_2PO_4^-$) have negative charges and are thus not held directly by the negative charges on soil colloids. Phosphorus is retained in the soil primarily because it forms relatively insoluble Fe and Al compounds in acid soils and Ca in alkaline soils. This chemical process, which reduces P availability to plants, is known as P fixation (Jones, 1998).

Mohammed *et al.* (2005) indicated that the levels of plant available P in soils vary depending on land use system, altitude, slope position and other characteristics, such as contents of clay and calcium carbonates. According to Demelash (2010), available P showed variation along the toposequence and within the horizons in the studied profiles of Dilla zuria District of Gedeo Zone. Apart from that, its level was also low in most of the soils; thus it is one of the major crop production limiting nutrient elements in the study area. As reported by Tadesse (2002) and Shimeles (2006) in some parts of steeply sloped areas, the amount of available P decreases with depth of the soil. The lower concentration of available P with depth of the soil is due to fixation by clay and Ca, which are found to increase with depth of the soil. According to Mebit (2006), the available P extracted by the Olsen method showed extremely high value (86.40 mg kg^{-1}) in the Mollic Leptosols of the summit area. This could be due to the relatively high organic matter content or high inherent P content of the parent material. Available phosphorus was low to medium (0.69 to 11.73 μgg^{-1}) in all the slope position on a toposequence in Ikwuano, Umuahia (Nuga *et al*., 2008). Osodeke and Osondu (2006) observed a wide variation in phosphorus (P) distribution along a toposequence in southeastern Nigeria. Lawal *et al*. (2014) recorded increased P concentration with decrease with slope position in toposequence under a *Tectona grandis* Plantation in Minna, Southern Guinea Savanna of Nigeria.

2.8.5 Cation exchange capacity

Cation exchange capacity (CEC) is the ability of the soil solid phase to attract or store and exchange cationic nutrients with the soil solution and render them available to plants through exchange reactions (Muller-Samann and Kotschi, 1994). Cation exchange capacity is an important parameter of soil because it gives an indication of the type of the dominant clay mineral present in the soil and its capacity to retain nutrients against leaching. The CEC of soilis strongly affected by the nature and amount of mineral and organic colloids present in the soil. Soils with large amounts of clay and OM have higher CEC than sandy soils low in OM. In the surface horizons of mineral soils, where the contents of OM and clay in the soil are significantly high, OM and clay fractions frequently contribute similar values to the CEC while in the subsoils, particularly where Bt horizons exist, more CEC is contributed by clay fractions than by OM due to the decline of the latter with profile depth (Sanchez, 1976). According to Ahmed (2002), the overall higher CEC values registered in the subsoil horizons of the soils of Mount Chilalo were due to the high clay (montimorillonite) accumulation that bring about higher CEC values at the subsoil layers of soil profiles. On the other hand, Wakene (2001) reported the highest CEC value on the surface layers of the soil profile at Bako area under the virgin land soil.

In considering the plow layers, the highest CEC (42.80 cmol (+) kg^{-1}) was obtained in the foot hill slope soil described at the Keyih-amed/Adi-adla site followed by 38.63 cmol (+) kg^{-1} in the foot hill slope soil studied at the Adi-silky site (Mebit, 2006). The same author pointed out that the values of CEC obtained in the subsoil layers of the soil profiles along the toposequence ranged from 32.54 cmol (+) kg^{-1}) at 23-37 cm of back slope soil described at the Keyih-amed/Adi-adla site to 51.23 cmol (+) kg^{-1}) at the 194-200 cm followed by 50.12 cmol (+) kg^{-1}) at the 131-194 cm both in Profile 2 opened at the foot hill slope soil of Adi-silky site. According to Ahmed (2002), the overall higher CEC values registered in the subsoil horizons of the soils at the western slopes of Mount Chilalo (Arisi) under different elevations and land use system were due to high clay (montimorillonite) accumulation or exchangeable bases that bring about higher CEC values at the subsoil layers of soil profiles.

Belay (1997) mentioned that the CEC of soils on the summit and back slope were much higher (129 to 196 cmol(+) kg^{-1} clay) when compared to those on the foot slope and toe slope (65 to 87 cmol(+) kg^{-1} clay). The CEC in the latter reflects the predominance of smectite clay while the higher values in the degraded soil on the crest and back slope showed the presence of significant amount of high exchange capacity clay minerals. On the contrary, Mohammed *et al.* (2005) reported that the values of CEC were uniformly high throughout most profiles and did not show any clear pattern of variability among horizons of the profiles except two pedons, which showed slight decrease with depth.

2.8.6 Exchangeable potassium and sodium

Potassium (K) is the third most important plant growth-limiting nutrient just next to N and P.Its behavior in the soil is influenced primarily by soil cation exchange properties and mineral weathering rather than by microbiological processes. Unlike N and P, K causes no offsite environmental problems when it leaves the soil system. It is not toxic and does not cause eutrophication in aquatic system (Brady and Weil, 2004). According to Johns and

Vimpany(1999), increasing applied rate of K fertilizers displaced both exchangeable Ca and Mg in to the soil solution from where they could be lost by leaching.Wakene (2001) reported that the variation in the distribution of K depends on the mineral present, particle size distribution, degree of weathering, soil management practices, climatic conditions, degree of soil development, the intensity of cultivation and the parent material from which the soil is formed. For instance, soils formed from sedimentary materials aregenerally low in K content, while soils formed from crystalline rocks contain relatively high K (Mokwunye, 1978). The greater the proportion of clay mineral high in K, the greater will be the potential K availability in soils (Havlin *et al.,* 2002). According to Berhanu (1980), soils consisting of exchangeable K value greater than 0.77, 0.51-0.77, 0.26- 0.51 and less than 0.26cmol(+) kg^{-1} are rated as high, moderate, low and very low in K, respectively. Mesfin (1996) reported low exchangeable K under acidic soils of south and southwestern parts of Ethiopia while Alemayehu (1990) observed low K content under intensive cultivations of Alfisols at Wollega state farms, Ethiopia. The critical level of soil exchangeable K below that fertilizer K is required for most crops is 0.38 cmol(+) kg-1 (Barber, 1984).

Sodium (Na) constitutes an appreciable fraction (2.8%) of the earth crust. Its presence in the soils in any but very small amount is restricted to those of arid and semiarid regions. In soils of humid regions, long continued application of sodium nitrate will result in measurable quantities of this element in an exchangeable form but Na is one of the most loosely held of the metallic ions and is readily lost in leaching waters (Havlin *et al.,* 2002).Although some plants may use Na as partial substitute for K, Na is not an essential plant nutrient (Landon, 1991). Plants grown in alkaline soils are constrained by specific toxicity of Na^+, OH^-, and HCO_3^- ions as well as by the very poor soil physical conditions and slow permeability of water. The two most important chemical parameters related to Na are exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR) which determine the degree to which the exchange complex is saturated with Na and give information on the comparative concentrations of Na^+, Ca^{2+} and Mg^{2+} in soil solution (Gupta, 2004). Soils that have ESP greater than 15% are regarded as sodic soils (Landon, 1991). In general, high exchangeable Na in soils causes soil sodicity which affects soil fertility and productivity mainly through its adverse effects on soil physical properties.

According to Samuel (2006), exchangeable K decreased with increasing depth in upper footslope and lower footslope areas, wheras it increased with depth in back slope areas. However, exchangeable K, remained almost constant (within the range of 2.04-2.31 cmol (+) kg $^{-1}$) in the foot hill slope soil of the Adi-silky site. The same author pointed out that the soils of the back slope and foot hill slope of the Adi-silky site and the cultivated land of lower footslope and the topsoil horizon of the foot hill slope of the Keyih-amed/Adi-adla site are rich in K content, while the back slope soil and subsoil layers of the foot hill slope soil at Keyih-amed/Adi-adla site is deficient in K. Among the surface horizons, the highest (0.14 cmol(+) kg $^{-1}$) of exchangeable K was recorded in the Mollic Leptosols of the summit area (Mebit, 2006). The statement disagrees with the common idea that Ethiopian soils are reach in K. But it agrees with Belay (1996) and Wakene (2001) who reported K deficiency in Eutric Vertisols of Melbe (Tigray) and Dystric Nitisols of Bako area, respectively. Shimeles (2006) reported that the average exchangeable potassium (K) content of soil is 1.2%, however, organic soil has low K (less than 0.03%). The variation in the distribution of K depends on the mineral present, particle size distribution, degree of weathering and soil management practices (Wakene, 2001).

Exchangeable Na decreased with increasing depth in back slope and increased with depth (within a depth of 27-200 cm) in upper footslope areas, while its relationship with depth in foot hill slope and lower foot slope areas was not consistent (Samuel, 2006). According to Mebit (2006), Exchangeable Na was relatively higher at lower than at the higher elevations of the study area. The exchangeable Na contents of the surface soils along the toposequence were generally very low as compared to the critical level that causes deterioration of soil structure and Na toxicity when the exchangeable Na percentage is greater than 15% as indicated by Miller and Donahue (1995). Oku *et al.*(2010) recorded Na level of 0.01 - 0.09, 0.09 - 0.14 and 0.10 - 0.13 cmolkg^{-1} and K level of 0.09 - 0.24, 0.10 - 0.48 and 0.09 - 0.10 cmolkg^{-1}on crest, midslope and foot slope along an Udalf toposequence in the humid forest zone of Nigeria.

2.8.7 Exchangeable calcium and magnesium

Calcium in acidic, humid region soils occurs largely in the exchangeable form and as primary minerals. Soils having 2:1 layer silicates have higher CEC and thus retain larger amount of calcium or magnesium. Soil pH is inversely related to exchangeable calcium. In acid soils, which can have high exchangeable aluminum, calcium concentration becomes low (Prasad andPower, 1997). According to Wakene (2001), continuous cultivation and inorganic fertilizers application resulted in declining of soil pH and caused loss of basic cations and especially under intensive cropping of inherently poor soils, the deficiencies of calcium and magnesiumare common. Contents of calcium carbonates increased in down slope positions. High contents were recorded in the lower horizons of the foot and toeslope soils (Mohammed *et al.,* 2005). The same authors proved that the contents of exchangeable Ca increased in a down ward slope position. In soils and profiles where exchangeable calcium was lower, the magnitude of exchangeable Mg proportionally increased. This shows that soil parent materials primarily release divalent cations. Contents of calcium increased in down slope positions. High contents were recorded in the lower horizons of the foot and toe slope soils (Mohammed *et al*., 2005).

According to Belay (1997), highest subsoil base saturation was registered for toeslope where the basic cations are carried down slope by through-flow accumulation and add to the total exchangeable bases on the exchange surfaces. The average concentration of total Ca is 3.6%, while non calcareous and highly weathered soils have less than 1% and it is above 10% in calcareous soils (Rai, 2002). The Ca content depends on its parent materials, degree of weathering and whether or not Ca has been added by liming (Barber, 1984). Research works conducted on some soils indicated that exchangeable Ca and Mg cations dominate the exchange sites of most soils and contributed higher to the total percent base saturations particularly in the Vertisols (Mesfin, 1998; Yohannes, 1999). Although different crops have different optimum ranges of nutrient requirements, the response to calcium fertilizer is expected from most crops when the exchangeable calcium is less than 0.2 cmolc kg^{-1} of soil, while 0.5 cmolc kg^{-1} of soil was the deficiency threshold level in the tropics for magnesium (Landon, 1991). On a slope position in toposequence under a *Tectona grandis* Plantation in Minna, Southern Guinea Savanna of Nigeria, Lawal *et al*. (2014) reported an increased Ca and Mg concentration with decreased slope. Oku *et al*.(2010) recorded Ca level of 1.92 - 5.44, 2.24 - 4.48 and 1.92 - 3.20 cmolkg^{-1} and Mg level of 1.00 - 2.24, 1.10 - 2.24 and 0.09 - 1.80cmolkg^{-1} on crest, midslope and foot slope along an Udalf toposequence in the humid forest zone of Nigeria.

