CHARACTERIZATION, CLASSIFICATION AND SUITABILITY OF SELECTED SOILS OF AMASIRI, EBONYI STATE: A GEOGRAPHICAL INFORMATION SYSTEM APPROACH

BY

OBASI, SUNDAY NATHANIEL
(B. AGRIC. TECH)
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CERTIFICATION

This is to certify that this research work was carried out by Mr. Obasi, Nathaniel Sunday a postgraduate student of Soil Science and Technology Department, School of Agriculture and Agriculture Technology, Federal University of Technology Owerri.

……………………………… ………………………………
Dr. E. U. Onweremadu Date
(Project Supervisor)

………………………….. …………………………………
Prof. G. E. Osuji Date
(Head of Department)

………………………… …………………………………….
Prof. C. D. Okereke Date
(Dean Post Graduate School)

……………………………… ……………………………………
Prof. C. A. Igwe Date
(External Examiner)

DEDICATION

I dedicate this work to my late mother: Mrs. Betsy Obasi for bringing me up in the fear of the lord. May her soul rest in perfect peace

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ABSTRACT

The study was carried out between October – November 2008 and aimed at applying Geographical Information System (GIS) approach in characterizing, classifying and making suitability recommendations of soils in Ohia Nekechi within Amasiri area, Afikpo north, Ebonyi State. This study site was identified in a farmland consisting of a toposequence some meters away from Okposi road, Amasiri. A transect was cut across the toposequence revealing its North facing and the South facing slopes as well as the three major crops commonly grown in the farmland; cassava, rice and yam. Three pedons were sunk on each side of the toposequence (North facing and South facing slopes) each representing the crest, midslope and footslope physiographic positions. Pedons were aligned along the transect at an inter-pedon distance of about 50m. Soil samples were collected from each of the pedons according to their horizonations while surface sampling was carried out on each of the crop based farmland. Samples collected were air-dried, crushed and sieved using 2-mm sieve and further subjected to physical, chemical analysis considering some selected parameters. Data generated from the analysis were subjected to coefficient of variation (CV) as well as analysis of variance (ANOVA) for the crop based soils and relationship among soil properties were estimated using correlation coefficient and test of levels of significance. Variations in soil parameters were as follow; percent sand was higher at the footslope (77.3, 80.5%), followed by crest (75.7, 76.8%) and then by midslope(73.8, 75.4%) of both NFS and SFS respectively at all physiographic positions. Percent organic matter was highest at the cassava plot (2.75%) when comparing the crop based soils and the surface horizons of the profiles. At the toposequence however, organic matter was higher at the surface of midslope(2.41%) at the NFS while at the surface of crest(1.28%) at the SFS. However, organic matter decreased down the profiles at all positions. Soil acidity ranged from strongly to moderately acidic (4.4-5.2). Exchangeable Ca^{2+} and Mg^{2+} were higher than Na^{+} and K^{+} in all physiographic positions. Percent base saturation decreased down the profile and increased down the slope in all the positions while Al^{3+} saturation was almost a direct opposite to percent base saturation except at the SF midslope where Percent Al^{3+} saturation was higher than that at the crest. There was a low variation in the particle size fractions especially sand in all physiographic positions, moderate to high variation in organic matter while base saturation varied

highly in all physiographic positions except at the footslopes where it indicated moderate variation. Soil pH VS OM, pH VS Avail. P, OM VS Avail P, indicated significant positive correlation (p=0.01 and p=0.05) while OM showed a negative and insignificant correlation with ECEC at the crest of NF and SF slopes. At the NF midslope, there was positive and significant (p=0.001, p=0.01 and p=0.05) correlation between soil parameters considered. However, at this physiographic position OM indicated negative and insignificant correlation with ECEC. At the SF midslope, OM had positive and significant (p=0.001) correlation with total N and Avail. P, while p=0.05 with ECEC. The NF footslope recorded non significant correlations with soil parameters while at the SF footslope, total N correlated significantly (p=0.05) positively with pH and (p=0.01) with OM, OM was p=0.05 with Avail. P. The crop bases soils indicated significant (p=0.01 and p=0.05) variations. The GPS was used to determine the geographical coordinates and also in generating data used to determine the Digital Elevation Modeling (DEM) of the study area. The DEM revealed both gentle and steep sloppy surfaces in the area but the place seems to have more steep slopes. This otherwise explains the reason why the place could be regarded as a place with rough terrain. The valley bottoms as shown by the DEM could be said to be suitable for rice and other crops which tolerate aquic conditions due to its submerged state. The toposequence can be suitable for cassava and yam which does not require much water condition while other geologic feature at the site such as rocks have been subjected to quarrying. The soils fall within Class II soils since they have some limitations that reduce the choice of plants or require moderate conservation practices while non agricultural activity such as quarrying was also evident. The DEM also reveals the pathway of Cross river which flows through valleys and most of the roads (both secondary and main roads) pass through valleys. Soils were classified as typic kandiudults (Plinthic Acrisol) at pedons A, D and E while in pedons B and F as typic kandiudalfs (Albic Luvisol) and Pedon C was classified as typic Kandiaqualfs (Gleyic Luvisols).

CHAPTER ONE

1.0 INTRODUCTION

Soil frequently occurs in a well defined and fairly regular sequence (Smyth and Montgomery, 1962). These sequences have been referred to as toposequence (Moormam 1981, Okusami *et al.,* 1985). 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 on a toposequence as well as the spatial distribution of the toposequence itself has considerable influence on the land use pattern of an area (Nuga *et al.,* 2008).

The greatest problem of agricultural development in Nigeria is among others, poor knowledge of land use management as well as suitability of our soils. However for better utilization of the soil, its characteristics and properties must be known (Unamba-Oparah 1985).

Human activities on land vary and may have differential impact on it (Onweremadu *et al.,* 2007a). Indeed, the sustainable use of inland valley soils for agricultural production is conceivably one way of revealing some of the current pressures on the natural resource base of upland agro-ecosystems (Izac et al., 1990, Eshett 1993). Farmers often cultivate the entire toposequence. Some however, restrict their cultivation to only a section of it. Eshett (1985) observed in South-eastern Nigeria, yam (Dioscorea Sp.) based cropping systems in the upper, middle and lower slopes of the toposequence, while the valleys are continuously used for rice (Oryza sativa) cultivation.

Stoop (1987), observed a high degree of variability in crops stands and low average productivity on the West African landscape and noted that crop field tends to decrease 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.

Onweremadu *et at.,* (2007b), noted that characterization and classification of soils of any given location help in generating soil and soil-related data which are useful in sustained use of soil resource. Appropriate and proper use of an area of land depends upon the characteristic of such a land. There is therefore need to characterize soils and classify them in a manner that will ease communication and transfer of knowledge about such soils to farmers and other stakeholders (Nuga *et al.,* 2008).

Geographical Information System (GIS) Approach to soil classification and mapping involves operations of data transformation into use- specific information, previously done via analogue system, can now be executed by computer-assisted procedures (Onweremadu, 2006). Automated operations concern soil classification, statistical treatment of soil attributes, selection of modal profiles, establishment of ranges of variation of soil properties, labeling map units, building soil legends, soil interpretations and land evaluation.

This involves the design of a soil database and rule base within the frame of geographic information, system (GIS), allowing for the combination of spatial and non-spatial attributes, data interpretation, 'spatial modeling and information display (Zinck and Valenzuela,1990).

A soil (geographic) database is a tool allowing the capture, storage, processing and display of soil data and information generated by soil survey operations from original sources. Quality control of primary data is therefore a major concern to guarantee reliable implementation of interpreted soil information for land use planning. The use of a soil database coupled with a, GIS, however considerably enhances the possibilities to satisfy Users needs through its capabilities of data processing, automated data interpretation, map overlying, and development of decision alternatives (Zinck and Valenzuela, 1990) The major objective of this study is to investigate soils properties for appropriate land use recommendations in Amasiri, Ebonyi State.

Specific objectives of the study are to:

- Characterize soils of the study area for the purpose of classifying them using USDA, Soil Taxonomy and FAO/UNESCO Legend.
- Determine levels of suitability for existing land uses using existing standards
- Apply Geographical Information System on generated soil data for the purpose of assessing their geospatial distribution

CHAPTER TWO

2.0 LITERATURE REVIEW

Soil is a natural body consisting of layers or horizons of minerals and organic constituent of variable thickness which differ from the parent material in the morphological, physical and chemical properties as well as their biological characteristics (Unamba-Oparah *et al.* 1987). There are a large number of different soils, reflecting different kinds and degrees of soil forming factors and their combinations (Brady and Weil 1999). Climate usually influences the variation in soil characteristics but where the land includes significant hills or toposequence, rainfall and temperature may differ greatly over distances (Brady and Weil 1999).

Brady and Weil (2005) noted that most small scale variations involve changes in topography. This is a very important factor when reference is made to variability in soil properties across landscape and profile characteristics. For any soil properties, variation in toposequence can be related primarily to differences in a particular factor of soil formation such as topography and drainage (Donahue *et al.* 1990). Donahue *et al.* (1990) also pointed out the range of soils according to changes in relief and topography across a landscape; patterns of soil with well drained, moderately drained and poorly drained characteristics were found.

Where all the soils in a toposequence have developed from the same parent material, the set of soils that differ on the basis of drainage or due to relief differentiation is termed a Catena (Brady and Weil 1999). The various soils in a Catena can be differentiated by colour and this helps in relating the soil to a given a region. In the tropical Catena, the colours varies from moderate to poorly drained dark gray soils at the middle and lower slope indicating an increased degree of iron hydration and a downslope seeping of moisture from the upperslope to the well drained dusky red soil at the upperslope indicating the presence of non hydrated iron oxide in the soil (Donahue et al., 1990; Brady and Weil 1999). Thus, differences in toposequence reflects gradual changes in in colour frequency as seen in Catena as a result of topographic variability.

2.1 Agriculture in Southeastern Nigeria

Farmers in the Southeastern Nigeria, like others in the humid tropical zones, initially practiced shifting cultivation with fallow periods that generally exceeded 10 years. In those early years of usage, this practice adequately sustained their peasant economics. Today, due to increasing pressure on rather static land resources as a result of steeply rising population, the fallow periods have been on the decrease, with attendant decrease in soil productivity (Eshett, 1991).

The farmers utilize the land on the bases of perceived productivities. Soils of the humid and sub humid tropics frequently occur in toposequences with at least three recognizable land types. These are crest, midslope and valley bottom lands. Soils occurring in such sequences have been identifies and described in parts of South-eastern Nigeria by Eshett (1985). Soils in the crest and middle slope positions of the toposequence were found to be porous, well-drained, and of sand to sandy loam texture (Onweremadu, *et al.* 2007a).

2.2 Characteristics of Tropical soils

Soils of humid and sub humid tropics are products of their environment. That is to say that their characteristics are determined by the interactions of five factors of soil formation, namely- climate, vegetation, topography, parent material, human influence and time (Eshett, 1996).

Most of the soils within this region are coarse-textured porous, deep with a friable surface horizon which is usually underlain by a clay-enriched subsoil (argillic horizon) or plinthite. The high temperature, rainfall and relative humidity conditions (Onweremadu, 2006) result in intensive leaching and weathering of the soils with the consequent development of strong acidity (Eshett, 1996). Such acidity conditions constitute a threat to productivity status of such soils.

Soils of the humid and sub-humid tropics have predominantly poor structural characteristics. This is largely due to the inherently low levels of organic matter, calcium and other components whose principal functions is to bind the soil particles together into stable aggregates. Aubest and Taverina (1972), in their work of humid tropics characterized the soils as highly weathered, low in cation exchange capacity (CEC) and well drained.

Several works have shown that kaolinite is the predominant mineral in the clay fraction of these soils. Other minerals like hematite, quartz, goethite, halloysite, and mica are also present in varying proportions. Montmorillonites may be found in the lowland soils. The mineral assemblage of most low activity clay alfisols and ultisols that characterize the humid/ sub-humid environment suggest an advanced stage of weathering. Another important feature of the soils of the humid and sub-humid tropics is the abundance of free iron oxides that may be leached out of the profiles in the form of mottles or concretions. They also occur as coatings on the surfaces of silicate clays (Eshett, 1996).

2.3 Soil Properties

Soil quality reflects a combination of physical, chemical properties and biological properties which measures the ability of the soil to carry out particular ecological functions (Brady and Weil, 1999). Some of these properties are relatively unchangeable, inherent properties that help define a particular soil type, example, soil textural and mineralogical makeup while others such as structure and organic matter can be significantly changed by management (Brady and Weil, 1999).

2.3.1 Soil Physical Properties

Soil Texture

Ibanga, (2006), noted that soil texture conveys an idea of size distribution of particles and indicate the general nature of soil physical properties which is considered very important in soil management and characterization. Soil texture describes the relative proportion of the various primary particles such as; sand (<2 mm > 0.5 mm), silt (<0.5 mm > 0.2 mm), clay (<0.02 mm) or the other group size smaller than gravel (<2 mm in diameter) present in the soil (Donahue et al.,1990). The soil texture is determined in the field using the feel method or the textural triangle or in the laboratory using the pipette or sedimentation method

(Brady and Weil 1999).

According to Irvin, (1996) as water empties from a river slope, its velocity starts to decrease. The larger size particles like sand begin to sediment first from the suspension. Fine clay particles can be further transported away from the foot of the slope before being deposited. Consequently, coarse textured soils tend to be found near the base of the toposequence and fine textured soils located further away from the base of the slope. Correlated differences in soil texture can be distributed to the differences in parent materials and to the topography (Tomer and Anderson, 1995).

Soil Structure

Soil structure relates to the arrangement of primary soils particles into groupings called aggregates or peds (Donahue et al., 1990). This defines the patterns of pores and peds which greatly influences water movement, heat transfer, aeration and porosity in soils (Brady and Weil, 1999). The soil structure is characterized in terms of shapes, of spheroids, platy, prismatic and blocky.

At the crest there is the formation of coarse textured soils as a result of less organic materials due to surface run off and this in turn reduces the microbial activities and organic carbon content of the upland (Pennock et al., 1994). Fine textured soils are deposited at the valley bottom as a result of erosion. This increases the aggregation of soil structure and the total porosity because large pores occur between aggregates allowing penetration of root and movement of water and air (Pennock and De Jong, 1987).

Soil Colour

Soil Colour in some case is a diagnostic criterion for classification and can tell us a great deal about a soil (Brady and Weil, 1999). This is therefore extensively used in classifying and distinguishing the different horizons of a soil profile. Because of the importance of soil colour in classification and interpretation, a standard system for accurate colour description has been developed using Munsell colour charts. Each colour is described by a 3 component of colours; the hue (usually redness or yellowness), the croma (intensity or brightness) and the value (lightness and darkness) (Brady and Weil 2005)

Soil colour may vary from place to place in the landscape as when adjacent soils have defferring surface horizon colour. Colours also typically change with depth through the various layers within a soil profile and can provide extremely valuable insights into the hydrologic regime or drainage status of a soil (Foth, 1990).

Porosity

Soil porosity is described as an index of the relative pore volume or the volume fraction of the pores or the volume of total pore space (Foth, 1984). It is a function of the size, shape and orientation of the peds. According to Brady and Weil (2005), coarse textured soils have fewer pores than fine textures soils, though the main size of individual pore is greater in the former than the later. This implies that the upland of the toposequence, fine clay sized particles are transported and deposited at the foot slope and this leads to the formation of fine textured soils (Irvin, 1996) which increases the crop performance through increase in porosity.

But coarse textured soils the pore spaces which results in reduction in the moisture status and water holding capacity of the soil (Forth, 1990).

Consistence

This describes the degree of resistance of a soil mass to deformation or rupture when force is applied (Donahue *et al.* 1990). This is determined by cohesive and adhesive properties of the entire soil mass and deals with the nature of the forces between particles. Brady and Weil, (1999) describes consistency for 3 moisture levels; wet, moist and dry and this defines the characteristics of a particular soil's ability to maintain its structure under various conditions.

Soil Moisture Content

This measures the variation in the amount of water in a unit mass or volume of soil (Brady and Weil, 1999). Numerous soil properties depend upon water content; consistency, plasticity, soil strength, compatibility, penetrability, swelling and shrinkage of clays (Wild, 1993). Soil moisture enhances root development, activities of micro organisms and affects the chemical state of the soil as in oxidation-reduction potential (Alexander, 1977)

Irvin, (1996) noted that attributes of topography and vegetative cover affect soil moisture by governing the proportions of surface run off to infiltration. Soils with impermeable sub-soils and those developing on slopes may show appreciable lateral surface flow. Thus, at the crest, soils drain freely with a considerable water table. As the drainability decreases, the oxidized soil profile with its orange red colour due to ferric oxides is transformed into the mottled and grayed profile of a reduced soil. This describes the soil's hydrologic sequence.

2.3.1.1 Topography

McCraken and Southard, (1997) defined topography as the earth's surface contour. This influences soil formation and its corresponding characteristics primarily through its associated water and temperature relations (Donahue et al., 1990). Topography influences the total amount of rain or water which finds its way into the soil and this influences the transformation of soil materials with differences existing between the sloping and the low lying soils (Brady and Weil 2005).

Effect of Topography on yield

Yield variability is partly caused by soil variability and varying topographic features of the field. Although yield is a function of a host of factors, including soil properties, field topography, climate, biological factors, and management, in certain years as much as 60% or even more of the yield variability can be explained by a combination of soil properties and topographic features (Yang et al., 1998). Many soil properties such as available water, texture, bulk density, clay content (Miller et al., 1988), organic C (Wright et al., 1990), pH (Moore et al., 1993), subsoil acidity (Wright et al., 1990), fertility, and soil thickness (Kreznor et al., 1989) have been found to affect crop yield.

Crop growth and yield are also affected by field landscape features. Previous studies have looked closely at elevation, slope steepness, slope aspect, and surface curvature (Ciha, 1984; Daniels et al., 1985; Stone et al., 1985; Simmons et al., 1989; Yang et al., 1998; Kravchenko and Bullock, 2000). Field topography can have a direct effect on crop growth and yield by redirecting and changing soil water availability and an indirect effect through its influence on distribution of certain soil chemical and physical properties such as organic matter content, base saturation, soil temperature, and particle size distribution (Franzmeier *et al*., 1969; Bennett et al., 1972; Stone et al., 1985).

Walker et al. (1968) investigated a series of soil properties such as A horizon thickness, distance from surface to mottles, and distance to CO_3 and Mn segregations. They concluded that slope position was strongly related to these soil properties. In addition, they reported that topographic features account for 49 to 84% of the yield variability in some areas of the field. Higher wheat yields were generally found at lower elevation and gentle slope positions. Lower wheat yields were found at higher elevation levels and steep slope positions.

However, quite different results were presented in previous studies that found different relationship patterns between soil properties and topographic features across locations and years. Furthermore, the relationship of topographic features to yield can be even more complicated by extreme weather conditions (Simmons et al., 1989; Kravchenko and Bullock, 2000). Fiez et al. (1994) pointed out that due to the inconsistent effect of topographic features on crop yield, research was needed to determine and investigate the soil factors that vary with field topography. This would result in a better understanding of yield variability under varying soil conditions and field topography.

2.3.2 Chemical Properties

The knowledge of soil chemical characteristics helps in the improvement of soil production status. This provides information on the improvement of soil's available nutrients, stabilizing the soil, avoid toxicity of elements, enhance microbial population, reduce soil and water pollution (Donahue *et al.*, 1990). The chemical properties of the soil includes organic carbon content, cation exchangeable capacity (CEC), exchangeable base saturation, exchangeable acidity, available nutrient, soil pH and other biological transformation (Brady and Weil, 1999).

Soil properties exhibit variability with topographic organization due to aspect- landscape position and difference in elevation and slope structure (Birkeland, 1999). In the slope aspect, topographic effects occur on the absorbance of solar energy in a given landscape. In the northern hemisphere, south-facing slopes are more perpendicular to the sun's rays and thereby commonly lower in moisture than the north-facing counterparts and consequently soils on the south slopes tend to be lower in organic matter and are not so deeply weathered (Brady and Weil, 1999).

Soils on steep terrain have relatively shallow, poorly differentiated soil profiles compared to nearby soils on more level terrain. This encourages erosion of the surface layers and allows less rainfall to enter the soil before running off, thus preventing soil formation from getting very far ahead of soil destruction (Brady and Weil 2005). In many landscapes, topography reflects the distribution of nutrient residues of colluvial and alluvial parent materials with residual material on the upper slope, colluviums filling the foot slope (McCraken and Southard, 1997).

Topographic position affects the build up and deposition of soluble salts at a given location. Dissolved salts from crest soils move on the surface and through the underground water table to the lower lying areas and give rise to accumulation to toxic levels and deficiencies of the micro-nutrients (Brady and Weil, 1999).

Cation exchange is the exchange between a cation in solution and another cation on the surface of any surface-active material such as clay or organic matter (Donahue *et al*., 1990). The sum total of Exhangeable cations that a soil can adsorb refers to its cation exchange capacity (Brady and Weil 1999). Cation exchange capacity of a soil is a measure of the negative or positive charged nutrient element it can hold or adsorb at a given pH (Unamba-Oparah *et al.* 1987).

The CEC of a given soil horizon is determined by the relative amounts of different colloids in that soil. This is expressed in terms of moles of positive charge adsorbed per unit mass or as melliequivalent per 100g of soil or recently as centimole (cmol) of positive or negative charge per kilogram of soil (Brady and Weil, 1999). The cation exchange capacity bases of a soil is the some of the exchangeable bases (Ca, Mg, K, Na) and the exchangeable acidity (Al and H) (Foth,1990). Cation exchange capacity is also a measure of the potential fertility of any soil because it shows the mineral constituent of soils.