2.8.8 Exchangeable acidity

According to Demelash (2010), there was clear difference observed in the quantity of exchangeable acidity along the toposequence of Dilla zuria District of Gedeo Zone Ethiopia, because in low altitude areas its content was relatively low in both surface and sub-surface horizons in all profiles and in high altitude areas its content was high both at surface and subsurface horizons. The exchangeable acidity observed on the surface horizons of the Eutric Vertisols in the toeslope, Dystric Nitisols in the lower footslope and that of the Haplic Nitisols of the upper footslope areas were the same (0.076 cmol(+) kg^{-1}) (Mebit, 2006). The same author described that the highest exchangeable acidity (0.191 cmol(+) kg^{-1}) was observed at the subsurface horizon (20-90 cm) and the C-horizon of the upper footslope area of the study site. However, there was no significant difference in the quantity of exchangeable acidity along the toposequence of the Woreta agricultural technical vocational education and training college research farm of Ethiopia. Usually, when exchangeable acidity is concentrated in appreciable amounts in soils with pH range of 4-5 and lower, it produces strongly acidic soil condition (Rowell, 1994). As reported by Mebit (2006) exchangeable acidity tends to decrease with the profile depth under the grazing land, while in the cultivated land of the same elevation, the exchangeable acidity was uniformly distributed in the surface and sub-surface horizons except the extreme lower sub-soil horizon which deviated from the overlying horizons and had higher value. On a slope position in a toposequence under a *Tectona grandis* Plantation in Minna, Southern Guinea Savanna of Nigeria, Lawal *et al.* (2014) reported decreased total acidity with decreased slope while Oku *et al.*(2010) reported a total exchangeable acidity of 3.36 - 5.28, 3.04 - 4.8 and 2.24 - 5.76cmolkg^{-1} on crest, midslope and foot slope along an Udalf toposequence in the humid forest zone of Nigeria.

2.8.9 Micronutrients

Micronutrients are just as important in plants as the major nutrients except that they simply occur in plants and soils in much smaller concentrations. However, the information available about the status and limitation of micronutrients particularly in soils of sub-Saharan Africa is not adequate and is currently difficult for users to access (Haque, 1988).Krauskopf (1972) stated that the main source of micronutrient elements in most soils is the parent material, from which the soil is formed. Iron, Zn, Mn and Cu are somewhat more abundant in basalt. The solubility and availability of micronutrients is largely influenced by clay content, pH, OM, CEC, P level in the soil and tillage practices (Fisseha, 1992). Brady and Weil (2004) indicated that the solubility, availability and plant uptake of micronutrient cations (Cu, Fe, Mn and Zn) are more under acidic conditions (pH of 5.0 to 6.5).

The highest amounts of available Fe and Zn (31.64, 2.09 mg kg^{-1}, respectively) were observed at the surface horizons of the summit area at Woreta agricultural technical vocational education and training college research farm. Whereas, the highest amounts of Cu (1.8 mg kg-1) and Mn (17.16 mg kg-1) were recorded at the subsurface and surface horizon of the toeslope and the backslope areas, respectively (Mebit, 2006). Mulugeta and Sheleme (2010) reported that micronutrients contents decreased with increasing depth of the profile in order of micronutrient concentration in the profile was Mn > Zn > Fe > Cu. The trend of Mn concentration under different slope position was similar to that of Fe distribution indicated that these two elements have similar chemical behaviour in tropical soil. The distribution of Cu consistently decreased from the surface to the subsurface horizons, which might be attributed to strong association of Cu soil organic matter. Positive correlation between Cu and organic matter was reported that Cu is strongly complexed with organic matter as describe by Wakene and Heluf (2003).

2.9 Effect of topographic orientation/aspect and position on soil quality (physical and chemical properties)

A point on a hillslope may also be defined by its orientation/slope aspect, or the direction it faces,e.g. north, south, east, or west. Slope aspect can affect soil temperature, evapotranspiration, andwhich winds act (Soil Survey Division Staff, 1993). Some studies have indicated that soil properties are related to topographic positions in different ecosystems (Bohlen *et al.*, 2001). Soil moisture content is affected by the slope and aspect in the landscape (Daniels *et al.*, 1987). Temperature and precipitation varying with elevation have influence on the pedogenic processes as well. Birkeland (1984) added that both slope aspect and slope gradient are considered as having relatively higher significance with respect to many of the soil forming processes, soil erosion, and vegetation growth. He indicated that soil aspect showed a considerable effect on the microclimate and that in turn influence soil organic matter and clay content as well as soil reaction and nutrient level. Furthermore, it has been indicated that north facing slopes generally are less subjected to sunlight but higher moisture levels resulting in greater vegetation cover. That is in contrast to the south facing slopes as reported by Kutiel (1992), Kutiel and levee (1999). According to Rezaei and Gilkes (2005 a) soil fertility, in general, is higher on north-facing slopes than those corresponding to the south-facing slopes.

Ritter (1986) postulated that difference in some soil attributes such as their richness in clay, organic matter and moisture content could be rendered to differences in slope gradient as soils associated to low slope gradient are higher in moisture content, richer in clay and organic matter content if compared with those with steeper slope gradient. According to Birkeland (1984) steep slope tend to be freely drained which is in contradiction to low slope gradient or flat soils that are usually poorly drained. Soil properties such as clay, sand and pH (Ovalles and Collins, 1986) and organic matter (Bhatti *et al*., 1991) correlate highly with landscape position.

All soils are naturally variable with their properties changing across the landscape and vertically down the soil profile (Brubaker *et al*., 1993; Brady and Weil, 2004). Soils commonly occur in groups, each member of the group occupying a characteristic and different sequential topographical position from top to bottom of a slope, termed as toposequence. Apart from soil degradation by poor management, slope length can also play a role. Slope length affect soil chemical quality by altering the fertility of the soil and hence reduction in crop yield and growth. Slope length is a biophysical factor which affects soil quality. To sustain crop growth in the tropics soil and water resources must be managed (Lal, 1997; Su *et al*., 2010). Lal (1997) found out that soil chemical properties vary with slope length and the type of tillage used. The nutrients lost due to slope length and conventional tillage ranged from 8.4 -17.8 kg ha^{-1} in the 10 m slope length. The major elements (nutrients) lost include Ca, K, Na, PO_4-P, Zn and Fe. The higher the slope length the higher the runoff and hence the higher the nutrient loss. Slope length paired with tillage cause reallocation and redistribution of soil particles and this can change its quality either positively or negatively, for example the accumulation of SOC and aggregate stability is affected by soil erosion on a raised slope (Tang *et al*., 2010). A number of researchers have reported that land slope affect soil properties like moisture availability and redistribution, rate of infiltration, cumulative infiltration and hydraulic conductivity among others.

Due to slope difference in crop fields, erosion is forced to occur mostly on steep slopes and this is referred to as accelerated erosion, whereas erosion on flat land is mainly sheet termed as natural. Both affect the soil quality and according to Su *et al*., (2010) erosion by tillage is the most dominant type especially on the upper slope and this transports most plant nutrients while on the middle and lower slope erosion is mainly by water and nutrients such as SOM are carried away. There are many studies carried out on the relationship of soils and geomorphic surfaces. Pierson and Mulla (1990) studied the soil properties on different slope positions and concluded that soils formed on footslope and toeslope positions contained higher organic carbon and aggregate stability compared to summit position.

Walia and Chamuah (1990), investigated some soil parameters e.g. soil texture, organic matter content , pH, kind and the presence of surface and subsurface horizons in four pedons formed on flood plains, piedmont plains, hillslopes and lowlands. Brubaker *et al*., (1993), studied the soil properties highly related to landform position and found significant differences among 13 properties. Sand, silt, pH, calcium carbonate content, and exchangeable Ca^{2+} and Mg^{2+} mostly decreased down the slope. Young and Hammer (2000) found that most of the soil properties were similar between ridge and shoulder positions. Differences were minimal within the backslope. Backslopes differed from ridges and shoulders, with more argillic horizon clay, thinner epipedons, and less organic C, lower pH and base saturation, and less silt on a clay free basis. Color patterns suggest that backslopes are wetter than ridges and shoulders, with more redoximorphic activity and organic matter accumulation on ped faces. Tsui *et al*. (2004) reported that the slope aspect and gradient can control the movement of water and soil material on a hillslope and hence contribute to the spatial differences of soil properties. Soils were reported to have properties such as redder color, moderate to high acidity, lower than 50% base saturation in the argillic horizon, in the sloping landscapes (Bhaskar *et al.,* 2004). Soils of the upper slope positions had higher available Fe, Mn, Cu and Zn. These soils were classified as Ultisols and

Entisols while soils of valleys were of Inceptisols order. Soils particles 0.5 mm in diameter decreased downslope, and those of 0.05 and 0.5 mm formed a larger soil fraction in the midslope position other than summit or footslope. Total organic C, N and P in the middleslope soil were the lowest among the soils in the three topographic positions (Chen *et al*., 2002).

CHAPTER THREE

3.0 Materials and Methods

3.1 Study area

The study area is Olokoro in Umuahia East local government area of Abia State, southeastern Nigeria. Olokoro is located between Latitudes 5°26'N and 5°37'N; and Longitudes 7°23'E and 7°36'E. Generally, soils of the study area are derived from Coastal Plain Sands (Benin formation) and Falsebedded Sandstones (Ajali formation) (Orajaka, 1975). The area lies within the lowlandplain areas of southeastern geomorphology. The major hydrologic resource of the area is Imo river and its tributaries.

3.2 Climate

The study area is characterized by a humid tropical climate with alternate wet and dry seasons (Obi, 1982). The average annual rainfall of the area ranges from 1750 to 2500 mm per annum andannual temperature ranges from 26 ^{o}C to 31 ^{o}C, with a high relative humidity (above 80%) during the rainy season (NIMET, 2008).

3.3 Vegetation/land use

Olokoro Umuahia is in the tropical rainforest zone (Obi, 1982). The original vegetation has been destroyed; the present forest cover is merely secondary forests/regrowths, farmlands at various stages of crop growth and fallow lands; a situation which has greatly affected the plant species composition. *Gmelina arborea*constitutes the dominant plant specie in the stusy are, occupying about one-half of the area of the forest reserve while *Tectona grandis* is the secondary dominant tree species

3.4 Socioeconomic acticities

Agriculture is a major socio-economic activity of the area, about 70% of the total area is used as cultivated land. Slash-and-burn technique has been the major method of land clearing, whereas bush fallow is a soil fertility regeneration practice that has prevailed for over 7 decades. Very few of the farmers use inorganic fertilizers as supplementary nutrient.In addition to agriculture, minority of the inhabitants are traders.