The cation exchange capacity of most soils increases with pH. At very low pH values, the cation exchange capacity is also generally low. Silver et al., (1994) noted a down slope increase in concentration of exchanbeable bases from the crest to the foot slope as a result of leaching.

Soil pH also referred to as Soil reaction measures the degree of acidity or alkalinity effect on soil properties such as; chemical, physical and biological (Brady and Weil, 1999). pH is defined as the negative logarithm to base ten of the hydrogen ion activity in the soil (Donahue *et al.,* 1990. Soils can be acidic, neutral or basic in a range of 0 (extremely acidic) to 14 (extremely basic) and measures in pH units with a satisfactory neutral range of 5.5-7.5 (Leonard, 1986).

Soil pH to a very large extent controls plant nutrient availability and microbial reactions in soils (Alexander, 1977). Brady and Weil (1999), noted that soil pH regulates the solubility and availability of most elements. At high soil pH, there is increased availability of micro nutrients and fixation of macro nutrients and vice versa.

Leonard (1986) observed that pH is affected by climate as it tends to stimulate either acidity or alkalinity. In humid regions, soils tend to be quite acidic because of sufficient rainfall to leach out much of the base froming cations leaving the exchangeable complex dominated by Al and H ions unlike in the low rainfall areas where leaching is not very intense and results in neutral to alkaline condition (Donahue *et al.* 1990).

Silver et al., (1994) also reported that soil pH increased from crest to foot slope; i.e. from crest acidity to foot slope alkalinity.

2.4 Characterization and Management of Tropical Soils

Tropical soils have many peculiarities most of which are basically related to geology and climate and to the sequence of soil development (Foth, 1990). Unamba-Oparah *et al.* 1987) noted the following about tropical soils compared to their temperate counterpart:

- Ionization of water in the tropics is 4 times as high as at 10^{o}C in the temperate
- The silica content is 8 times as soluble in the tropics as in temperate soils
- Solution of material proceeds more quickly in the tropics than temperate
- Less CO_2 penetrates the soil in the tropics than in the temperate
- Soil water is less viscous in the tropics than in the temperate
- Water penetrates deeper into soils of the tropics than temperate and as this water penetrates, it carries organic acids along
- Rubification as a result of oxidation of ions is greater in the tropics than temperate soils

The soils therefore are more susceptible to runoff and erosion losses (Donahue et al 1990). The ability of soils to retain water and supply it to plant becomes a critical factor in tropical agriculture. Characteristically, tropical soils are coarse textured and low in organic, base-exchange properties and natural fertility (Kang and Juo, 1983).

Organic matter accumulation is often favored at the bottom of hills. There are two reasons for this accumulation: conditions are wetter than at mid-or upper-slope positions, and organic matter is transported to the lowest point in the landscape through runoff and erosion. Similarly, soil organic matter levels are higher on north-facing slopes (in the Northern hemisphere) compared with south facing slopes (and the other way around in the Southern hemisphere) because temperatures are lower (Quideau, 2002). However, techniques which promote sustainable soil management such as organic matter maintenance, fertility, soil management and nutrient availability maintenance should be adopted.

2.4.1. Soil Organic Matter Maintenance

Soil organic matter is said to be the totality of organic matter in soil and also includes organisms that live in the soil, soil biomass, although they usually account for less than 5 percent of the soil organic carbon (Jenkinson, 1981). Arable top soils commonly contain 1-3 percent organic matter with grassland and forest soils containing somewhat more, particularly if poorly drained. This organic matter consists of a whole series of products which ranges from decayed plants and animal tissues through ephemeral products of decomposition to fairly stable brown to black material bearing no trace of anatomical structure from which it was derived; this later material is normally referred to as humus (Russel1988; Obasi 2005).

Donahue et al. (1990) defined soil humus as a complex array of substances left after extensive chemical and biological breakdown of soil organic matter. Organic matter is the nitrogen reservoir (90-95%), it furnishes large portion of the phosphorus and sulfur, it protects soil against erosion, supplies cementing substances for desirable aggregate formation and it loosens up the soil proving better aeration and water movement (Brady and Weil, 1999).

A variety of properties have been geared towards organic matter enhancement through organic farming. Wild, (1993) defined organic farming as farming without the use of synthetic chemicals but rely on biological processes for agro production. Leguminous crop production and organic residue addition are used to maintain the soil carbon-nitrogen ratio. This however provides the requirements of soil which are primary agents of soil maintenance as well as structural development.

The use of ground rock phosphate as against water soluble phosphate fertilizer for soil amendments has been emphasized by Foth (1990). This is due to its many beneficial qualities as it forms from natural destruction by rain drops and the resultant erosion damages. Also, it has the relative efficiency of recycling nutrients and its potential for organic matter accumulation. Through shifting cultivation, the nutrients are conserved by eliminating these practices which destroy the soil organic matter (Wild 1993).

2.5 Soils and their Classification

According to Baldwin*, et al.* (1938) soil classification usually means criteria based on soil morphology in addition to characteristics developed during soil formation. Criteria are designed to guide choices in land use and soil management. As indicated, this is a hierarchical system that is a hybrid of both natural and objective criteria. USDA soil taxonomy provides the core criteria for differentiating soil map units. Soil taxonomy based soil map units are additionally sorted into classes based on technical classification systems. Land Capability Classes, hydric soil, and prime farmland are some examples.

Scientists have developed different systems of soil classification to group soils of similar properties in one class, allowing them to exchange information on soils found in different areas. Soil classification also helps in determining the best possible use and management of soils. Although many soil classification systems exist; however, two systems are widely used: The USDA Soil Taxonomy and the FAO/UNESCO legend. The French system (ORSTROM) is also commonly used in France and in Francophone Africa (FAO, 1983).

The classification of soils starts with examination of soil profiles. Morphologically, soils are composed of a series of horizons. Soil horizons are layers of different appearance, thickness, and properties which have arisen by the action of various soil-forming processes. The horizons are normally parallel to the surface. Collectively, the horizons make up what is called the soil profile or soil "pedon". A soil profile is defined as a vertical section of the soil to expose layering. Individual soils have one or more of these horizons. Very young soils may not yet have started the soil horizonization process.

In soil classification, the item to be classified is the soil profile. The classification or study of the entire profile consists of recognizing and naming the horizons which make up the profile. In the study of soil profiles, sub-soil horizons are given greater emphasis than surface horizons which are frequently changed by human activity to such an extent that they bear hardly any relationship with genetic process.

2.5.1 The History of Soil Classification

The properties and management of soil may be remembered if the soils are classified according to a definite system. A genetic classification was suggested in about 1880 by a Russian Scientist by name Dokuchaev; it has been further developed by European and American researchers. This system is based on the theory that each soil has a definite morphology that is related to a particular combination of soil forming factors. This system reached its maximum development in 1949 and was in primary use especially in the United States until 1960.

In 1960, the United States Department of Agriculture (USDA) published Soil Classification: a Comprehensive System. Tin's classification system places a major emphasis on soil morphology and gives less emphasis to genesis or soil forming factors, as compared to previous systems. "Soil classification: a Comprehensive system" has been improved since 1960 and was re-published as Soil Taxonomy in 1975 by (Soil Survey Staff, 1975).

Brady and Weil (1999) provided a hierarchical grouping of natural bodies. They include soil properties that can be objectively observed or measured while the other employed nomenclature which gives a definite connotation of the major characteristics of the soil in question. Soil Survey; (1993) presented the basic elements of soil classification as chemical, physical and biological properties. Others are moisture and temperature status, colour, texture and structure of the soil etc. These pieces of information make classification more objective.

In 1974, the food and Agricultural Organization (FAO) joined the Americans to correlate the world soils, developed a classification called World Soil Classification which offers useful generalizations about soil pedogenesis in relation to the interaction with the main soil forming factors. It was published in the form of UNESCO Soil Map of the World. Many of the names offered in that classification are known in many countries and so have similar meanings. Wikipedia (2003) published FAO Soil Units, which formed 26 soil classes. They include Acrisols, Andosols, Arenosols, Cambisols, Chernozems, Gleysols, Ferralsols, Fluviso!s/ Vertisols/ Solonetz and others. The most interesting thing about the FAO Soil Units is that it accommodates all the bases of field descriptions

2.5.2 Types of Soil Classification

Soil classification generally refers to Taxonomic Classification for specific practical purposes such as suitability of crops, ability to support foundation of building and suitability for airfield construction (Brady and Weil, 2005). Taxonomic Classifications of the soil exist according to each country of the world. Brady and Weil, (2005) listed the following classification systems;

i. The Russian Classification System.
ii. Commission for Technical Co-operation in Africa (CTCA)
iii. The Brazilian Classification System
iv. The French Classification System
v. The British Classification System
vi. The South Africa and Ghana Soil Classification
vii. The FAO/UNESCO World Soil Legend
viii. The American Classification System (Soil Taxonomy)

Avery (1980), noted that the criteria for classification varies among the different countries of the world. In Russia, classification is based on soil genesis or soil formation. In America, it is based on the properties of the soil as ascertained from both field and laboratory analysis. The British Classification System is based on both the genesis and morphology of the soil while the Brazilian Classification System is based on the texture and colour as well as the moisture and temperature regimes. However, in the proposed National Classification for Nigeria, properties utilized are; particle size distribution, mineralogical classes as well as soil reaction. This systems has made it possible for countries of the world to know how to classify and characterize their soils for planning purposes and executions for crop production.

2.5.3 The USDA soil taxonomy

The Soil Taxonomy developed since the early 1950's is the most comprehensive soil classification system in the world, developed with international cooperation it is sometimes described as the best system so far. However, for use with the soils of the tropics, the system would need continuous improvement.

2.5.3.1 Hierarchy of Categories in the Soil Taxonomy

There are six levels in the hierarchy of categories: Orders (the highest category), suborders, great groups, subgroups, families and series (the lowest category) (Soil Survey Staff, 1978).

Orders

There are twelve orders, differentiated on gross morphological features by the presence or absence of diagnostic horizons or features which show the dominant set of soil-forming processes that have taken place. The twelve orders and their major characteristics are shown in Table 1. The occurrence of the major soils in the humid and subhumid tropics is shown in Table 2.

Suborders

It is the next level of generalization. It permits more statements to be made about a given soil. In addition to morphological characteristics other soil properties are used to classify the soil. The suborder focuses on genetic homogeneity like wetness or other climatic factors. There are 47 suborders within the 12 orders. The names of the suborders consist of two syllables. The first connotes the diagnostics properties; the second is the formative element from the soil order name. For example, an Ustalf is an alfisol with an ustic moisture regime (associated with sub-humid climates).

Great groups

The great group permits more specific statements about a given soil as it notes the arrangement of the soil horizons. A total of 230 great groups (140 of which occur in the tropics) have been defined for the 47 suborders. The name of a great group consists of the name of the suborder and a prefix suggesting diagnostic properties. For example, a Plinthustalf is an ustalf that has developed plinthite in the profile. Plinthite development is selected as the important property and so forms the prefix for the great group name.