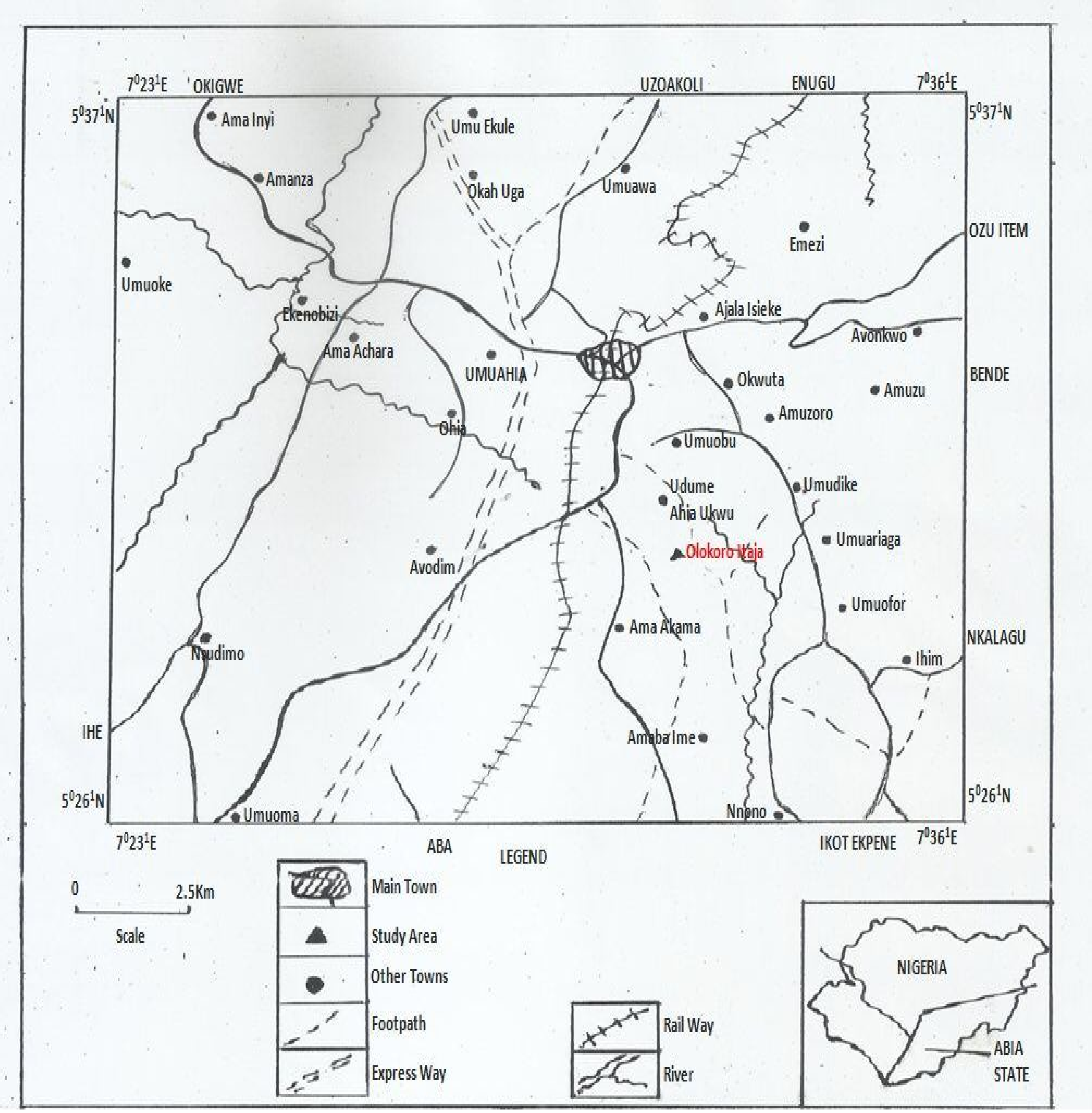

Fig. 3.1: Location map of the study area

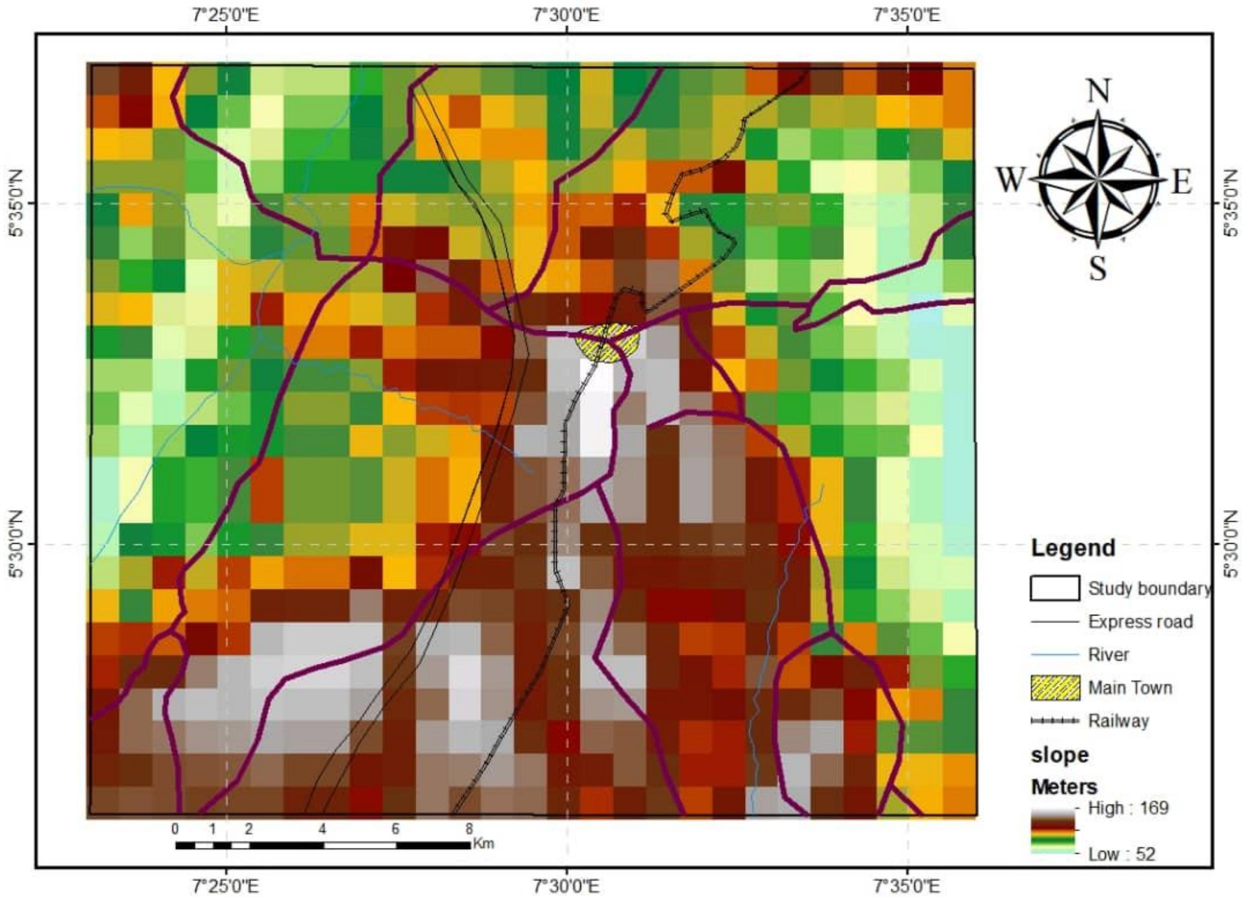

Fig. 3.2: Map of the study locations showing the slope lines

3.5 Description of the sampling sites

3.5.1 Umudike East lying slope

All the slope positions (summit, midslope and footslope) of this location are used for cassava (*Manihotspp*) and maize cultivation. However, there were scanty stands of oil palm (*Elaeis guineensis*) guava (Psidium guajava) trees and many shrubs and weeds. At the footslope, a fallow of about a year was noticed. Undulating topography with good drainage characterized this slope. It has a coordinate of Lat 5°28'.914''N and Long 7°31'.395''E with elevation of 141m and slope of 5.0° at the crest, Lat 5°28'.546''N and Long 7°31'.414''E with elevation of 138m and slope 7.2° at the midslope and Lat 5°28'.983''N and Long 7°31'.458''E with elevation of 121m and slope 7.9° at the footslope. Signs of sun setting in the morning hours are usually noticed in this area compared to Itu West-lying slope.

3.5.2 Itu West lying slope

The toposequence used in this area also comprised of summit, midslope and footslope. Agricultural activities are also pronounced in this site where cassava (*Manihot spp*), maize (Zeamays) and yam (*Diascorea*) are dominant crops. Other scanty plants observed around the area include plantain and bananna (*Musa spp),* oil palm (*Elaeis guineensis*), and raffia palm trees. High population of weed and shrubs was also observed at the midslope of this site. This site has a coordinate of Lat 5º28'.844"N and Long 7º31'.352"E with elevate on of 143m and slope of 5.7º at the crest, Lat 5º28'.844"N and Long 7º31'.304"E with elevation of 142m and slope 6.8º at the midslope and Lat 5º28'.804"N and Long 7º31'.265"E with elevation of 135m and slope 5.2º at the footslope.

3.6 Field studies

Transect soil survey technique was used in field sampling. One profile pit was sunk each in summit, midslope and footslope in Umudike East-lying slope and Itu-Westtoposequencies located in different orientations. A total of six (6) profile pits were used in the study. All soil profiles were georeferenced using handheld Global Positioning System (GPS) Receiver (Garmin Ltd, USA). Soil colour was determined using soil Munsell colour chart. The profile pits were described using FAO, (1998) guidelines and samples were collected according to horizons.

Undisturbed soil samples for determination of bulk density were collected using core samplers. The soil samples were air dried, crushed and sieved through a 2 mm sieve, the soils used for organic matter determination were further ground to pass through 0.5 mm mesh.

3.7 Laboratory analysis

3.7.1 Bulk density was measured using core method as described by Grossman and Reinsch (2002).

$BD= M_s/V_t$ (g cm^{-3})

Where M_s = mass of oven dry soil (g)

V_t = Total soil volume (cm^2)which is equivalent to the volume of the cylinder core

$V= \pi r^2 h$

Where V= volume of core (cm^2) assumed to be equal to soil volume.

3.7.2 Particle Size Distributionwas determined by hydrometer method according to the procedure of Gee and Or (2002) using water and sodium hexametaphosphate (calgon) as dispersant.

3.7.3 Moisture content was determined by gravimetric method.

3.7.4 Total porosity was computed from the bulk density as described by Vomocil (1965). The calculation

$\%Tp = 1 - \frac{BD}{PD} \times \frac{100}{1}$ is as follows

Where, Tp = Total porosity, BD = Bulk density (g cm^{-3}), PD = particle density (2.65g cm^{-3})

3.7.5 Soil pH was determined in water and 0.1kcl using pH meter in soil/liquid suspension of 1:1 (Hendershot *et al.,* 1993).

3.7.6 Organic Carbon was determined using the wet oxidation method (Nelson and Sommers, 1996)

3.7.7 Available phosphoruswas determined using Bray 2 solution method according to (Olsen and Sommers, 1982).

3.7.8 Exchangeable K and Na were extracted using 1N neutral ammonium acetate (NH_4OAC) and determined photometrically using flame photometer (Thomas, 1982).

3.7.9 Exchangeable Magnessium and Calcium was determined using ethylenediaminetetraacetic acid (EDTA) (Thomas, 1982).

3.7.10 Total Nitrogen was determined by kjehdahl digestion method using concentrated H_2SO_4 and a Sodium Copper Sulphate catalyst mixture (Brenner and Yeomans, 1988)

3.7.11 Exchangeable Aciditywas determined titrimetrically (Mclean, 1982).

3.7.12 Effective Cation Exchange Capacity (ECEC**)** was calculated from the summation of all exchangeable bases and exchangeable acidity (IITA, 1982).

3.7.13 Percentage Base Saturation (%BS)was determined by computation, these is achieved using the formular

$$\%\mathrm{BS} = \frac{\mathrm{TotalExchangeableBases}}{\mathrm{ECEC}} \times \frac{100}{1}$$

3.8 Soil classification

The pedons were classified according to USDA Soil Taxonomy System (Soil Survey Staff, 2010) and correlated with World Reference Base for Resources (IUSS Working Group WRB, 2010).

3.9 Data analysis

Field and Laboratory analytical data generated were subjected to mean, coefficient of variation, T-test and correlation analysis. The coefficient of variation (CV) was ranked according to the procedure of Wilding *et al.* (1994), where CV< 15% = least variation, CV>15 < 35% = moderate variation, CV> 35 <100% = high variation.

CHAPTER FOUR

4.0 Resultsand Discussion

4.1 Morphological properties of the studied toposequences

Results of the morphological properties of both toposequences studied are presented in Table 4.1 and 4.2. It was shown that the soils were generally shallow at all slope position. At Umudike East-lying slope, the soil depth ranged from 0 – 130 cm, 0 – 150 cm and 0 - 150 cm in summit, midslope and footslope, respectively (Table 4.1) , whereas at Itu West-lying slope, it ranged from 0 – 120 cm, 0 – 110 cm and 0-180 cm in summit, midslope and footslope, respectively (Table 4.2). However, the soils generally had similar horizon pattern of A, AB, Bt_1, Bt_2 and Bt_3 with the exception of Umudike summit that had BA as the third horizon.

Soil colour is probably the most relevant type of feature to assess the soil moisture required in landscape (Peter Schmitt *et al*., 1996). Soil colour of Umudike East-lying slope varied from very dark grayish brown (10YR3/2) moist at A horizon of summit soil position, while it had strong brown (7.5YR5/8) moist at the Bt_3 horizon. The grayish colour of A and AB horizons may be attributed to poor internal drainage condition (Esu, 2010). At the midslope of Umudike toposequence, dark brown (7.5YR3/2) moist colour was recorded at the A-horizon while it had strong brown (7.5YR5/8) moist colour at the Bt_3 horizon whereas, dark gray (5YR4/1) moist and reddish yellow (7.5YR6/8) colour characterized A horizon and Bt_3 horizon of Umudike footslope, respectively (Table 4.1). On the other hand, summit of Itu West lying slope was characterized of brown (7.5YR4/2) moist and yellowish red (5YR5/6) moist colour at the A and Bt_3 horizons respectively, while at the midslope very dark gray (7.5YR3/1) moist and yellowish red (5YR3/2) moist characterized the upper and bottom horizons, respectively whereas, very dark grayish brown (10YR3/2) moist and reddish yellow (5YR6/6) moist colour dominated A and Bt_3 horizons respectively of this footslope (Table 4.2).

Topsoil of Umudike east-lying slope had fine crumb at summit and midslope while at footslope, it had very coarse blocky structure whereas, in Itu west-lying slope it had very fine gravel at summit and midslope while it had very coarse blocky at footslope. However, soil structure was fine crumb, very coarse blocky and medium crumb at bottom horizon of summit, midslope and footslope of Umudike east-lying slope, respectively. On the other hand, bottom horizons of Itu west-lying slope had fine crumb, blocky crumb and very crumb angular blocky at summit, midslope and footslope, respectively (Table 4.1 and 4.2).

Presence of roots and faunal activity was generally shown to be abundant at the epipedons. However, while very few roots and faunal activity was recorded at the bottom horizon of midslope and footslope, few roots and faunal activity was recorded at the summit of Umudike slope (Table 4.1). At Itu East-lying slope, abundance and very few roots and faunal activity were recorded in epipedon and bottom horizon of summit and footslope, respectively whereas at the midslope, abundance of roots and faunal activity was recorded at the A horizon whereas there was absence of roots and faunal activity at the bottom horizon.

Consistency of the soils generally varied from very friable (Vfr) to very firm (Vfi) at the soil position irrespective of toposequence (Table 4.1 and 4.2). The observed difference in soil consistency could probably be as a result of size distribution, particularly clay content and also nature of the clay particles. In line with the findings of this study, Moradi (2013) indicated that soil consistency varied with soil texture. Clear smooth (cs) dominated epipedon of soil positions at Umudike toposequence while diffuse smooth (ds) boundary dominated the sub-horizons (Table 4.1) similar trend of boundary pattern was also shown in Itu toposequence apart from footslope that had inverse trend (Table 4.2). The variations in nature of the horizon boundaries may indicate the existence of variations in process that have formed the soils and in some cases they affect anthropogenic impacts (Cools and De Vos, 2010). At Umudike East-lying toposequence, soil texture was dominantly sandy clay loam for summit while sandy clay dominated the midslope and foot slope. At Itu West-lying toposequence, soil texture was dominantly sandy clay loam for the summit and midslope and then sandy loam for the foot slope.

TABLE 4.1: Morphological properties of Umudike East-lying slope

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

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

TABLE 4.2: Morphological properties of Itu West-lying slope

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

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

4.2 Physical properties of the studied toposequences

Soil properties differ due to degree of wind and rainfall erosion, transport and deposition of particle components of the soil (Krasilnikov *et al*., 2005). Results of effect slope orientation on soil physical properties of Umudike East-lying toposequences and Itu West-lying toposequence is displayed in Table 4.3 and 4.4 respectively. In Umudike East-lying toposequence, sand particles ranged from 764-618 gkg^{-1}, 724-418 gkg^{-1}, and 664-504 gkg^{-1} in summit, midslope and footslope respectively (Table 4.3) , whereas in Itu West-lying slope sand particles ranged from 724-604 gkg^{-1}, 684-524 gkg^{-1} and 604-564 gkg^{-1} in summit midslope and footslope respectively (Table 4.4). Sand particle slightly decreased with depth in both toposequence.Apart from summit of Umudike East-lying slope that showed low (CV $\leq$ 15%) variability in sand particles, other slope positions showed medium (CV $\geq$ 15 $\leq$ 35%) variability. Low variability recorded for sand in all the pedons of Itu West-lying slope indicates homogeneity of this soil property.

Silt ranged from 114-14 gkg^{-1}in both east and west lyingsummits, 122-14 gkg^{-1}and 194-94gkg^{-1} in midslope and 114-14gkg^{-1}and 154-54 gkg^{-1}in footslope of East and West lying slopes respectively. Silt content of the soil (CV > 35%) varied in all the pedons studied. Clay particles of the soil followed similar trend with silt particlesdecreasing with depth in all the pedons studied. Highest (345.6 and 306) gkg^{-1} mean clay values were recorded in midslope and footslope of East and West lying slopesrespectively (Table 4.3 and 4.4). However, lowest (271.2gkg^{-1} and 255.2 gkg^{-1}) mean values were recorded in the summit of East and West lying slopes, respectively. Sand dominated the mineral fraction in all landscape positions studied which may be partly attributed to parent material rich in quarter mineral, an essential component in granite, and partly due to geological processes involving sorting of soil materials by biological activities, clay migration through eluviation and illuviation, or surface erosion by runoff or their combination (Akinbola *et al*., 2009). Texture of both toposequences ranged from Sandy Clay Loam (SCL) to Sandy clay (SC). This result agrees with the works of Ashanafi *et al*. (2010); Sheleme (2011) who reported that the texture of the subsurface horizons became finer with soil depth, due to migration of clay from surface to lower horizons. Silt Clay Ratio (SCR) of the soils followed similar decreasing trend with clay. It ranged from 0.93-0.04 and 0.7-0.04 in summit of the two toposequences, 1.26-0.04 and 1.59-0.27 in midslope and 0.66-0.04 and 1.08-0.14 in footslope of East and West Lying Slope respectively. Silt to clay ratios have been used to study the degree of pedegenic weathering in soils (Sombroek and Zonneveld, 1971). Generally low values (< 0.75) indicate old age of soils; values between 0.75 and 1.5 indicate moderate pedogenic weathering processes, while high values (>1.5) indicate recent pedogenic processes (Sombroek and Zonneveld, 1971). Therefore, the mean values of SCR of the present study revealed old age of soils of both toposequences. However, high (CV >35%) variability of SCR in the study indicated non-homogeneity of SCR distribution.

Bulk density (BD) of the soils generally decreased with depth and slope in West toposequence. Mean bulk density ranged from 1.37-1.32gcm^{-3} in West toposequence while it varied from 1.36-1.32gcm^{-3} in East toposequence. Mean values of BD recorded in the study are below the critical minimum value (1.5gcm^{-3}) capable of enhancing crop root growth and development (Aune and Lal, 1997). Increase in bulk density with depth could be attributed to decrease in organic matter accumulation with depth, less root penetration and compaction caused by the weight of the overlying layers (Brady and Weil, 2004). Bulk density of the soil is inversely related to the porosity (Chaudhary *et al*., 2013). This assertion was supported by the present study. Hydraulic conductivity provides important information about the hydraulic behaviour of a soil and allows the characterization of the water flow in the soil profile, distinguishing conductivity through macropores from the water movement in the soil matrix (Vauclin *et al*., 1993).

Similar to bulk density, hydraulic conductivity (Ksat) decreased with depth in all the pedons studied while it also decreased with decreasing slope percentage of Umudike East-lying toposequence. It ranged from 0.602-0.14cm hr^{-1} in East Lying Slope while it varied from 0.608-0.366cm hr $^{-1}$ in West lying toposequence. Hydraulic conductivity may be influenced by several factors, including total porosity and pore structure which are quantifiable (Hallaire *et al*., 1998). According to Guehl (1984), the availability of water in the soil is one of the most important factors for plant growth. Moisture content of East toposequence varied from 180-280gkg^{-1}, 40-310gkg^{-1}and 190-330gkg^{-1} with mean values of (246, 214 and 280) gkg^{-1}in summit, slope and footslope respectively (Table 4.3) while in Table 4.4, moisture content of West toposequence varied from 200-280gkg^{-1}, 200-290gkg^{-1}and 200-300gkg^{-1}in summit, slope and footslope, respectively.

Table 4.3: Physical properties of the Umudike East-lying toposequence

Horizon	Depth (cm)	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)	SCR	BD (g/cm^3)	TP (%)	Ksat (cm/hr)	MC (g/kg)
				Umudike East-lying summit					
A	0-5	764	114	122	0.93	1.23	51.95	2	180
AB	5-23	664	94	242	0.39	1.26	50.78	0.43	240
Bt1	23-56	618	54	328	0.16	1.33	48.05	0.2	270
Bt2	56-95	664	14	322	0.04	1.44	43.75	0.2	260
Bt3	95-130	624	34	342	0.1	1.54	39.84	0.18	280
Mean		**666.8**	**62**	**271.2**	**0.324**	**1.36**	**46.87**	**0.60**	**246**
CV		**8.769**	**66.89**	**33.96**	**112.28**	**9.49**	**10.01**	**130.94**	**16.16**
				Umudike East-lying midslope					
A	0-7	724	122	154	1.26	1.21	52.73	1.97	190
AB	7-37	644	114	242	0.47	1.24	51.56	0.43	240
Bt1	37-66	604	14	382	0.04	1.26	50.78	0.14	290
Bt2	66-100	418	34	548	0.06	1.41	44.92	0.11	40
Bt3	100-150	564	34	402	0.08	1.49	41.79	0.13	310
Mean		**590.8**	**63.6**	**345.6**	**0.382**	**1.32**	**48.36**	**0.556**	**214**
CV		**19.17**	**78.68**	**48.89**	**136.68**	**9.19**	**35.18**	**144.13**	**50.39**
				Umudike East-lying footslope					
A	0-7	664	94	242	0.66	1.19	52.73	1.48	190
AB	7-20	604	54	342	0.16	1.25	51.17	0.18	280
Bt1	20-52	604	14	382	0.04	1.39	45.70	0.14	290
Bt2	52-98	504	54	442	0.12	1.41	44.92	0.12	330
Bt3	98-150	504	114	382	0.3	1.47	42.57	0.16	310
Mean		**576**	**66**	**358**	**0.26**	**1.34**	**47.42**	**0.42**	**280**
CV		**17.25**	**59.07**	**36.11**	**95.59**	**8.73**	**8.95**	**143.08**	**19.23**

Key: TC=textural class, S=sand,SL=sandy loam,SCL=sandy clay loamy, SC= sandy clay, BD=bulk density, TP=total porosity, Ksat= hydraulic conductivity, MC=moisture content.

Table 4.4: Physical properties of the Itu West-lying toposequence

Horizon	Depth (cm)	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)	SCR	BD (g/cm^3)	TP (%)	Ksat (mm/sec)	MC g/kg
				Itu West-lying summit					
A	0-6	724	114	162	0.7	1.21	52.73	1.11	200
AB	6-38	624	134	242	0.55	1.29	49.60	0.44	240
Bt1	38-83	604	114	282	0.4	1.37	46.48	0.3	260
Bt2	83-106	638	14	348	0.04	1.48	42.19	0.17	280
Bt3	106-120	724	34	242	0.14	1.51	43.02	0.41	230
Mean		**662.8**	**82**	**255.2**	**0.37**	**1.37**	**41.02**	**0.486**	**242**
CV		**49.103**	**61.50**	**51.27**	**237.98**	**119.44**	**38.79**	**235.74**	**47.87**
				Itu West-lying midslope					
A	0-7	684	94	222	1.59	1.19	53.52	1.96	200
AB	7-Jul	564	194	242	0.8	1.23	51.95	0.47	250
Bt1	26-50	564	114	322	0.35	1.29	49.61	0.23	280
Bt2	50-73	564	94	342	0.27	1.46	42.97	0.19	290
Bt3	73-110	524	134	342	0.39	1.5	41.40	0.19	290
Mean		**580**	**126**	**294**	**0.68**	**1.33**	**47.89**	**0.61**	**262**
CV		**10.46**	**27.21**	**36.99**	**80.67**	**10.40**	**10.54**	**125.78**	**14.63**
				Itu West-lying footslope					
A	0-8	604	154	242	1.08	1.17	54.30	1.47	200
AB	8-29	664	154	182	0.85	1.24	51.56	0.87	220
BA	29-86	564	94	342	0.27	1.28	50.00	0.19	290
Bt1	86-110	564	54	382	0.14	1.42	44.53	0.15	300
Bt2	110-180	564	54	382	0.14	1.48	42.19	0.15	300
Mean		**592**	**102**	**306**	**0.50**	**1.32**	**48.52**	**0.57**	**262**
CV		**10.63**	**49.22**	**43.11**	**88.51**	**9.75**	**37.94**	**104.42**	**18.38**

Key: TC=textural class, S=sand,SL=sandy loam,SCL=sandy clay loamy, SC= sandy clay, BD=bulk density, TP=total porosity, Ksat= hydraulic conductivity, MC=moisture content, SCR = silt-clay ratio

4.3 Chemical properties of the studied toposequences

The effect of slope position on selected soil chemical properties of the two toposequences studied is shown in Table 4.5 and 4.6.The pH (H_20 and KCl) of the soils were generally acidic and slightly increased with depth with the exception of summit of Itu West-lying slope. In East toposequence, highest value of (4.78) pH (water) was recorded in midslope followed by summit (4.64) and footslope (4.58) while in West toposequence, soil pH (water) decreased with decreasing slope percentage. Highest value of (5.3) and lowest value of (4.52) were recorded in summit and footslope respectively. Soil pH (KCl) indicates the potential acidity and presence of weatherable minerals when the difference (ΔpH) of soil pH (H_20) and pH (KCl) is greater than unity (Boul *et al*., 2003). Low (CV $\leq 15\%$) variability was recorded in pH of the both toposequences, this indicated more stability of this property. This was in agreement with the reports of Ogunkunle (1993), Mulla and McBratney (2001).

Soil Organic Carbon (SOC) is a key indicator of soil quality and overall soil productivity. Organic matter content of the soils were generally low and decreased with depth with the highest (26.44 and 30.64) gkg^{-1} and lowest (23.26 and 18.9) gkg^{-1}occurring in midslope and summit of East and West tposequences respectively (Table 4.5 and 4.6). The low organic matter recorded in the study could be attributed to small accretion of organic materials coupled with high rate of mineralization of organic matter in the soils (Lal *et al*., 2004). Organic carbon decrease with increasing soil depth in all the pedons probably might be due to decreased faunal activities in the underlying horizons as suggested by Browaldh (1995). Total nitrogen (TN) of the soils generally followed decreasing trend like organic matter. In other words, the TN content of the soil is directly associated with its OC content (Mengel and Kirkby, 1996, Tisdale *et al*., 1995).In East slope, mean TN varied from (1.26-1.43) gkg^{-1},while in West-lying slope, it ranged from (1.10-1.36) gkg^{-1}. According to Havlin *et al*. (1999), TN of the soils were generally low (< 1.5g/kg). Low nitrogen contents associated with steep inclination may be due to a high degree of leaching (Cotching, 2002; Vezina, 2006).