Table 1. Brief descriptions of the twelve soil orders according to Soil Taxonomy

SOIL ORDERS	DESCRIPTION
ALFISOLS	- Soils with a clayey B horizon and exchangeable cation (Ca + Mg + K + Na) saturation greater than 35% calculated from NH_4OAC-CEC at pH 7.
ANDISOLS	-The unique property of andisols is a dominance of Al- humus complexes that result from weathering of minerals. Most andisols formed in volcanic or vulcaniclastic minerals, rich in P retention, available water and CEC.
ULTISOLS	- Soils with a clayey B horizon and base saturation less than 35%. They are acidic, leached soils from humid areas of the tropics and subtropics.
OXISOLS	- Oxisols are strongly weathered soils but have very little variation in texture with depth. Some strongly weathered, red, deep, porous oxisols contain large amounts of clay-sized Fe and Al oxides.
VERTISOLS	- Dark clay soils containing large amounts of swelling clay minerals (smectite). The soils crack widely during the dry season and become very sticky in the wet season.
MOLLISOLS	- Prairie soils formed from colluvial materials with dark surface horizon and base saturation greater than 35%, dominating in exchangeable Ca.
INCEPTISOLS	- Young soils with limited profile development. They are mostly formed from colluvial and alluvial materials. Soils derived from volcanic ash are considered a special group of Inceptisols, presently classified under the Andept suborder.
GELISOLS	- Presence of permafrost, and soil features associated with freezing and thawing. e.g. irregular or broken horizons and incorporation of organic materials in the lower horizons
ENTISOLS	- Soils with little or no horizon development in the profile. They are mostly derived from alluvial materials.
ARIDISOLS	- Soils of arid region, such as desert soils. Some are saline.
SPODOSOLS	- Soils with a bleached surface layer (A2 horizon) and an alluvial accumulation of sesquioxides and organic matter in the B horizon. These soils are mostly formed under humid conditions and coniferous forest in the temperate region.
HISTOSOLS	- Soils rich in organic matter such as peat and muck.

Source: Soil Survey Staff, 1999

Table 2. Occurrence of major soils in the Humid and Subhumid Tropics

Classification(USDA)	Occurrence
1. Alfisols	Savanna and drier forest zones
2. Vertisols	Alluvial plains in savanna
3. Ultisols	Rain forest zone and derived savanna
4. Oxisols	Rain forest and savanna
5. Inceptisols	All regions
6. Entisols	Limited and localized distribution relating to present and past volcanic activities

Source: Soil Survey Staff, 1978

Subgroups

There are three kinds of subgroups:

1. The typical subgroup which represents the central concept of the great group, for example Typic Paleustalfs.
2. Intergrades are transitional forms to other orders, suborders or great groups, for example Aridic Paleustalfs or Oxic Paleustalfs.
3. Extragrades have some properties which are not representative of the great group but do not indicate transitions, for example, Petrocalcic Paleustalf.

Families

The grouping of soils within families is based on the presence or absence of physical and chemical properties important for plant growth and may not be indicative of any particular process. The properties include particle size distribution and mineralogy beneath the plough layer, temperature regime, and thickness of rooting zone. Typical family names are clayey, kaolinitic, isohyperthermic, etc. There are thousands of families.

Series

The soil series is the lowest category. It is a grouping of soil individuals on the basis of narrowly defined properties, relating to kind and arrangement of horizons; colour, texture, structure, consistence and reaction of horizons; chemical and mineralogical properties of the horizons. The soil series are given local place names following the earlier practice in the old systems in naming soil series. There are tens of thousands of series.

1.3.2 Distribution of USDA - Classified Soils in the Tropics

According to the Soil Survey Staff, (2003) Oxisols are the most abundant soils in the humid and sub-humid tropics covering about 35 percent of the land area. Ultisols are the second most abundant, covering an estimated 28 percent of the region. About half of the Ultisols and 60 percent of the Oxisols are located in humid and perhumid tropical Africa and Asia. In tropical Africa, they are abundant in the eastern Congo basin bordering the lake region; in the forested zones of Sierra Leone; in Ivory Coast; in parts of Liberia; and in the forested coastal strip from Ivory Coast to Cameroon.

The **Alfisols**, which have high to moderate fertility, cover a smaller area of the humid tropics. In west Africa they are found in Ivory Coast, Ghana, Togo, Benin, Nigeria and Cameroon. They are, however, the most abundant soils in Africa's subhumid and semi-arid zones, covering about one third of these regions. The Alfisols are widely distributed in the subhumid and semi-arid tropical regions of Africa, including large areas in western, eastern, central, and southeastern Africa.

Table 3. Geographical distribution of soils in the humid and semi-arid tropics (millions of hectares)

Soil order	Tropical Africa	Tropical Asia	Tropical America	Total	Percent
Humid Tropics[1]					
Oxisols	179	14	332	525	35
Ultisols	69	131	213	413	28
Alfisols	21	15	18	54	4
Others	176	219	103	498	33
Total	445	379	666	1490	100
Semi-arid Tropics[2]					
Alfisols	466	121	107	694	33
Ultisols	24	20	8	52	1
Others	972	178	198	1348	66
Total	1462	319	313	2094	100

[1] *Data from NAP (1982).*

[2] *Data adapted from Kampen and Burford (1980). Part of the subhumid tropics is included.*

2.5.4 The FAO/UNESCO system

According to (FAO, 1974), the FAO/UNESCO system was devised more as a tool for the preparation of a small-scale soil map of the world than a comprehensive system of soil classification. The map shows only the presence of major soils, being associations of many soils combined in general units. The legend of the soil map of the world lists 106 units classified into 26 groupings. The soil units correspond roughly to great groups from the USDA Soil Taxonomy, while larger main grouping are similar to the USDA soil suborder. Table 4 shows the rough correspondence between the Soil Taxonomy and the FAO/UNESCO system.

In 1986 FAO published a soil map of Africa following the FAO/UNESCO system of soil classification. In this map, all the soils of Africa have been grouped into 10 soil associations (Figure 3). Though it is not very precise, the map provides an overview of the soil resources of the continent of the ten major associations, the desert and shallow soil associations (comprising Yermosols, Xerosols and Luvisols) occupy about one-third of Africa's land area. However, only a part of the area occupied by these associations falls in the tropics

Table 4. Correlation between systems of soil classification: the Soil Taxonomy, FAO/UNESCO legend

FAO/UNESCO	Soil Taxonomy*
Acrisols	Ultisols
Andosols	Andepts
Arenosols	Psamments
Cambisols	Tropepts
Ferralsols	Oxisols (Latosols)
Fluvisols	Fluvents (Alluvial soils)
Gleysols	Aquepts and Aquents (Aquic great groups of . Entisols, Inceptisols)
Histosols	Histosols
Lithosols	Lithic subgroups
Luvisols	Alfisols
Nitisols	Tropics, Rhodic great groups of Alfisols and . Ultisols
Podzols	Spodosols
Regosols	Orthents, Psamments
Vertisols	Vertisols

* = Name in old USDA system.

Data from Ibanga, 2006

2.5.5 Characteristics of the major soils of the tropical Africa

The main characteristics of the soil orders were summarized briefly in Table 1. The following sections provide additional information on the properties and management of the most important soils in the humid and subhumid zones of tropical Africa.

Alfisols

The Alfisols are less leached and have lower acidity than Ultisols and Oxisols, but they exhibit high base saturation and their fertility is low to moderate. The Alfisols and associated soils support a wide variety of cereal crops (maize, rice, sorghum, millet), root and tuber crops (yam, cassava, cocoyam, sweet potato), and grain legumes (soybean, cowpeas, groundnuts, pigeon peas, chick peas).

The productivity of the Alfisols is limited mainly by their physical characteristics: They have low structural stability and are susceptible to surface crusting, soil compaction and erosion. They have low water retention capacity and are subject to drought (Lal, 1974, Kang and Juo, 1983). Deficiencies of N and P are common while deficiencies of K, Mg, S. Fe, and Zn occur under intensive cultivation (Kang and Fox, 1981; Cottenie et al., 1981). Because of their low buffering capacity, Alfisols acidify rapidly under continuous cultivation, particularly with the use of high rates of nitrogenous fertilizers (Kang and Juo, 1983).

However, (Kang and Fox 1981) documented the benefits from N. P. and K application for continuous crop production on the Alfisols in western Nigeria. With intensive cropping, N is the primary limiting nutrient, followed by P. Potassium is generally needed with long-term continuous cropping, particularly on soils derived from sedimentary rocks. The Alfisols and associated soils have low P-fixation and high residual effects from applied P. In addition, mycorrhiza symbiosis is common and effective on these soils particularly with root crops, resulting in a low P requirement for crop production.

Continuous cultivation and fertilizer application can significantly affect the properties of Alfisols and associated soils. Cropping, and in particular fertilizer application, reduces soil p^H, soil organic matter, and extractable cations. Lowering of soil p^H on the Alfisols can result in increased toxic levels of Al and Mn (Kang and Spain, 1986).

Ultisols and Oxisols

The Oxisols and especially the Ultisols are acidic, with low base saturation. Both soil orders commonly have multiple nutrient deficiencies (N. P. K, Ca and Zn), as shown by Kang and Juo (1983). Oxisols are highly weathered and leached, while Ultisols are susceptible to erosion and compaction. The poor productivity of these soils is due to their low capacity to provide nutrients to crops as well as their Al and Mn toxicity. Soils have medium to high P fixation.

The Ultisols and Oxisols support a lesser variety of food crops than Alfisols, being more suitable for tree crop production. Crops that do well on the Ultisols and Oxisols include some cereal crops (e.g., rice), root and tuber crops (cassava, yam, cocoyam, sweet potato), grain legumes (cowpeas, groundnuts). Plantains and bananas also do well. In traditional system, maize is grown only on newly cleared and burnt plots.

In many early studies, acid soils in the humid tropics were limed to neutral pH, with generally poor results due to nutrient imbalance. Following the finding in the 1950s that acid soils contain more exchangeable Al^3+ than H^+, primary consideration has been given to removal of toxic factors which limit plant growth. Research on acid soils in West Africa has confirmed these findings. Low lime rates are needed to reduce toxic levels of Al^3+ and application of 0.5 to 1.0 tons of lime per hectare was found to be adequate for highly acid soils (IITA, 1984). These soils are usually deficient in P as well. Rock phosphates can be used on unlimed acid soils as an inexpensive and efficient way of supplying P to acid-tolerant crops

2.5.6 Classification of Nigerian Soils

The first work aimed at the taxonomic classification of Nigerian Soils was carried out by Vine (1954) who divided the soils into three broad zones which were further divided into 16 soil groups based on differences in mechanical composition and organic matter content (Ojanuga and Awojuola, 1971). Vine further defined “Soil fasees” roughly equivalent to families at the honest level of his classification system. He divided the soils of Nigeria into 27 “fasees” which he grouped together into three separate zones of latosol, based on the degree of leaching and human content of the profile (Ojo-Afere and Oladimeji, (1977).