Phosphorus is an essential nutrient for plant growth, and is a primary fertilizer element. It controls cell division and growth as well as deoxyribonucleic acid (DNA) molecules (Bandel *et al*., 2002). Available phosphorus content of the soils studied did not follow any particular trend. However, it ranged from (14.2-21) mgkg^{-1}, (13.5-30.7) mgkg^{-1}, (13.5-43.5)mgkg^{-1} with mean values of (16.62, 20.08 and 23.2) mgkg^{-1} in summit, midslope and footslope of Umudike East-lying slope (Table 4.5), whereas in Itu West-lying slope it ranged from (11.2-68.9) mgkg^{-1} , (10.5-17.2)mgkg^{-1} and (7.2-13.2) mgkg^{-1} with mean values of (42.34, 14.08 and 17.9) mgkg^{-1} in summit, midslope and footslope pedons respectively (Table 4.6). It was shown in the present study that available phosphorus had medium (CV > 15 ≤ 35%) variability in all the slope positions with the exception of West lying summit. Nevertheless, mean available P were generally high > 15 mgkg^{-1}(FPDD, 1990) with the exception of West Lying midslope. Lower level of available P in this soil position indicates that P may be chemically bound as phosphates of Fe and Al owing to the observed higher acidity of the soil (Effiong *et al*., 2006) compared to other soils or due to absolute low level of soil P or that P is removed by sedimentation (Ogban*et al*., 1999).

Exchangeable cations (Calcium, Magnesium, Potassium and Sodium) did not follow any particular trend in their distribution down the soil depth. However, highest values of (8.56 and 3.2) cmolkg^{-1} and lowest values of (4.24 and 2.56)cmolkg^{-1}mean Calcium and Magnesium were recorded in East Lying footslope and midslope respectively whereas , the reverse was the case for potassium and sodium, where highest values of (0.084 and 0.415)cmolkg^{-1}mean was recorded in East midslope. In West toposequence, highest value (9.4 cmolkg^{-1}) mean Calcium was also recorded in midslope position whereas magnesium concentration increased with decreasing slope percentage. It varied from (2.2-4.64) cmolkg^{-1}.This is in agreement with the finding of Tadele *et al*. (2013), who reported relatively higher accumulation of divalent cations in lower topographic position due to washing away from upper areas and accumulation in the lower areas. In addition, highest value of (0.092cmolkg^{-1}) mean potassium was recorded in midslope followed by footslope (0.066cmolkg^{-1}) and summit (0.058cmolkg^{-1}) while sodium concentration also followed similar trend with magnesium by increasing with depth. It varied from (0.381-0.452) cmolkg^{-1}(Table 4.6). According to the ratings of Hazelton and Murphy (2007), Calcium content of the pedons studied were generally moderate with the exception of midslope Of East toposequence that was low (2-5) cmolkg^{-1}. Magnesium concentration of the pedons rated high (3-8) cmolkg^{-1}with the exception of midslope of East and summit of West toposequences that rated moderate (1-3) cmolkg^{-1}. Potassium and sodium concentration of the soils were generally very low (0-0.2) cmolkg^{-1}and moderate (0.3-0.7) cmolkg^{-1}respectively

Hazelton and Murphy (2007). These moderate values of sodium are of little concern, but present in excess it can degrade soil structure, slow infiltration rates and interferes with calcium, magnesium and potassium uptake (Hodges, 2002).

Aluminum and hydrogen ion concentration of the soil did not follow any particular trend down the soil depth. But rather increased with decreasing slope percentage of East toposequence. Mean values of Aluminumand hydrogen ranged from(0.94-1.14) cmolkg^{-1}and (0.27-0.45) cmolkg^{-1}, respectively (Table 4.5) whereas in West toposequence, highest values of (0.10 and 0.67) cmolkg^{-1}and lowest values (1 and 0.50) cmolkg^{-1}mean Al^{3+} and H^{+} were recorded in midslope and summit positions, respectively (Table 4.6). Total exchangeable acidity (TEA) of both toposequences studied generally and slightly increased with depth. TEA increased with slope percentage in East toposequence, it varied from (1.22-1.59)cmolkg^{-1} whereas in West toposequence, it followed no particular pattern, highest value of (1.78cmolkg^{-1}) mean Al^{3+} occurred in midslope followed by footslope (1.65 cmolkg^{-1}) and summit (1.50cmolkg^{-1}). Increased exchangeable acidity with slope suggests solubilization of Al^{3+} which may not imply high activity of hydrogen ions in these soils (Styczen, 1992). Apart from summit and midslope of East toposequence that showed low (CV $\leq$15%), variability of TEA, other pedons studied moderately (CV $> 15 \leq 35\%$) varied. This indicated more stability of TEA in Umudike East toposequence compared to Itu West toposeqence.

In Umudike East-lying slope, total exchangeable bases ranged from (7.3-12.2) cmolkg^{-1}whereas in Itu West lying slope it ranged from (8.919-14.336)cmolkg^{-1}. Exchangeable bases were dominated in footslope and midslope of East and West respectively (Table 4.5 and 4.6). In addition, total exchangeable bases at East summit and footslope showed low variability (CV $\leq$ 15%) whereas it highly (CV > 35%) varied at the midslope. This may be due to the slope percentage that resulted in unstable distribution of basic cations at this soil position. However, total base saturation of Itu west-lying slope showed moderate variation with the exception of footslope that had more stability (Table 4.6). Effective cation exchange capacity (ECEC) of both toposequences studied did not follow any particular trend down the profile and slope. However, in Umudike East- lying slope, highest (13.79cmolkg^{-1}) mean ECEC was recorded in footslope followed by summit (10.06cmolkg^{-1}) and midslope (8.63 cmolkg^{-1}) while in West, highest (16.31 cmolkg^{-1}) mean ECEC was recorded in midslope followed by footslope (15.77cmolkg^{-1}) and summit (10.42cmolkg^{-1}). According to the rating of ECEC given by Landon (1996) (i.e in cmolkg^{-1}) > 40 very high, 25-40 high, 15-25 medium, 5-15 low. Therefore it can be inferred that with the exception of midslope and footslope of West toposequence which showed medium ECEC level, all the soils studied had low ECEC status. The low ECEC of these soils indicates low capacity of these soils to retain nutrient elements. Low cation exchange capacity which is a consequence of low clay and organic matter content, renders soils unsuitable for intensive agriculture (Kparmwang *et al.*, 2004). Percentage base saturation is also directly related to soil pH and represents the relative availability of many positively charged cations such as calcium, magnesium, and potassium. Percentage base saturation (%BS) of the soils ranged from (85.77-89.78) %, (65.86-87.30)% and (82.66-93.59) % with mean values of (87.76, 82.44 and 86.33) % in summit midslope and footslope of Umudike East-lying slope (Table 4.5) while in Itu West-lying slope, %BS ranged from (79.75-92.50) %, (80.04-93.97) % and (84.81-97.13) % with mean values of (85.51, 87.50 and 90.76) % at the summit, midslope and footslope, respectively (Table 4.6). The low base saturation values (< 99%) by sum of cations (Soil Survey Staff, 1990) can be attributed to kaolinitic clay content nature of the parent material from which the soils have been formed. However mean %BS values recorded in this present study were above recommended 80% limit to be maintained in most cropping systems (Hodges, 2002). Low variability (CV ≤15%) recorded for %BS in all the pedons studied indicated more stability of this soil property.

Table 4.5: Chemical properties of the soils of Umudike East-lying toposequence

Horizon	Depth (cm)	pH (H_20)	pH (KCl)	OM g/Kg	TN g/Kg	Av P(mgkg^{-1})	Ca	Mg	K	Na (Cmolkg^{-1})	Al	H	TEA	TEB	ECEC	%BS
summit																
A	0-5	4.5	3.7	40	2.3	14.2	5.2	4.8	0.132	0.417	0.9	0.3	1.2	10.549	11.75	89.78
AB	5-23	4.4	3.6	29.3	1.4	21	5.2	1.6	0.065	0.348	0.92	0.28	1.2	7.213	8.41	85.77
Bt1	23-56	4.7	3.1	20	0.98	14.2	5.6	3.2	0.039	0.356	1.01	0.35	1.36	9.195	10.56	87.07
Bt2	56-95	4.8	3.8	17.8	0.91	15	6	2.4	0.049	0.478	0.92	0.12	1.04	8.927	9.97	89.53
Bt3	95-130	4.8	3.8	9.2	0.7	18.7	4.8	3.2	0.042	0.304	0.96	0.32	1.28	8.346	9.63	86.67
Mean		**4.64**	**3.6**	**23.26**	**1.26**	**16.62**	**5.36**	**3.04**	**0.065**	**0.381**	**0.94**	**0.27**	**1.22**	**8.846**	**10.06**	**87.76**
CV		**3.92**	**8.10**	**50.63**	**50.52**	**18.51**	**8.51**	**39.03**	**58.969**	**17.795**	**4.652**	**32.81**	**9.76**	**13.782**	**12.19**	**2.06**
midslope																
A	0-7	4.6	3.7	42.3	2.4	19.5	5.6	1.6	0.107	0.304	0.93	0.27	1.2	7.611	8.81	86.39
AB	7-37	4.8	3.9	38.4	1.68	30.7	5.2	3.6	0.08	0.461	1.03	0.33	1.36	9.341	10.7	87.30
Bt1	37-66	4.6	3.8	31.5	1.4	13.5	4.4	3.6	0.137	0.478	1	0.28	1.28	8.615	9.9	87.02
Bt2	66-100	4.9	3.9	12.6	0.98	20.2	2	0.4	0.047	0.339	1.11	0.33	1.44	2.786	4.23	65.86
Bt3	100-150	5	3.7	7.4	0.7	16.5	4	3.6	0.05	0.495	1.02	0.34	1.36	8.145	9.51	85.65
Mean		**4.78**	**3.8**	**26.44**	**1.43**	**20.08**	**4.24**	**2.56**	**0.084**	**0.415**	**1.02**	**0.31**	**1.33**	**7.300**	**8.63**	**82.44**
CV		**3.74**	**2.63**	**59.03**	**46.05**	**32.39**	**33.09**	**58.04**	**45.53**	**21.049**	**6.34**	**10.45**	**6.87**	**35.646**	**29.58**	**11.13**
footslope																
A	0-7	4.2	3.5	44.8	2.56	18.5	4.8	3.6	0.141	0.33	0.88	0.32	1.2	8.871	10.07	88.09
AB	7-20	4.4	3.7	31	1.4	18	5.2	1.6	0.076	0.365	0.9	0.62	1.52	7.241	8.76	82.66
Bt1	20-52	4.8	3.8	25.9	1	13.5	4	2.8	0.046	0.391	0.99	0.45	1.44	7.237	8.68	83.38
Bt2	52-98	4.7	3.7	20.6	0.91	43.5	21.2	6	0.089	0.461	1.42	0.48	1.9	27.75	29.65	93.59
Bt3	98-150	4.8	3.8	9.8	0.7	22.5	7.6	2	0.032	0.269	1.5	0.4	1.9	9.901	11.8	83.91
Mean		**4.58**	**3.7**	**26.42**	**1.31**	**23.2**	**8.56**	**3.2**	**0.077**	**0.363**	**1.14**	**0.45**	**1.59**	**12.2**	**13.79**	**86.33**
CV		**5.86**	**3.31**	**48.96**	**56.42**	**50.81**	**84.02**	**54.49**	**55.345**	**19.622**	**26.20**	**24.41**	**19.15**	**71.855**	**64.93**	**5.30**

Key: OM= organic matter, TN=total nitrogen, Av. P=available phosphorus, TEA=total exchangeable acidity, TEB=total exchangeable bases, ECEC=effective cation exchange capacity,%BS=percentage base saturation.