Ohaeri (1961) recognized a wide level of coastal plain in it. Less well drained part, the delta; the coastal plain is connected with the sea by a large number of creeks. Jungerius and Leveli (1964), studies the clay mineralogy of soils over the sedimentary rocks in Eastern Nigeria over and observed that the soils in this area derived most of the clay mineral from the underlying sedimentary rocks. Kaolinite is dominant in all the soils.

Jungerius (1964), in his work observed that the coastal plain sands are the youngest formation, which covers the wide plain extending from Owerri southward to the coastal areas. Ogunkunle (1995) noted that the soil classification in Nigeria at the soil series level differ between regions. The implication of this according to him is the hindrance to direct transfer of newly developed technology.

It is however true that soil survey started in Nigeria with Vine (1954) a more comprehensive work with the production of soil map was done by Smith and Montgomery (1962). The FDLAR (1985) exercise resulted in the grouping of Nigerian soil into 58 soil groups showing different characteristics associated features of the soil. It is on the basis that soil classification was done in Nigeria using soil taxonomy and FAO-UNESCO system of soil classification.

2.6.7 Land Capability Classification

The technique which allows determination of the most suitable use for any area of land is called land classification (FAO, 1983). A great number of systems of land classification are in use, varying mainly according to the purpose for which the land is classified. Land may be classified according to its present land use, its suitability for a specific crop under the existing forms of management, its capability for producing crops or combinations of crops under optimum management, or its suitability for non-agricultural types of land use. A good knowledge of the land capability and suitability combined with good understanding of the soil characteristics and management aspects are the keys to more productive and sustainable agriculture.

The purpose of land capability classification systems is to study and record all data relevant to finding the combination of agricultural and conservation measures which would permit the most intensive and appropriate agricultural use of the land without undue danger of soil degradation.

2.5.7.1 The USDA Land Capability Classification System

The best known of these systems is the United States Department of Agriculture system (Klingebiel and Montgomery, 1961). The USDA land classification system is interpretative, using the USDA soil survey map as a basis and classifying the individual soil map units in groups that have similar management requirements. At the highest of categorization, eight soil classes are distinguished, namely:

Class I soils have few limitations restricting their use. Erosion hazards on these soils are low; they are deep, productive and easily worked. For optimum production, these soils need ordinary management practices to maintain productivity, as regards both soil fertility and favorable physical soil properties.

Class II soils have some limitations that reduce the choice of plants or require moderate conservation practices. Limitations of soils in Class II include (singly or in combination) the effect of gentle slopes, moderate susceptibility to erosion, less than ideal soil depth, somewhat unfavorable soil structure, slight to moderate correctable salinity, occasional damaging overflow, wetness correctable by drainage, slight climatic limitation. Soils in this class require more than ordinary management practices for obtaining optimum production and for maintaining productivity.

Class III soils have severe limitations that reduce the choice of plants or require special conservation practices. The limitation of soils in this class are those of Class II, but in higher degree; including additional limitations such as shallow depth, low moisture-holding capacity, and low fertility that is not easily corrected. Class III soils require considerable management inputs, but even so, choice of crops or cropping systems remains restricted because of inherent limiting factors.

Class IV soils have very severe limitations that restrict the choice of plants and or require very careful management. Restrictions, both in terms of choice of plants and or management and conservation practices are greater than in Class III to such an extent that production is often marginal in relation to the inputs required. Limiting factors are of the same nature as in the previous classes but more severe and difficult to overcome. Several limitations such as steep slopes are a permanent feature of the land.

Some of the limitations due to sloppiness and erosion hazards in classes II to IV can be reduced by biological terracing as practiced in agro forestry and alley cropping. In the USDA system, soils of classes V to VIII are generally not suited for cultivation, although certain of them may be made suitable for agricultural use with costly measures.

Class V soils have few or no erosion hazards but have other limitations, impracticable to remove, that restrict their use to pasture, range, woodland, or wildlife food and cover. Although they may be level or nearly level, many of these soils are subject to inundation or are stony or rocky.

Class VI soils have severe limitations- that make them generally unsuited to cultivation and limit their use largely to pasture or range, woodland, or wildlife food cover. This class is a continuation of Class IV, with very severe limitations that cannot be corrected. They may serve for some kinds of crops, such as tree crops, provided unusually intensive management is practiced.

Class VII soils have very severe limitations that make them unsuited to cultivation and also, restrict their use largely to grazing, woodland, or wildlife. The limitations are such that these soils are not suited for any of the common crops.

Class VIII soils and land forms have limitations that preclude their use for commercial plant production.

In the second level of generalization of the USDA land capability classification system, sub classes specify the kind of limitations. Four kinds of limitations are recognized at this level, namely, risk of erosion; wetness, drainage or overflow; rooting zone limitations, and climatic limitation. The third level of the capability unit provides more specific and detailed information for application to specific fields on a farm.

A new standard framework for land evaluation by means of land suitability classification has been developed by FAO (1983). As in other systems, the land suitability component of land evaluation is based on the survey of the physical attributes of the land (soils, climate, vegetation, topography, hydrology, etc.), and consequently requires interpretation of these attributes. The proposed FAO land suitability classification integrates relevant social and economic factors with the technical suitability classification. At the present stage, the system mainly concentrates on the classification of land based on technical suitability

2.5.8 Soil Suitability Classification of Nigeria

FAO (2002), under the auspices of Gateway to Land and water information, recognized the soil suitability classification of Nigeria as presented below.

- Class 1 Soils-Highly Suitable

  There are no class 1 soils in Nigeria. These are very good land with minor or no physical limitations to mechanical cultivation.

- Class II Soils- Fairly Highly Suitable (SI)

  In this class are moderate to good lands with few physical limitations to mechanized cultivation but which can be corrected. These soils are found on nearly level to gentle undulating plains with slope ranges of 0-2% and are derived from sandstone, shales and Basement complex materials. The soils are deep, well drained. They have loamy sandy sand to sandy loam surfaces underlain by sandy clay loam to sand clay sub soils. The class II soils cover about 244,949.33km^2 (27.51%)in the country and the major crops grown in these soils include guinea corn, maize and vegetables (FAO 2002).

- Class IIs Soils-Moderately Suitable (S2)

In this class are moderately suitable lands with limitations such as moderate to shallow depth due to the presence of rock outcrops and inselbergs. The soils occur on gently undulating plains with scattered rock outcrops and inselbergs. The slope ranges are 2-6% while the soils are derived from sandstone, shales and undifferentiated Basement complex. The soils are shallow to moderately deep and deep, well drained. They have sands to sandy loam surfaces underlain by sandy clay loam to sandy clay sub soils. The soils of this class cover about 160,858.27km^2 or (17.38%) of the country land mass (FAO 2002).

- Class IIIe,s Soils- Marginal Suitability (S3)

In this class are fair to good lands that can be mechanically farmed with great care. There are moderate to high erosion hazards owing to undulating hilly dissected topography with scattered rock outcrops. Other limitations include shallow depth to iron-pan, concretion or stony/gravelly substratum. The soils are found on undulating dissected plains with scattered rock outcrops and hills. The slope ranges are 6-13% while the soils are derived from sandstone and undifferentiated Basement complex and ironstone sheet. The soils are shallow to moderately deep, well drained. They have sand to loamy sand surfaces underlain by loamy sand, sandy loam to sandy clay loam sub soils. The soils of this class cover about 126,589.84km^2 or 14% of the country land mass (FAO 2002).

- Class IVe,s Soils- Currently Not Suitable (N1)

  In this class are lands not suited to mechanical cultivation but suited for limited clearing and land cultivation for the production of perennial crops. The soils commonly occur on hilly or steep topography. Soils are better used for forest reserve and wildlife. The limitations include moderate to severe erosion hazards; steep or rocky slopes; very shallow depth and stoniness. Other limiting characteristics are slow permeability, low moisture holding capacity and poor capacity to utilize added fertilizers. The establishment of stringent erosion control practices is essential even when such soils are hand cultivated. The shallow soils occur in dissected plateau plains, hills and ridges. The slope ranges are 13-55%, while the soils are derived from sandstone, shales and undifferentiated Basement complex. The soils are shallow, well drained. They have sand to loamy sand surfaces underlain by bedrock. The soils of this class covers about 244,949.33km^2 or 27.51% of land area of Nigeria (FAO, 2002)

2.5.8.1 The Suitability of Southeastern Nigerian Soils

In southeastern Nigeria, land use is not according to suitability but availability (Onweremadu *et al.,* 2007c). Therefore with heightened demographic pressure, the soil resource is subjected to conflictive uses without consideration of its load bearing capacity and response to moisture content changes. Therefore the knowledge of the soil and land use capabilities in southeastern Nigeria is the bedrock of any modernization process in agriculture. This calls for intensive and costly soil survey to achieve self sufficiency in food production (Lekwa, 1998).

2.5.9 Soil Suitability and Survey Information

Soil has both utilitarian and aesthetic value and varies in time and space. The value of soil for agriculture and other uses increases over time but its quality declines due to population induced and economy-driven demands for necessities of life (Onweremadu *et al.,* 2007c). It becomes necessary for soils to be investigated as a way of generating information vital to sustainable soil management (Fanning, 2004). Holdren et al.,(1995) observed that accurate assessment and mapping of soils are imperative as many land uses depend on soil and availability of soil data is resulting to mismanagement and its sustainability.

Onweremadu *et al.,* (2007d), noted that soil survey at varying intensities can give spatial and temporal information on soils physical, chemical and biological properties. Consequently, the soil manager uses data acquired in soil survey activities in assessing the resource potential for environmental management, including soil nutrient recycling which enhances wise decision on land use (Scherr and Yadav, 1996).

2.5.10 Application of Soil Survey Information in Southeastern Nigeria

The use of soil survey information in the southeastern Nigeria has been very minimal; this is because, recorded information on soil surveys especially at semi-detail and detail levels of intensities has been scanty (Lekwa, 1998). Systematic soil survey of the then Eastern Nigeria was started in early 1960 by the staff of Eastern Nigeria Agricultural Research station headed by A.O. Nnodi. Obihara *et al* (1963) survey of Anambra River Basin area at a scale of 1: 50,000 appears to be the first organized major survey the documentation of which was made possible by the joint funding of the Eastern Nigeria Government and that of United Kingdom.

This has resulted in soil and soil related environmental problems such as nutrient depletion, nutrient toxicity, collapse of architectural structures, compaction, flooding, poor yield and food insecurity (Onweremadu *et al.,* 2007d). These problems are aggravated by socio-economic pressure on the soil causes by population increase (Ruecker, 2003). The indispensability of soil survey information rises as Krall and Lee (2004) reported a widened spectrum of usage of detailed soil information bringing in other soil users, and this becomes critical in the southeastern Nigeria where the resource is put in many and sometimes conflictive land use types (Onweremadu *et al.,* 2007).