Horizon	DEPTH (cm)	pH (H_2O)	pH (KCl)	OM (g/Kg)	TN (g/Kg)	Av P ($mgkg^{-1}$)	Ca	Mg	K	Na	AI ($Cmolkg^{-1}$)	H	TEA	TEB	ECEC	%BS
									ItuWest-lying summit							
A	0-6	5.3	3.6	42.4	2.1	68.9	5.2	1.6	0.127	0.443	1	0.36	1.36	7.37	8.73	84.42
AB	6-38	5.8	3.9	25.3	1.4	45.5	5.4	2.6	0.063	0.321	0.9	0.46	1.36	8.384	9.74	86.08
Bt1	38-83	5.9	3.8	12.6	0.98	68.9	7.2	1.2	0.039	0.495	1.1	0.5	1.6	8.934	10.53	84.84
Bt2	83-106	5	4.1	9.2	0.56	11.2	8.4	3.6	0.029	0.304	0.88	0.4	1.28	12.333	13.61	92.50
Bt3	106-120	4.5	3.7	5	0.44	17.2	5.2	2	0.033	0.343	1.12	0.8	1.92	7.576	9.5	79.75
Mean		**5.3**	**3.82**	**18.9**	**1.10**	**42.34**	**6.28**	**2.2**	**0.058**	**0.381**	**1**	**0.50**	**1.50**	**8.919**	**10.42**	**85.51**
CV		**10.921**	**5.035**	**80.251**	**61.74**	**64.924**	**23.141**	**42.64**	**69.862**	**21.875**	**11.045**	**34.526**	**17.399**	**22.524**	**18.176**	**4.545**
midslope																
A	0-7	4.5	3.6	43.6	2.24	13.5	12.8	7.6	0.153	0.374	1.05	0.31	1.36	20.927	22.27	93.97
AB	7-26	4.6	3.9	38	1.48	10.5	9.2	2	0.133	0.391	1.01	0.67	1.68	11.724	13.4	88.35
Bt1	26-50	4.7	3.9	31.5	1.12	17.2	6.8	4.8	0.052	0.452	1.11	0.73	1.84	12.104	13.95	86.77
Bt2	50-73	4.8	3.8	24.1	1.1	14.2	10	4	0.06	0.522	1.12	0.8	1.92	14.582	16.5	88.38
Bt3	73-110	4.8	3.8	16	0.84	15	8.2	3.6	0.064	0.478	1.22	0.86	2.08	12.342	15.42	80.04
Mean		**4.68**	**3.8**	**30.64**	**1.36**	**14.08**	**9.4**	**4.4**	**0.092**	**0.443**	**1.10**	**0.67**	**1.78**	**14.336**	**16.31**	**87.50**
CV		**10.921**	**5.035**	**80.251**	**61.74**	**64.924**	**23.141**	**42.64**	**69.862**	**21.875**	**11.045**	**34.526**	**17.399**	**22.524**	**18.176**	**4.545**
footslope																
A	0-8	4	3.6	44.8	1.98	27	8.8	5.2	0.094	0.408	0.8	0.48	1.28	14.502	15.78	91.90
AB	8-29	4.5	3.8	36.2	1.12	12	7.2	4.4	0.057	0.495	0.96	0.72	1.68	12.152	13.83	87.87
BA	29-86	4.6	3.6	24.7	0.98	28.8	13.2	6.8	0.07	0.522	1.06	0.7	1.76	20.592	22.36	92.09
Bt1	86-110	4.6	3.8	17.6	0.84	10.5	8.2	3.6	0.045	0.452	1	0.36	1.36	12.297	12.66	97.13
Bt2	110-180	4.9	3.8	7.2	0.56	11.2	8.4	3.2	0.062	0.382	1.26	0.9	2.16	12.044	14.2	84.81
Mean		**4.52**	**3.72**	**26.1**	**1.10**	**17.9**	**9.16**	**4.64**	**0.066**	**0.452**	**1.02**	**0.63**	**1.65**	**14.317**	**15.77**	**90.76**
CV		**7.237**	**2.945**	**56.93**	**48.887**	**51.208**	**25.481**	**30.842**	**27.872**	**12.899**	**16.434**	**33.684**	**21.326**	**25.506**	**24.428**	**3.373**

Key: OM= organic matter, TN=total nitrogen, AvP=available phosphorus, TEA=total exchangeable acidity, TEB=total exchangeable bases, ECEC=effective cation exchange capacity,%BS=percentage base saturation

4.4 Some selected fertility indices of the studied toposequences

Table 4.7 and 4.8 displayed resultsof some selected fertility indices studied. The ratio between Carbon (C) and Nitrogen (N) is very important for the ecosystem productivity and the terrestrial C cycle. It was shown that C/N ratio of both toposequences did not follow any particular pattern down the soil depth and slope, although higher values were recorded at the surface horizons compared to sub-surface horizons. At Umudike East-lying slope, highest (11.82) mean C/N was recorded in footslope compared to summit (10.58) and midslope (10.0) (Table 4.7). In Itu West-lying toposequence, highest (13.21) mean C/N was recorded in midslope followed by footslope (13.18) and summit (9.13) (Table 4.8). It was observed in the study that C/N showed moderate (CV > 15 ≤ 35%) variability in all the slope positions. Soil texture had a great impact on the C/N ratio (Nianpeng *et al*., 2012). Comparatively higher C/N values in the surface soil layer than the subsurface rates might be due to resolution and separation rates (Sakin *et al*., 2010). According to the rating given by Hazelton and Murphy (2007), C/N less than 25 such as recorded in the present study indicates that decomposition proceeded at the maximum rate possible under hot conditions which is true for the environment of the study.

The ratio of Calcium (Ca) to Magnessium (Mg) has been suggested for diagnostic purposes on the basis that it takes into consideration the competing effect of Mg on Ca availability (Mclean, 1981). Ca/Mg of Umudike East-lying slope ranged from 1.08-3.25, 1.11-3.5 and 11.33-3.53 with mean values of 2.02, 2.45 and 2.67 in summit, midslope and footslope respectively (Table 4.7), while it ranged from 2.08- 6, 1.42-4.6 and 1.64-2.63 with mean values of 3.25, 2.50 and 2.04 in summit, midslope and footslope, respectively in Itu West-lying slope . According to Landon (1991), the approximate optimum range for most crops is 3 to 4. Dontsova and Norton (2001) after modifying Mg and Ca in four soils with low organic matter content, clay and mineralogy (similar to the study area), demonstrated that Mg has specific effect on clay flocculation and surface scaling due to its hydration behaviour that differs from that of calcium. Therefore a soil with high Ca/Mg such as footslope of Umudike (2.67) and summit of Itu (3.25) will have more stable aggregates than other soils studied. It was also shown in Table 4.7 and 4.8 that Potassium (K) to Magnessium (Mg) (K/Mg) ratio of the soils generally and slightly decreased with depth with general high variation in all the pedons studied.In Umudike toposequence, highest (0.05) mean K/Mg ratio was recorded in midslope followed by footslope (0.03) and summit (0.02), whereas, in Itu toposequence, K/Mg ratio decreased with decreasing slope percentage. Thus, highest (0.03) and lowest (0.01) mean values were recorded in summit and footslope, respectively (Table 4.8). According to Fact Sheet (2005), the ideal K/Mg ratio is 0.2 - 0.35 for most crops.

Table 4.7: Selected Fertility indices of the Umudike East-Lying Toposequence Studied

Horizon	Depth (cm)	C/N	Ca/Mg	K/Mg
		summit		
A	0-5	10.06	1.08	0.03
AB	5-23	12.11	3.25	0.04
Bt1	23-56	11.81	1.75	0.01
Bt2	56-95	11.31	2.5	0.02
Bt3	95-130	7.6	1.5	0.01
Mean		**10.578**	**2.016**	**0.022**
CV		**17.391**	**42.743**	**59.265**
		midslope		
A	0-7	10.2	3.5	0.07
AB	7-37	13.22	1.44	0.02
Bt1	37-66	13.01	1.22	0.04
Bt2	66-100	7.44	5	0.12
Bt3	100-150	6.11	1.11	0.01
Mean		**9.996**	**2.454**	**0.052**
CV		**32.089**	**70.385**	**85.355**
		footslope		
A	0-7	10.12	1.33	0.04
AB	7-20	12.81	3.25	0.05
Bt1	20-52	14.98	1.43	0.02
Bt2	52-98	13.1	3.53	0.01
Bt3	98-150	8.1	3.8	0.02
Mean		**11.822**	**2.668**	**0.028**
CV		**22.906**	**44.688**	**58.685**

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

Table 4.8: Selected Fertility indices of the Itu West-Lying Toposequence Studied

Horizon	Depth	C/N	Ca/Mg	K/Mg
summit				
A	0-6	11.68	3.25	0.08
AB	6-38	10.45	2.08	0.02
Bt1	38-83	7.44	6	0.03
Bt2	83-106	9.5	2.33	0.01
Bt3	106-120	6.57	2.6	0.02
Mean		**9.128**	**3.252**	**0.032**
CV		**23.105**	**43.921**	**76.594**
midslope				
A	0-7	11.26	1.68	0.02
AB	7-26	14.85	4.6	0.07
Bt1	26-50	16.27	1.42	0.01
Bt2	50-73	12.67	2.5	0.02
Bt3	73-110	11.01	2.28	0.02
Mean		**13.212**	**2.496**	**0.028**
CV		**23.105**	**44.962**	**76.594**
footslope				
A	0-8	13.08	1.69	0.02
AB	8-29	18.7	1.64	0.01
BA	29-86	14.58	1.94	0.01
Bt1	86-110	12.12	2.28	0.01
Bt2	110-180	7.43	2.63	0.02
Mean		**13.182**	**2.036**	**0.014**
CV		**30.961**	**20.519**	**39.123**

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

4.5 Relationship among selected soil properties of the studied toposequences

Results of the association existing among some selected soil properties studied is displayed in Table 4.9. It was shown that organic matter had significant positive association with Total Nitrogen (TN) (r=0.911), Carbon/Nitrogen (C/N) ratio (r = 0.588), Silt Clay Ratio (SCR) (r = 0.755), Potassium (K) (r = 0.796), sand (r = 0.549), silt (r = 0.626) and Ksat (r = 0.732). This indicates that increase in organic matter (OM) content of the soil will result in significant increase in the soil properties mentioned and vice versa, whereas negative significant association that OM had with clay (r = - 0.730), Aluminium (Al) (r = -0.466) and Bulk Density(BD) (r = - 0.933) implies that increase in OM will result in significant decrease of these soil parameters. The pH in water only had serious association with Available phosphorus (Av P) (r = 0.629). This shows that increase in soil pH will result in increased phosphorus. This was in consonant with the findings of Uzoho and Oti (2004). TN had significant positive association with SCR (r = 0.790), K (r = 0.837), sand (r = 0.631), silt (r = 0.574) and Ksat (r = 0.865). However, TN showed significant negative correlation with Total Exchangeable Acidity (TEA) (r = - 0.499), clay (r = - 0.767), Moisture content (MC) (r = - 0.519), Sodium (Na) (r = - 0.10) and BD (r = - 0.857). Similarly, C/N only had serious negative association with BD (r = - 0.527). This indicates that increase in soil bulk density will result in significant decrease of C/N.

Total exchangeable acidity of the soil showed significant positive relationship with Al (r = 0.767) and Hydrogen (H) (r = 0.877) while it had significant negative relationship with sand (r = - 0.526). Table 4.9 also showed that Total exchangeable Bases (TEB) had significant relationship with Effective Cation Exchange Capacity (ECEC) (r = 0.996), Calcium (Ca) (r = 0.965), Magnessium (Mg) (r = 0.827) and Percentage Base Saturation (%BS) (r = 0.705). This denotes that increase in TEB will bring about a significant increase in ECEC, Ca, Mg and %BS whereas, significant negative correlation between TEB and K/Mg (r = - 0.467) implies that increase in TEB will result in decrease in K/Mg content of the soil. Similarly, ECEC had significant negative association with K/Mg while it had significant positive association with Ca (r = 0.966), Mg (r = 0.813) and %BS (r = 0.677). Ca/Mg ratio showed significant positive and negative relationship with K/Mg (r = 0.565) and Mg (r = - .0.586) respectively (Table 4.9). However, K/Mg had serious negative association with MC (r = - 0.715), Mg (r = - .0.589) and %BS (r = 0.653). This shows that increase in MC, Mg and %BS will result in an increase in K/Mg ratio of the soils and vice versa. Clay content of the soil showed significant negative relationship with SCR (r = - 0.842), K (r = - 0.576), sand (r = - 0.873), silt (r = - 0.674) and Ksat (r = - 0.857) while it showed significant positive relationship with Al (r = 0.498) and BD (r = 0.685). Furthermore, SCR recorded serious positive association with K (r = 0.661), sand (r = 0.538), silt (r = 0.865) and Ksat (r = .0.900). This implies that increase in SCR of the soil will result in significant increase in K, sand, silt and Ksat. However, negative significant association that SCR had with MC (r = - 0.450) and BD (r = 0.708) implies that increase in SCR will bring about significant decrease in MC and bulk density of the soil. Similar significant negative association that moisture content had with Ksat implies that increase in hydraulic conductivity (Ksat) of the soils will result in reduced moisture content.