2.6 Geographical Information System (GIS) Approach

2.6.1 Meaning of GIS,

Cowen (1990), identified some definitions of GIS based on some approaches as follow; *the process-oriented approach*: in this definition, the Environmental Systems Research Institute (1991) defines GIS as "an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced information.

Chang (2006), in the same approach defines GIS as “a computer system for capturing, storing, querying, analyzing, and displaying geographically referenced data”.

The application approach: Cowen (1990) noted that this approach defines GIS according to the information being handled. Here, the idea is to define GIS based on whether it is for general-purpose or specialized application. The subject matter provides the basis for definition. Thus, under this approach, GIS is defined based on, for example, whether its subject matter is on land (Land Information system), soil (Soil Information System), urban (Urban Information System), and so on.

The toolbox approach: Burrough (1986), wrote that GIS is “a powerful set of tools for storing and retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes”.

The database approach: this approach makes the data component independent from the programs that access it (Hexhold, 1991). Thus, Smith et at., (1997) defines GIS as “a database system in which most of the data are spatially are indexed and upon which a set of procedures operated in other to answer queries about spatial entities in the database”. However, whether the term ‘geographical information system’ is defined or descrbed, such effort should aim at highlighting the essential characteristics of a typical GIS (Uluocha 2007).

2.6.1.1 GIS and Agriculture

Modern computer-based geoinformation (GI) system have greatly transformed the way we acquire, manage, disseminate and use agro-related geoinformation (Uluocha, 2004). The agricultural sector happens to be one of the earliest beneficiaries of the GIS technology. Various agricultural lands, crops and livestock management practices can be more effectively and efficiently executed with the aid of GIS. Using the GIS in combination with earth observing remote sensing systems, it is possible to provide timely and agro-related information that can guide both the public and private operators in the agricultural sector in making sound management decisions. The following are some of the specific agricultural projects for which the powerful GIS technology could be efficiently and economically used.

- Inventory and mapping of agricultural land parcels (field units).
- Agricultural development planning
- Mapping and management of agricultural biodiversity
- High level spatial analysis and measurement of agro-related variables
- Provision of field specific condition information for precision agriculture (farming)
- Mapping of crop patterns
- Crop area identification and delineating crop-soil relations
- Estimating crop yield
- Provision of accurate, relevant and timely information for effective agro extension services
- Monitoring of crop health and growth conditions
- Identifying the presence of pests and diseases
- Monitoring the effect of pesticides and herbicides

- Agro-risk assessment and management (for insurance companies, agro managers and agribusiness entrepreneurs)
- Inventory of crop and livestock
- Management of grazing field
- Agricultural land evaluation and classification
- Assessing environmental impacts of existing agro projects, or the likely impacts of proposed ones
- Monitoring crop and livestock production.
- Measuring crop hectareage
- Determining harvest system options
- Mapping soil characteristics
- Site selection for locating agricultural projects and infrastructural facilities.

2.6.1.2 GIS and Land-use Planning and Management

According to Uluocha (2007), the GIS technology offers land use planners almost limitless opportunities for intelligent land-use allocation. Land-use planning is a decision making process; it is also a spatial process. Hence, planner needs appropriate geographical information to enable him make sound decisions relating to the sharing of land to various competing uses. The GIS can be effectively and efficiently used to provide the land-use planner information that will guide to reduce risk in his decision making.

The use of GIS in land-use planning and management is absolutely imperative, especially given that about 80% of the data needed for healthy land-use planning and management is space related (Uluocha, 1999).

Uluocha (2007), however, noted some areas in which GIS can be useful to a land-use planner;

- Create and update land-use maps
- Display vacant or marginal lands.
- Analyze land accessibility
- Identify areas of land dereliction
- Inventory present land uses
- Monitor and analyze changing patterns of land-use
- Access suitability of lands for different forms of uses
- Manage records of land ownership
- Facilitate land-use analysis, planning and allocation
- Identify areas suitable for further physical development.

2.6.2 Global Positioning System (GPS)

The GPS is a worldwide satellite-based navigation and positioning system (Uluocha, 2007). The GPS comprises of three segments namely; space segment, control segment and user segment (Ramadan, URL). The space segment is made up of twenty-four satellites in six orbital planes with an inclination of 55^{o}. The control segment is ground-based and is responsible for operating the global positioning system. It has five control stations, which are spaced almost evenly around the globe. The control stations track the GPS signals, which are used in controlling the satellites and predicting their orbits. The user segment of the GPS consists of the receivers and associated computer software for receiving the satellite signal and calculating position velocity and time.

By determining the actual locations of three or four of the satellites, and the exact distance from each of the satellites, the GPS receiver can precisely determine its own position by calculating its latitude, longitude, altitude, course and speed (Hum, 1993). Good quality GPS receiver can calculate their position anywhere on earth to better than a hundred meters, and do it faster than once a second. Different GPS receivers provide relative positional accuracy of 3-5m, with reference to a control point, the location of which must have been determined independently (Jones, 1998).

The positional data recorded using a GPS receiver can, therefore, be downloaded directly into a GIS through a software module similar to a digitizer controller (Ramadan, URL). However, where it is not possible to establish a direct link between GPS and GIS, the GPS receiver captures and stores geographical data using its own format. This data is later rendered GIS-compatible by translating it to any GIS data formats. Subsequently, the translated data can then be referred to GIS software and stored as a GIS file.

2.6.3 Geo-referencing

According to Kasianchuk and Taggart (2004), Geo-referencing is the process of establishing a relation between the data displayed in your GIS software and its real world-location. Uluocha (2007) refers to geo-referencing as the process of assigning spatial location identity to pieces of information. In other words, it is the process of giving a cartographic material such as digital satellite imagery, aerial photograph, map or statistical data a real world coordinates system and map projection.

2.6.4 Geostatistical Analysis

One thing that clearly sets GIS apart as a veritable spatial data mining technology is its capability to handle a variety of geographical analysis using geostatistical techniques. Geostatistics was traditionally used in geosciences. Geostatistics is concerned with spatial data. In other words, geostatistics is a kind of statistics that specifically describe spatial relationships among sample data. Several geostatistical operations involve spatial interpolation- which is the process of using samplepoints with known values (usually x-, y-, and z- values) to estimate values at other points (chang, 2006). Hence, each data value that is to be used in a geostatistical operation must be associated with a location in space. Geostatistics are used to explain spatial patterns and to interpolate values at unsampled locations (Krivoruchko, URL).

The basic concept of geostatistics is that of scales of spatial variation. Hence, it has common characteristics with GIS and spatial statistics in general (Myers, URL). Geostatistics techniques are used in several surface modeling (spatial interpolation) and other geospatial analytical processes such as Inverse Distance Weighting (IDW), Trend Surface Analysis, Digital Elevation Modeling (DEM), Spatial Autocorrelation and so on.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location

The study area is located some few kilometers away from Okposi road which is about 3 km from Amasiri Town in Afikpo North Local Government of Ebonyi State. It lies on the latitude $5^{o}53'$N and longitude $7^{o}54'$E, and has an altitude between 30m to 150m above sea level (Ofomata, 1975).

3.1.1 Geology and Geomorphology

The soils of the area are generally dominated by planes and lowland and a fairly uniform landform of low relief. These plains and lowlands exhibit a gently rolling toposequence with a characteristic physiographic differentiation of highly steeped slope usually below 100 above sea level (Ofomata, 1975).

The geology is mainly from Nkporo shale and Afikpo sandstone which spreads through Abakaliki region and dislocation of the depocenter into the Anambra Platform and Afikpo region. The resulting succession comprises the Nkporo Group, Eze Aku group (which includes Amasiri sandstone), Mamu Formation, Ajali Sandstone, Nsukka Formation, Imo Formation and Ameki Group commenced in the Late Eocene as a result of a major earth movement that structurally inverted the Abakaliki region and displaced the depositional axis (Ofomata, 1975; Obi et al., 2001).

3.1.2 Climate

The site location has its moisture regime to be Udic and experiences rainfall duration in all the months in a year with highest intensities occurring between June-August and receives a mean annual rainfall of about 1800-2100mm. The hours of daylight are also long because of the long duration of solar radiation incident on the location throughout the year owing to a mean annual temperature of 28-30°C with 2 months of relatively low rainfall less than 100mm. The mean relative humidity at 10:00 hours in January is 30-50% while the mean relative humidity in July at 10:00 hours is 70-80% (Ofomata, 1975).