Table 4.9: Relationships among the soil properties studied

	OM	pHw	TN	C/N	TEA	TEB	ECEC	Ca/Mg	K/Mg	Clay	SCR	MC
OM	-	-	-	-	-	-	-	-	-	-	-	-
pHw	-0.401ns	-	-	-	-	-	-	-	-	-	-	-
TN	0.911**	-0.294ns	-	-	-	-	-	-	-	-	-	-
C/N	0.588**	-0.339ns	0.222ns	-	-	-	-	-	-	-	-	-
TEA	-0.380ns	0.091 ns	-0.499*	0.041 ns	-	-	-	-	-	-	-	-
TEB	0.119 ns	-0.202 ns	-0.010 ns	0.337 ns	0.364 ns	-	-	-	-	-	-	-
ECEC	0.092 ns	-0.188 ns	-0.039 ns	0.328 ns	0.431 ns	0.996**	-	-	-	-	-	-
Ca/Mg	-0.225ns	0.382 ns	-0.144 ns	-0.254 ns	0.231 ns	-0.119 ns	-0.103 ns	-	-	-	-	-
K/Mg	0.263ns	0.041 ns	0.381 ns	-0.137 ns	-0.198 ns	-0.467*	-0.464*	0.565**	-	-	-	-
Clay	-0.730**	0.233 ns	-0.767**	-0.186 ns	0.342 ns	-0.019 ns	-0.001 ns	0.216 ns	-0.011 ns	-	-	-
SCR	0.755**	-0.239 ns	0.790**	0.211 ns	-0.210 ns	0.209 ns	0.195 ns	-0.047 ns	0.176 ns	-0.842**	-	-
MC	-0.377ns	0.110 ns	-0.519*	0.132 ns	0.380 ns	0.374 ns	0.386 ns	-0.205 ns	-0.715**	0.326 ns	-0.450*	-
AvP	0.079 ns	0.629**	0.157 ns	-0.123 ns	-0.009 ns	0.040 ns	0.040 ns	0.439 ns	0.184 ns	-0.139 ns	0.085 ns	-0.077 ns
Ca	0.027 ns	-0.109 ns	-0.087 ns	0.271 ns	0.435 ns	0.965**	0.966**	0.110 ns	-0.361 ns	0.060 ns	0.139 ns	0.391 ns
Mg	0.272 ns	-0.355 ns	0.149 ns	0.380 ns	0.121 ns	0.827**	0.813**	-0.586**	-0.589**	-0.181 ns	0.304 ns	0.247 ns
K	0.796**	-0.330 ns	0.837**	0.233 ns	-0.274 ns	0.221 ns	0.202 ns	-0.144 ns	0.353 ns	-0.576**	0.661**	-0.310 ns
Na	0.082 ns	0.088 ns	-0.100**	0.411 ns	0.221 ns	0.221 ns	0.360 ns	-0.134 ns	-0.247 ns	0.107 ns	-0.103 ns	0.282 ns
Al	-0.466*	0.184 ns	-0.466*	-0.188 ns	0.767**	0.360 ns	0.406 ns	0.342 ns	-0.115 ns	0.498*	-0.275 ns	0.354 ns
H	-0.202ns	-0.006 ns	-0.375 ns	0.199 ns	0.877**	0.259 ns	0.321 ns	0.079 ns	-0.202 ns	0.124 ns	-0.098 ns	0.287 ns
BS	0.339 ns	-0.218 ns	0.236 ns	0.373 ns	-0.103 ns	0.705**	0.677**	-0.431 ns	-0.653**	0.124 ns	-0.098 ns	0.287 ns
Sand	0.549**	-0.257 ns	0.631**	0.033 ns	-0.526*	-0.145 ns	-0.176 ns	-0.372 ns	-0.066 ns	-0.873**	0.538*	-0.260 ns
Silt	0.626**	-0.074 ns	0.574**	0.322 ns	0.114 ns	0.258 ns	0.268 ns	0.133 ns	0.122 ns	-0.674**	0.865**	-0.257 ns
BD	-0.933**	0.309 ns	-0.857**	-0.527*	0.407 ns	-0.057 ns	-0.026 ns	0.105 ns	-0.310 ns	0.685**	-0.708**	0.420 ns
TP	0.105 ns	-0.058 ns	0.090 ns	0.059 ns	-0.104 ns	0.177 ns	0.165 ns	-0.252 ns	-0.098 ns	-0.026 ns	0.069 ns	0.092 ns
Ksat	0.732**	-0.333 ns	0.865**	0.044 ns	-0.398 ns	0.083 ns	0.057 ns	-0.179 ns	0.209 ns	-0.857**	0.900**	-0.541*

Key: *= significant at 5% probability level,**= significant at 1% probability level, ns= not significant, OM =Organic matter,TN=Total Nitrogen,C/N =Carbon/Nitrogen ratio,TEA =Total Exchangeable Acidity,TEB =Total Exchangeble Bases,ECEC =Effective Cation Exchange Capacity,Ca/Mg= Calcium Magnessium Ratio,K/Mg= Potassium Magnessium ratio,SCR =Silt Clay Ratio,MC =Moisture Content

4.6: Comparison of soil physico-chemical properties of the topounits in the studied locations

4.6.1: The Physical properties

The results in Tables 4.10, 4.11 and 4.12 showed the comparison among soil physical properties in the same topographic units (the summit, midslope and footslope). In the summit, significant difference ($p = 0.05$) were observed in soil particle distributions and soil moisture content within the same topounits (Table 4.10). Similar results were observed in the midslope (Table 4.11) and in the footslope (Table 4.12). The differences could be attributed to variations in the intensity of vegetation and land use or management system. Since the soils are of the same parent material, it is expected that as a result of the differences in the management systems such as fertilizer application, tillage system and differences in the intensity of vegetative cover, variations in the moisture content could exist. Similar findings were made by Njoku *et al*., (2017a; 2017b) who observed differences in the soil physical properties on soils of the same summit in Ohafia area of Southeastern Nigeria and attributed the variability in the physical properties to differences in soil management practices. Similarly, Sunday *et al*., (2011) attributed the variations among soil physicochemical properties in the same topounits to differences in the management strategies.

Table 4.10: Comparison of soil physical properties on the same topounit (summit)

Soil Properties	Topounit Umudike East-lying summit	Itu West-lying summit	Mean difference
Sand	666.8	662.8	4*
Silt	62	82	20*
Clay	271.2	255.2	16*
SCR	0.324	0.366	0.042 ns
Bulk density	1.36	1.37	0.01 ns
Total porosity	46.87	46.8	0.07 ns
K sat	0.602	0.486	0.116 ns
Moisture content	246	242	4*

*= significant at 0.05 probability level; ns = not significant at 0.05 probability level

Table 4.11: Comparison of soil physical properties on the same topounits (midslope)

Soil properties	Topounit Umudike East-lying midslope	Itu West-lying midslope	Mean difference
Sand	590.8	580	
Silt	63.6	126	62.4*
Clay	345.6	294	51.6*
SCR	0.382	0.68	0.298*
Bulk density	1.322	1.334	0.012 ns
Total porosity	48.36	47.89	0.47 ns
K sat	0.556	0.608	0.052 ns
Moisture content	214	262	

*= significant at 0.05 probability level; ns = not significant at 0.05 probability level

Table 4.12: Comparison of soil physical properties on the same topounits (footslope)

	Topounit		
Soil properties	**Umudike East-lying footslope**	**Itu West-lying footslope**	**Mean difference**
Sand	576	592	16*
Silt	66	102	36*
Clay	358	306	52*
SCR	0.256	0.496	0.24^{ns}
Bulk density	1.342	1.318	0.024^{ns}
Total porosity	47.42	48.52	1.1*
K sat	0.416	0.566	0.15^{ns}
Moisture content	280	262	18*

*= significant at 0.05 probability level; ns = not significant at 0.05 probability level

4.6.2: The chemical properties within the same topographic units

Comparison of the chemical properties of soils in the same topounits is presented in Tables 4.13, 4.14 and 4.15. Significant differences *(P=0.05*) were observed in soil pH, organic matter, total N, available phosphorus, exchangeable bases and base saturation within the summit (Table 4.13). In the midslope, there were significant changes in soil pH, Organic matter , Total N, available P, exchangeable bases, ECEC and base saturation (Table 4.14). Organic matter, available P, total N, exchangeable bases, base saturation and ECEC significantly (P = 0.05) differed in the footslope (Table 4.15). These variations could be attributed to land use practices and variations in vegetative cover as well as management practices (Sunday et al., 2011).

Table 4.13: Comparison of soil chemical properties on the same topounit (summit)

Soil properties	Topounit Umudike East-lying summit	 Itu West-lying summit	Mean difference
pH(H_2O)	4.64	5.30	0.66*
pH(KCL)	3.6	3.82	0.22*
Org. Matter	23.26	18.9	4.36*
Total N	1.258	1.096	0.162*
Avail. P	16.62	42.34	25.72*
Ca	5.36	6.28	0.92*
Mg	3.06	2.2	0.86*
K	0.065	0.058	0.007 ns
Na	0.381	0.381	0.00 ns
H	0.942	1.00	0.058 ns
Al	0.274	0.504	0.23*
TEA	1.216	1.504	0.288*
TEB	8.846	8.92	0.074 ns
ECEC	10.06	10.42	0.36 ns
BS	87.76	85.52	2.24*

*= significant at 0.05 probability level; ns = not significant at 0.05 probability level

OM =Organic matter,TN=Total Nitrogen,C/N =Carbon/Nitrogen ratio,TEA =Total Exchangeable Acidity,TEB =Total Exchangeble Bases,ECEC =Effective Cation Exchange Capacity,Ca/Mg= Calcium Magnessium Ratio,K/Mg= Potassium Magnessium ratio,SCR =Silt Clay Ratio,MC =Moisture Content

Table 4.14: Comparison of soil chemical properties on the same topounit (midslope)

Soil properties	Topounit Umudike East-lying midslope	Itu West-lying midslope	Mean difference
Ph(H2O)	4.78	4.68	0.1*
Ph(KCL)	3.8	3.8	0.0^{ns}
Org. Matter	26.44	30.64	4.2*
Total N	1.432	1.356	0.076^{ns}
Avail. P	20.08	14.08	6.0*
Ca	4.24	9.40	5.16*
Mg	2.56	4.40	1.84*
K	0.084	0.092	0.008^{ns}
Na	0.415	0.443	0.028^{ns}
H	1.018	1.102	0.084*
Al	0.31	0.674	0.364*
TEA	1.328	1.776	0.448*
TEB	7.299	14.33	7.031*
ECEC	8.63	16.31	7.68*
BS	82.44	87.5	5.06*

*= significant at 0.05 probability level; ns = not significant at 0.05 probability level

OM =Organic matter,TN=Total Nitrogen,C/N =Carbon/Nitrogen ratio,TEA =Total Exchangeable Acidity,TEB =Total Exchangeble Bases,ECEC =Effective Cation Exchange Capacity,Ca/Mg= Calcium Magnessium Ratio,K/Mg= Potassium Magnessium ratio,SCR =Silt Clay Ratio,MC =Moisture Content

ble 4.15: Comparison of soil chemical properties on the same topounit (footslope)

	Topounit		
Soil properties	**Umudike East-lying footslope**	**Itu West-lying footslope**	**Mean difference**
Ph(H2O)	4.58	4.52	0.06 ns
Ph(KCL)	3.7	3.72	0.02 ns
Org. Matter	26.42	26.1	0.32*
Total N	1.314	1.096	0.218*
Avail. P	23.2	17.9	5.3*
Ca	8.56	9.16	0.6*
Mg	3.2	4.64	1.44*
K	0.077	0.066	0.011 ns
Na	0.363	0.452	0.089*
H	1.138	1.016	0.122 ns
Al	0.454	0.632	0.178*
TEA	1.592	1.648	0.056ns
TEB	12.1	14.32	2.22*
ECEC	13.79	15.77	1.98*
BS	86.33	90.76	4.43*

*= significant at 0.05 probability level; ns = not significant at 0.05 probability level

OM =Organic matter,TN=Total Nitrogen,C/N =Carbon/Nitrogen ratio,TEA =Total Exchangeable Acidity,TEB =Total Exchangeble Bases,ECEC =Effective Cation Exchange Capacity,Ca/Mg= Calcium Magnessium Ratio,K/Mg= Potassium Magnessium ratio,SCR =Silt Clay Ratio,MC =Moisture Content

4.7: Classification of the soils of studied toposequences

4.7.1: Umudike East oriented toposequence; Topo unit: summit

Altitude: 141m

Geographical coordinate: (latitude 5° 28'.914" N and longitude 7° 31'. 395" E)

Characteristics: It has a clay bulge indicating argillation. Sandier than all other topounits with mean value of 666.8 g kg^{-1} .Organic carbon decreased consistently with depth.Base saturation has a mean of 87.76 %.

Order: Alfisol

Sub – Order: Udalf since it has an udic moisture regime.

Subgroup: Paleudalf since it has 7.5 YR with chroma of 5-8 lower horizons

Greatgroup: Grossarenic Paleudalfs, since it has a sandy particle size throughout the argillic horizon of the profile.