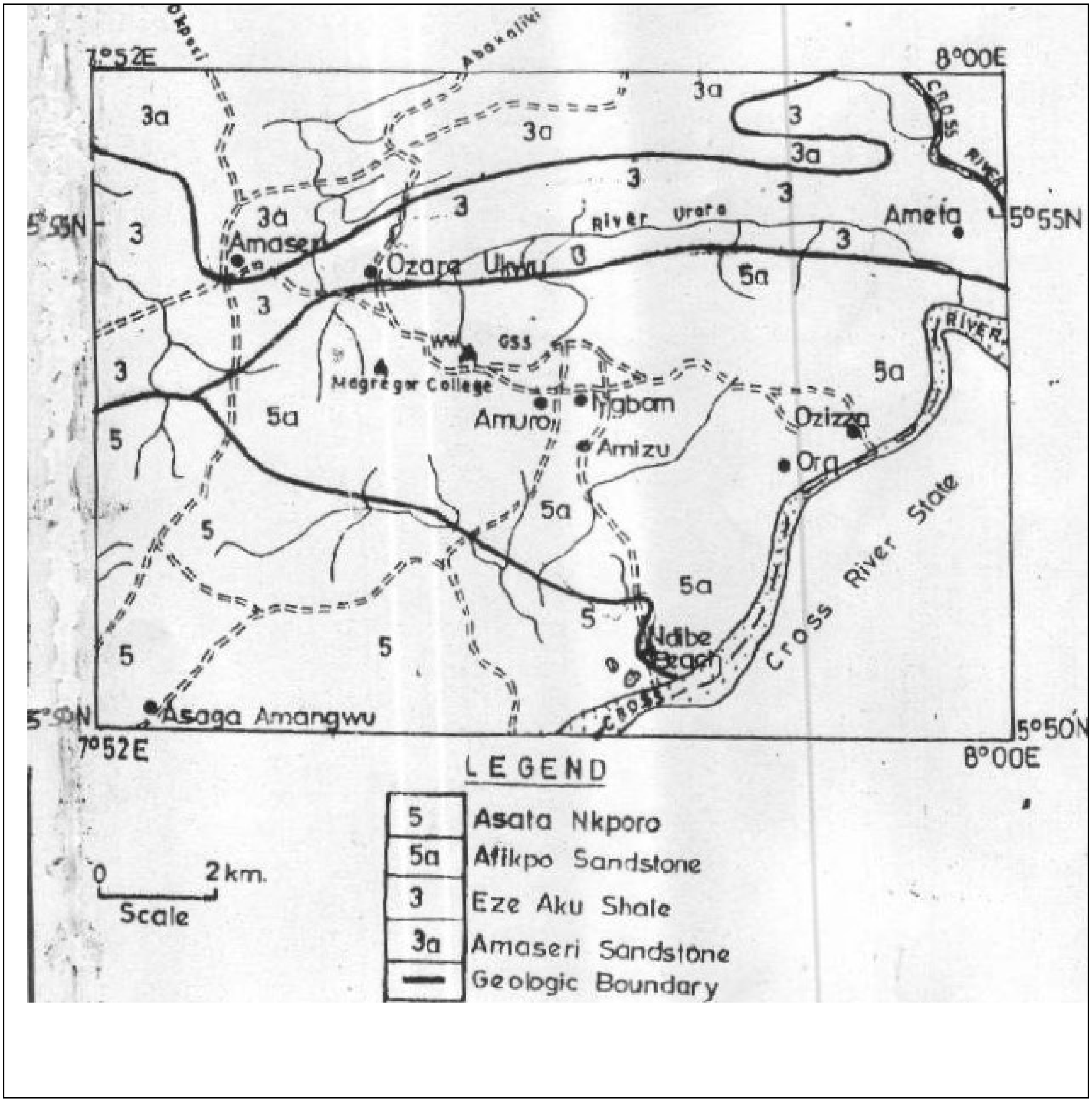

Fig. 1 Geological map of the study area

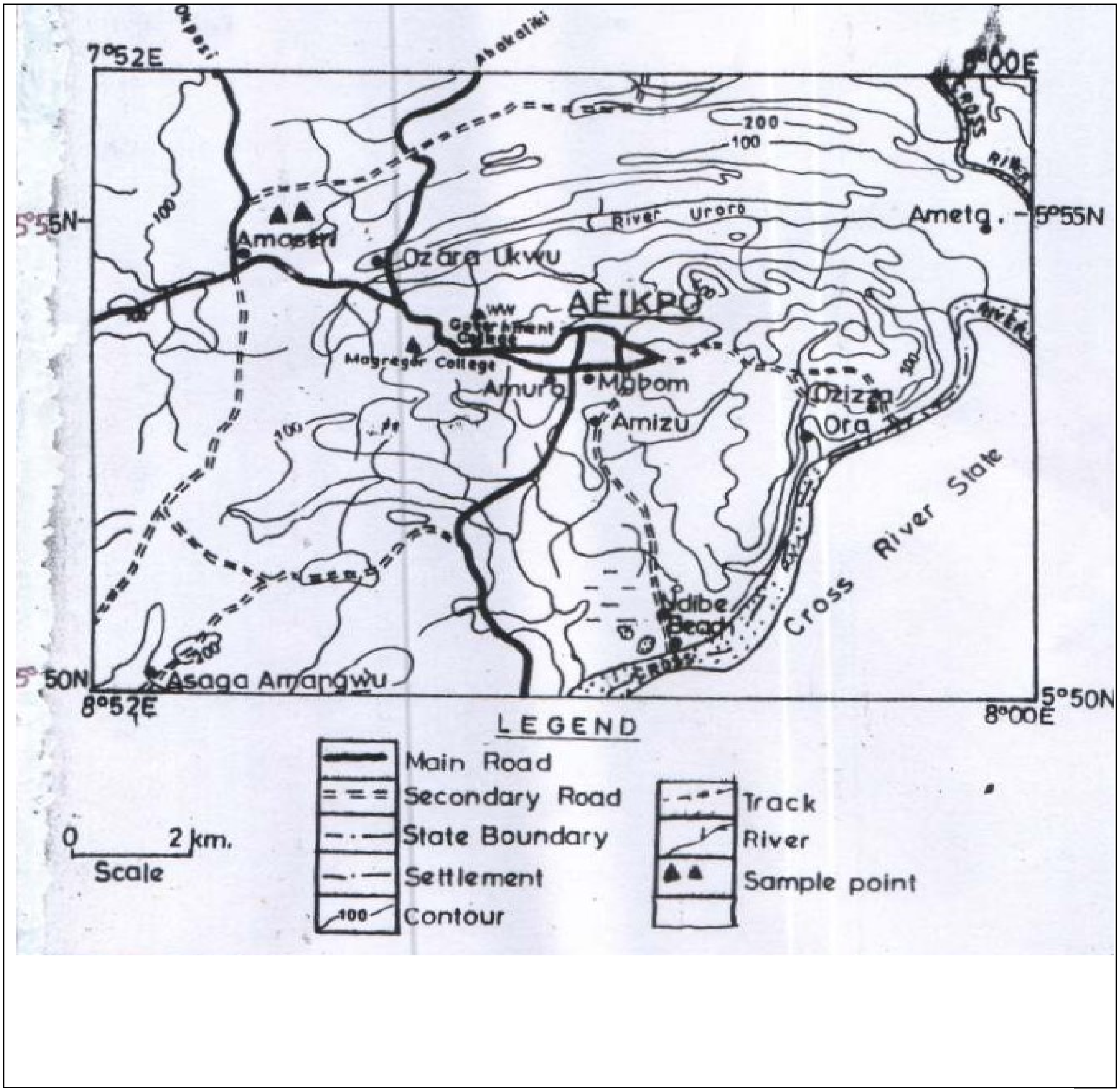

Fig. 2 Topographic map of the study area

3.1.3 Existing Information on Soil

Most tropical soils are usually described as inherently infertile and fragile, weak structured which encourages erosion, high soil acidity leading to nutrient imbalance and toxicity (Oparandi and Oranekwulu 1988). However the study area is made up of some Hydromorphic Soils**.** These are mineral soils whose morphology is influenced by seasonal waterlogging caused by underlying impervious shales. The soils of this class are usually pale-coloured and mottled in the sub-soil. The area consists of undulating to nearly level plains with low ridges and wide shallow valleys where yam, cassava and rice are the major crops grown. Abakaliki is also well known for rice production in the swamp (Ofomata, 1975).

3.1.4 Vegetation

The study site location is part of the Southeastern soils and its vegetation is derived savannah. The increased activities of man which includes bush burning, hunting and increased farming has apparently determined the type of vegetation. The bottom slopes are dominated by tall grasses which serve as food and hiding places to bush animals like rats, beavers, rabbits which are commonly seem in the area.

The toposequence however stretches for some relatively 600m long and has both the windward and the leeward sides otherwise recognized as the South facing slope and the North facing slope respectively which created a very wonderful sight in the area. The South facing slope has dense vegetation compared to the North facing slope which is only sparsely vegetated creating an alternation between the forest land and the savannah region on the toposequence. This has been extensively studied and referred to forest savannah mosaic by (Unamba-Oparah 1976).

The dominant trees and shrubs on the South facing slope are mainly; oil palm tree, rubber, and clusters of bamboo (mostly observed down the forest of the footslope with also medium sized trees). The North facing slope is however dominated by grasses.

3.1.5 Agricultural Activities

The major occupation of the people of Amasiri is subsistence farming with food crops dominating the practice. The rice production on the submerged soils would have enhanced commercial agriculture in the region if only there is large expanse of land to encourage mechanized farming. The agricultural type is mainly the mixed farming where foods crops predominantly planted are cassava, yam and rice.

Sometimes, mixed cropping of cassava with yam or other crops like vegetables is practiced. Generally, agricultural activities at the location are intense and the soils need to be rejuvenated through constant use of fertilizers as fallow is no more a common practice for a natural nutrient restoration.

3.2 Field Work

A reconnaissance study was carried out and the study area identified, in a farmland which consist of a toposequence. A transect was cut from the crest of the toposequence cutting across the windward and the leeward sides of the toposequence as well as the three major crop based (yam, cassava and rice) farmland in the area. Three profile pits was dug in each of the sides of the toposeqence (windward and leeward sides) each representing the crest, midslope and footslope respectively while surface sampling was carried out on the in each of the crop based farmland.

The profile pit length and breadth was 1.2m X 1.0m and the depth varying from 1.3m for crest to 1.43m for valley bottom. After careful horizon differentiation, the profile pits was described using the procedure outlined by the FAO (1980).

After description, soil samples were taken from each of the constituent horizons, placed in polythene bags appropriately labeled. The samples were air dried for three days under shade, crushed and sieved using 2mm sieve and the sieved samples preserved for laboratory analysis.

3.3 Laboratory Soil Analysis

Some physical and chemical properties of the soil will be used as parameters for the study. mechanical analysis (particle size distribution), porosity, bulk density, moisture content, while the chemical properties are: soil pH, exchangeable acidity (Al^{3+} and H^{+}), exchangeable bases (Ca^{2+} , Mg^{2+},K^{+}, Na^{+}), ECEC, percentage base saturation, total nitrogen, available phosphorus, total carbon, organic matter and carbon /nitrogen ratio. They are as follow:

a. Particle size distribution was determined by hydrometer method according to the procedure of (Gee and Or, 2002)
b. Bulk Density was measured by core method (Grossman and Reinsch, 2002). Porosity was computed from bulk density and particle density.

c. Atterberg limits were determined by the procedures recommended by head (1982).
d. Soil pH was determined in 1:2.5 soil liquid ratios in water and 0.1N KCl (Thomas, 1996).
e. Organic Carbon was determined using method described by (Nelson and Sommers, 1982).
f. Total Nitrogen was determined using modified micro Kjeldahl method (Bremner and Milvaney,1982).
g. Total available phosphorus was determined using Bray II method (Olsen and Sommers, 1982)
h. Cation exchange capacity (CEC) was measured by repeated saturation using 1M NH_4OAC followed by washing, distilling and titrating (Soil Survey Staff, 1996).

3.4 Statistical Analysis

Coeficient of Variation (C.V) as used by Aweto (1982) (Table 3.1) was also used in this study to estimate the degree of variability existing among soil properties in the study site. Comparisons was drawn from the results from the laboratory analysis of the pedons along the toposequence as well as the crop based soils. Variability among cropping systems was analysed using ANOVA and mean separation performed using Least significant difference (LSD) at 5% level of significance, (Wahua, 1999).

Percentage coefficient of variation was determined using the equation

$$\%CV = \frac{S.D}{X} \times \frac{100}{1}$$

Where S.D = standard deviation

X = mean

Table 3.1

Co-efficient of variation will be ranked according to Aweto (1982) as follow

Level (%)	Ranking
C.V < 20	Little variation
C.V 20-50	Moderate variation
C.V > 50	High variation

The results obtained from the laboratory analysis were presented in tables and represented graphically in straight lines bar charts and histograms.

A hand-held Global positioning system (GPS) receiver was used to generate the geographical coordinates of sampling points. Data generated from the GPS receiver with the topo-map were used to develop the Digital Elevation Model (DEM) for Geographical Information System (GIS) study to assess the geospatial distribution of the study area.

Chapter Four

4.0 Results and Discussion

4.1 Morphology

Pedons A, B and C represent; the Crest, Midslope and Footslope of the North Facing Slope (NFS), respectively. The locations of the pedons are as shown in Table 1. Table 2 shows the morphological properties of the soils under investigation.