4.7.2: **Umudike East oriented toposequence; Topo unit:** midslope

Altitude: 138m

Geographical coordinate: (latitude 5° 28'. 546" N and longitude 7° 31'. 414" E)

Characteristics: Clay bulge is prominent, Organic matter decreased consistently with depth. Base saturation is high showing 82.44% on average.

Order: Alfisol

Suborder: Udalf since it has an Udic moisture regime.

Subgroup: Paleudalf with chroma of 6-8

Greatgroup: Typic paleudalf since the prominent clay bulge is typical of all Alfisols.

4.7.3 Umudike East oriented toposequence; Topo unit: footslope

Altitude: 121m

Geographical coordinate: (Latitude 5° 28'. 983" N and Longitude 7° 31'. 458" E)

Characteristics: Presence of Clay bulge with apex at Bt1 and Bt2. Organic matter decreased with depth. Base saturation has mean value of 86.33%.

Order – Alfisol

Suborder – Udalf

Subgroup – Kandiudalf (Other Udalfs)

Greatgroup - Arenic Hapludalfhaving a sandy particle size class throughout the horizon extending from the mineral soil surface to the top of argillic horizon to a depth of 50cm or more.

4.7.4 Itu West oriented toposequence; Topo unit: summit

Altitude: 143m

Geographical coordinate: (Latitude 5^o 28'. 844" N and Longitude 7^o 31'. 352" E)

Characteristics: It has a clay bulge with a mean value of sand showing 662.8g kg^{-1} and base saturation showing 85.51% respectively.

Order – Alfisol

Sub-order –Udalf

Subgroup –Glossudalf since there is presence of glossic horizon.

Greatgroup – Arenic Glossudalf having sandy particle size class throughout a horizon extending from the mineral soil surface to the top of an argillic horizon on a depth of 50cm or more below the mineral soil surface .

4.7.5 Itu west oriented toposequence; Topo unit: midslope

Altitude: 142m

Geographical coordinate: (Latitude 5^o 28'. 844" N and Longitude 7^o 31'. 304" E)

Characteristics: This has a distinct clay bulge, Organic matter decreased with depth and its mean value of base saturation is 87.50%

Order – Alfisol

Suborder –Udalf

Subgroup – Paleudalf with chroma of 6-8

Greatgroup: Typic Paleudalf.

4.7.6 Itu West oriented toposequence; Topo unit: footslope

Altitude: 135m

Geographical coordinate: (Latitude 5^o 28'. 804" N and Longitude 7^o 31'. 265" E)

Characteristics: It shows an argillic horizon, where organic matter decreased with depth and base saturation value is 90.76% on the average

Order –Alfisol

Suborder –Udalf

Subgroup –Ferrudalf, since it has a chroma of 2 up to a depth of 86cm.

Greatgroup- Typic ferrudalf, since other conditions like mottles were not prominent at that depth.

Table 4.16: Classification of the soils of studied toposequences

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

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

CHAPTER FIVE

5.0 Summary, Conclusions, Recommendations and Contribution of study to knowledge

5.1 Summary

Slope orientations influence pedogenesis and properties of soils. The study classified the soils on slopes of two orientations in Olokoro, Umuahia, southeastern Nigeria. Umudike east-lying and Itu west-lying toposequencies were used for the study. Transect soil survey technique was used in the field study to align soil properties.Six (6) profile pits were sunk in summit, midslope and footslope of each toposequence. The soil profiles were sampled using standard method. Soil samples collectedwere sent to the laboratory for physical and chemical properties determination. Statistical analysis of the laboratory data was conducted using Genstat statistical Package in which correlation and coefficient of variability and t-test were done.

Results showed that the soils were dominated by sandy clay loam texture as a result of high clay content of the soils which increased with depth especially in Umudike east-lying slope. Bulk density values (1.36- 1.32) g cm^{-3}and (1.37- 1.32) g cm^{-3} in East and West slopes were adequate for agricultural production. Low and moderate coefficient of variability recorded in most of the soil physical properties indicated homogeneity in the distribution of these soil properties.The pH of the soils at all positions were acidic ranging from 4.78- 4.64 and 5.3- 4.52 in east and west lying slopes, respectively. Organic matter in Umudike east (26.44- 23.36) g kg^{-1}and Itu west-lying slope (30.64- 18.9) g kg^{-1} were generally high likewise total nitrogen (1.43- 1.26) g kg^{-1}and (1.43- 1.26) g kg^{-1} in East and West, respectively. Also, available phosphorus content of the soils decreased with depth and were high in all the pedons apart from midslope of west. Accumulation of organic matter, total nitrogen and available phosphorus at the topsoil and within the midslope and footslope of both sites indicates adequate plant residue decomposition and mineralization and its subsequent transportation from summit to midslope and footslope. In addition, there was clear dominance of Calcium (Ca) in total basic cations of the soils and highest values of (8.56 and 9.16) cmol kg^{-1} were recorded at the footslope of East and West toposequence respectively.On the other hand, there were higher values (0.084 and 0.415) cmol kg^{-1} and (0.092 and 0.443) cmolkg^{-1} sodium in midslope of East and West, respectively.

Furthermore, moderate total exchangeable acidity values were recorded in the study resulting in favourable base saturation ranging from (87.76- 82.44)% in Umudike east-lying slope and (90.76- 85.51) % in Itu west-lying slope. In other words, there was more saturation of basic cations in East summit and west-lying footslope compared to other slope positions studied. Results of fertility indices showed higher values of C/N, Ca/Mg and K/Mg ratios at midslope and footslope of East whereas, the reverse was the case in West where high values were recorded in summit and midslope. It can therefore be inferred that slope angle and orientation of these toposequencies played a prominent role in regulating these fertility indices. However, low ($CV \leq 15\%$) variability recorded for pH, Al^{3+}, and percentage base saturation in this study suggested more stability of these properties down the soil profiles in both East and West lying toposequences.

Using USDA soil taxanomy, the soils of Umudike east-lying slope were classified as Gross Arenic Paleudalfs, Typic Paleudalfs and Arenic Hapludalfs at summit, midslope and footslope respectively and were generally classified as Mollic Luvisols using World Reference Base. On the other hand, using soil taxanomy, the soils of Itu west-lying slope were classified as Arenic Glossdalfs, Typic Paleudalfs and Typic Ferrudalfs at the summit, midslope and footslope respectively and were correlated as Haplic Albeluvisols using WorldReference Base.

5.2 Conclusions

The study classified the soils on slopes of varying orientation (east-lying and west-lying) slopes in Olokoro, Umuahia, Southeastern Nigeria using transect soil survey technique in which six (6) profile pits were sunk in summit, midslope and footslope of each toposequence. Statistical result of laboratory analysis showed that the soils were dominated by sandy clay loam texture as a result of high clay content of the soils which increased with depth especially in Umudike east-lying slope. Bulk density values in East and West slopes were adequate for agricultural production. Low and moderate coefficient of variability recorded in most of the soil physical properties indicated homogeneity in the distribution of these soil properties. The Soil pH of the soils at all positions was acidic. Organic matter in both toposequences was generally high likewise total nitrogen. Also, available phosphorus content of the soils decreased with depth and was high in all the pedons apart from midslope of west. Accumulation of organic matter, total nitrogen and available phosphorus at the topsoil and within the midslope and footslope of both sites indicates adequate plant residue decomposition and mineralization and its subsequent transportation from summit to midslope and footslope. In addition, there was clear dominance of Calcium in total basic cations of the soils especially at the footslopes.

Furthermore, moderate total exchangeable acidity values were recorded in the study resulting in favourable base saturation in East summit and west-lying footslope compared to other slope positions studied. There were higher values of C/N, Ca/Mg and K/Mg ratios at midslope and footslope of East lying slope whereas, the reverse was the case in west lying slope where high values were recorded in summit and midslope. It can therefore be inferred that slope angle and orientation of these toposequencies played a prominent role in regulating these fertility indices. However, low (CV≤ 15%) variability recorded for pH, Al^{3+}, and percentage base saturation in this study suggested more stability of these properties down the soil profiles in both East and West Lying slopes.

5.3 Recommendations

As a result of these result findings, the following recommendations were made;

- ✓ Farmers in this study area are advised to lime the soils due to its acidity since this will improve the availability of mostnutrient elements.
- ✓ Agricultural activities should therefore concentrate more around the Umudike east-lying summit and Itu west-lying fooootslope as a result of greater accumulation of basic cations observed in these soil positions.

5.4 Contribution of study to knowledge

The study has revealed that topograhphy and slope orientation greatly influence soil properties.

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APPENDIX 1

PLATE 1 :ITU WEST- LYING FOOT SLOPE VEGETATION

APPENDIX 2

PLATE 2 :**Itu WEST-lying foot slope**

APPENDIX 3

PLATE 3: **UMUDIKE East - lying summit**

APPENDIX 4

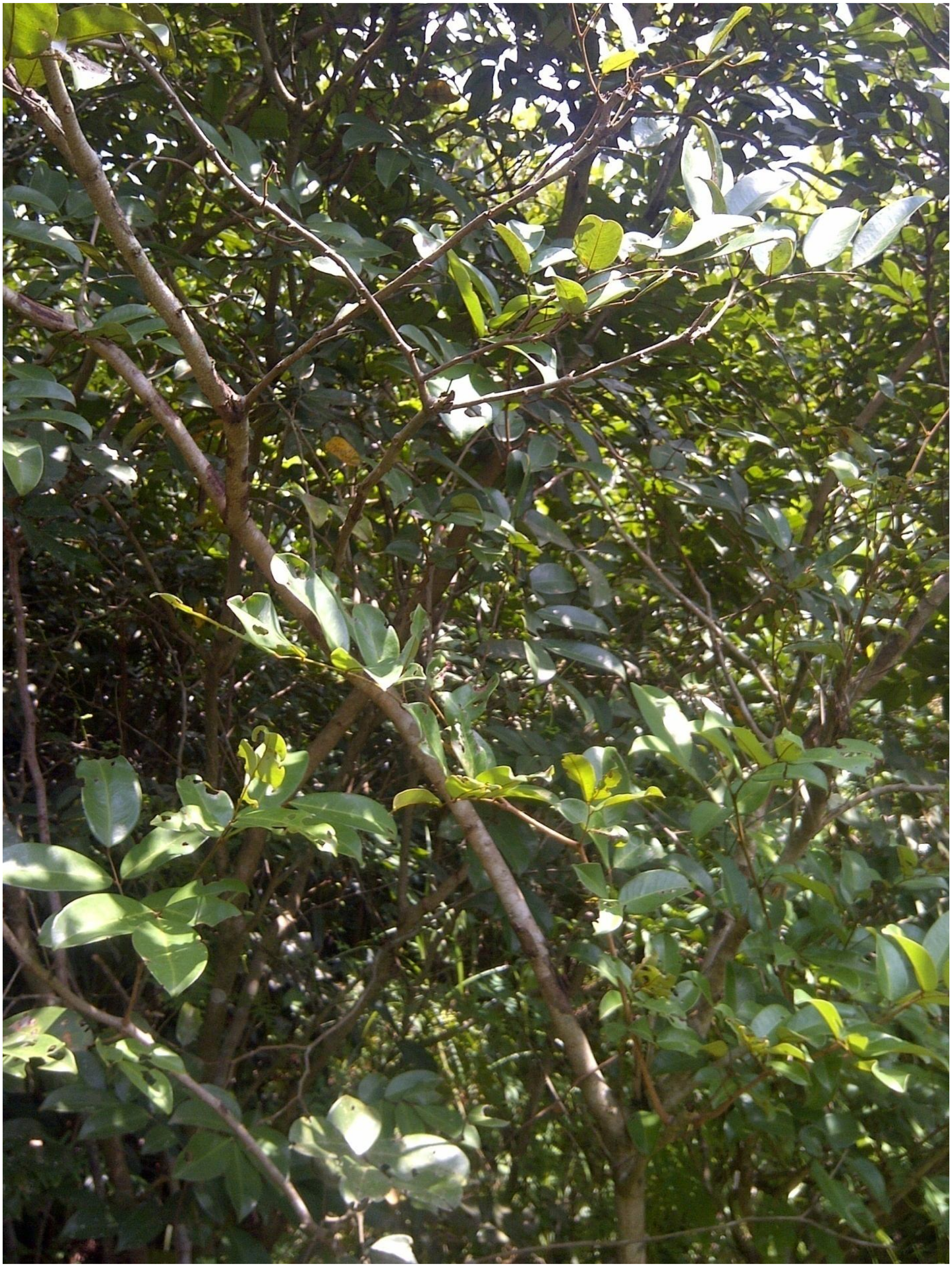

PLATE 4 : ITU WEST LYING MIDSLOPE VEGETATION

APPENDIX 5

PLATE 5:Itu West midslope