The soils are formed under Ezeaku Shale and Amasiri Sandstone as the parent material. The various pedons have different colour matrix ranges which are described as follow;

In pedon A (Crest), the colour ranges from dull brown (7.5 YR 6/3) when dry and brown (7.5 YR4/4) when moist at the upper horizon to orange (2.5 YR 6/8) dry and bright brown (2.5 YR 5/8) when moist down the profile. In pedon B (Midslope), the colour ranges from dull brown (7.5 YR 5/3) when dry and dark brown (7.5YR3/3) when moist to pale orange (5YR 8/3) when dry and yellow orange (7.5YR 8/8) when moist. The pedon C (Footslope) has colour matrix ranging from light gray (10 YR 7/1) when dry and grayish yellow brown (10 YR 5/2) when moist to dull yellow orange (10YR7/3, 10YR6/4) at both dry and moist conditions, respectively.

At the South Facing Slope (SFS), pedons D, E and F represent the Crest, Midslope and Footslope respectively. Pedon D (Crest), the colour matrix ranges from grayish red (2.5 YR 5/2) when dry and dark reddish brown (2.5 YR3/2) when moist to dull orange (7.5 YR 7/4) when dry and orange (7.5 YR 6/8) when moist. In pedon E (Midslope), the colour matrix ranges from light gray (10YR 7/1) when dry and gray yellow brown (10 YR 5/2) when moist to light yellowish orange (10 YR 8/4) when dry and bright yellowish brown (10 YR 7/6) when moist. Lastly, Pedon F (Footslope), has colour matrix ranging from dull yellow orange (10 YR 7/3) when dry and dark brown (10YR 3/3) when moist to dull orange (5 YR 7/4) when dry and yellowish brown (10 YR 5/8) when moist.

Generally, at the North Facing Slope (NFS), pedons A and B have their upper horizons grading from dull brown (7.5YR6/3, 7.5YR5/3) when dry to orange (2.5 YR4/4) and pale orange (5YR8/3) respectively when dry at the lower horizons. Pedon C varied slightly as it graded from grayish red (2.5 YR 5/2) at the top to dull orange (7.5 YR 7/4) down the profile when dry. At the South Facing Slope (SFS), pedons D, E and F graded thus; grayish red (2.5 YR 6/4) to dull orange (7.5 YR 7/4), light gray (10 YR7/1) to light yellowish orange (10YR 8/4) and dull yellow orange (10YR7/3) to dull orange (5YR7/4) respectively at dry condition. Drainage condition and physiographic position may have influenced the observable change in the soil colour matrix in the topographic unit

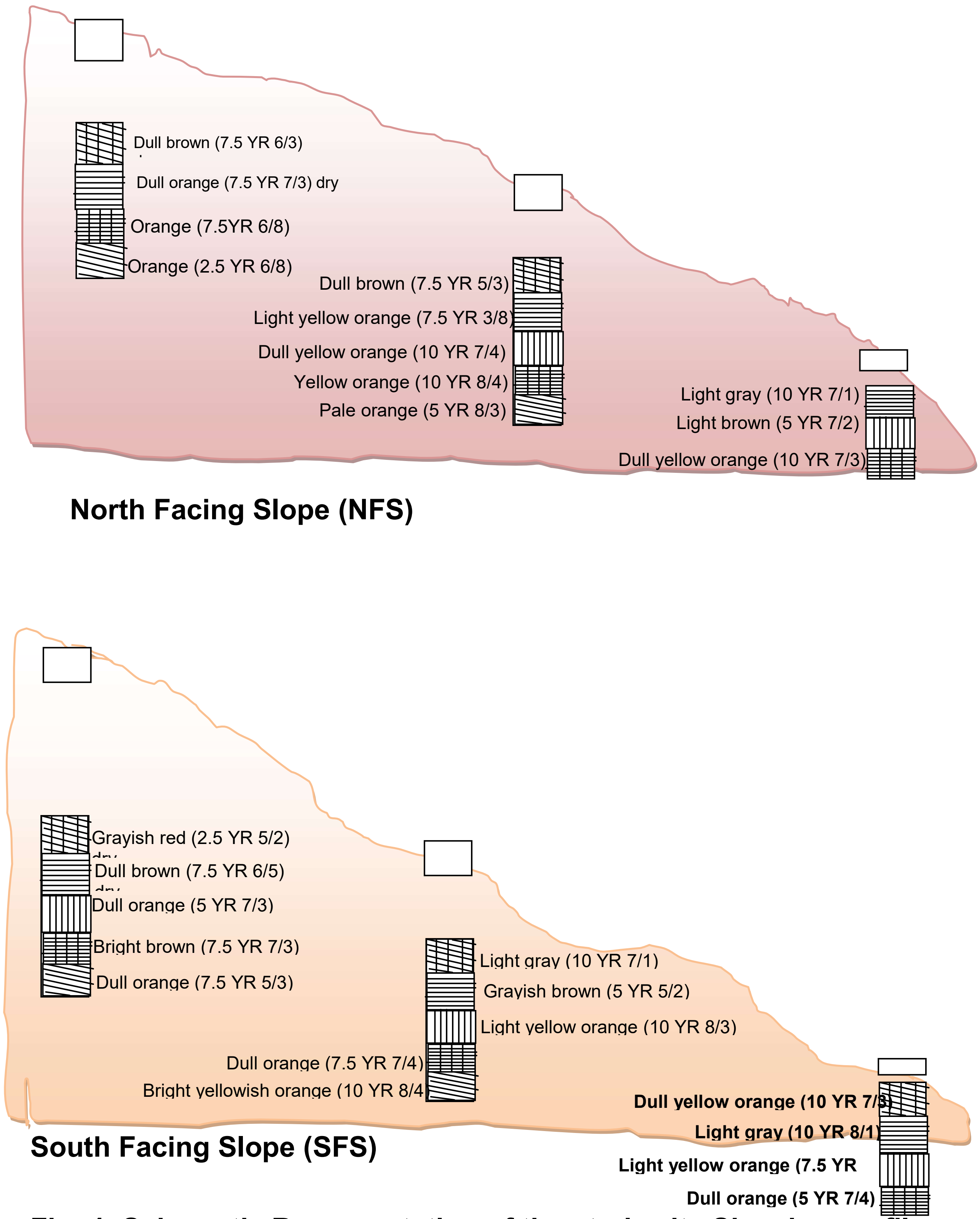

Fig. 4: Schematic Representation of the study site Showing profile locations and Soil Colour

4.2 Other Soil Physical Properties

Pedons A, B, D and E (Tables 5 and 6) were deep enough since their depth exceeded 100 cm which is in line with the ranking of the Federal Department of Agricultural Resources (1985). Pedons C and F were at the foot of the valley where water table affected further movement down the profiles.

Table 5: Physical Properties of North Facing Slope (NFS)

Horizon	Depth	Sand (%)	Clay (%)	Silt (%)	Texture	SCR	LL (%)	PL (%)	PI (%)	BD g/cm3	TP (%)
Crest											
A	0-20	74	17	9	LS	0.53	Np	Np	Np	1.09	58.87
E	20-45	80	14	7	LS	0.51	28.6	23.4	5.20	1.29	52.32
Bt1	45-75	78	19	3	LS	0.16	34.7	21.9	12.8	1.33	49.81
Bt2	75-150	71	23	6	SCL	0.26	49.8	30.9	18.9	1.48	44.15
	mean	75.75	18.25	6.25	-	0.365	37.7	25.4	12.3	1.29	51.28
	AV	5.83	20.7	-	-	50.3	-	-	-	-	-
	CV	LV	MV			HV					
Midslope											
A	0-11	78	15	7	LS	0.47	Np	Np	Np	1.27	52.08
E	15-35	75	15	10	LS	0.67	31.9	23.9	8.0	1.28	51.70
Bt1	35-82	68	23	9	SCL	0.39	31.3	24.8	6.5	1.41	46.79
Bt2	82-105	72	16	12	LS	0.75	32.6	25.1	7.5	1.51	43.02
Bt3	105-165	76	19	5	LS	0.26	35	27.2	7.8	1.54	41.89
	mean	73.8	17.6	8.6	-	0.508	32.7	25.25	7.45	1.40	47.10
	AV	4.6	19.5	-	-	39.6	-	-	-	-	-
	CV	LV	LV			MV					
Footslope											
A	0-17	76	14	10	LS	0.71	23.2	19.2	4.0	1.12	57.73
Ap	17-50	77	9	12	LS	1.33	Np	Np	Np	1.48	44.15
Bg_1	50-75	79	10	11	LS	1.1	Np	Np	Np	1.50	43.40
	mean	77.3	11	11		1.05	23.2	19.2	4.0	1.36	48.43
	AV	2.0	24.5	-	-	29.9	-	-	-	-	-
	CV	LV	MV			MV					

BD=Bulk density, LL =Liquid limit, PL =Plastic limit, PI =Plasticity index, NP =Non plastic, TP= Total porosity, CV= Coefficient of variation, AV= Absolute values, LV= Low variation, MV= Moderate variation, HV=High variation

Table 5 shows some physical properties of the North Facing Slope. The distribution of sand has no particular trend in value at the North facing slope. It decreased with depth at the crest and midslope and increased at the footslope. The percent sand ranged from 74-71% at the crest, 78-76% at the midslope and 76-79% at the footslope. However, the mean sand at the North facing physiographic slope has more percent sand at the footslope (77.3%), followed by the crest (75.75%) and the least sand occurred at the midslope (73.8%). The percent clay in this same physiographic slope has no definite pattern of geometry. However at the crest and midslope, there is a consistent increase in clay content whereas at the footslope there is a more irregular clay distribution. Clay distribution ranged from 17-23% at the crest, 15-19% at the midslope and 14-10% at the footslope. The percent silt values decreased with depth at the topslope (9-6%) and midslope (7-5%) and increased (10-11%) at the footslope. However, the mean distribution of percent silt at the NFS showed a progressive increase from crest (6.25%) to midslope (4.8%) down the footslope (11%).

There is also no particular trend of values in percent sand distribution as regards depth at the SFS (Table 6). It decreased with depth at the crest (77-72%) and footslope (79-76%) and showed a slight increase at the midslope (76-77%). However, the mean sand followed same pattern with those of the NFS. The footslope (80.5%) recorded the highest value followed by the crest (76.8%) while the lowest occurred at the midslope (75.4%). Clay content showed increase with depth in all the physiographic positions; with the crest recording 14-22%, midslope 14-19% and footslope 11-12%. The mean clay content were highest at the midslope (16.4%) followed by the crest (15.4%) and footslope which is only 12%. This clay increase with depth agrees with Eshett (1996) that most soils within this region are coarse textured, porous, deep with a friable surface horizon which is usually underlain by a clay-enriched subsoil (argillic horizon) or plinthite.

Table 6: Physical Properties of South Facing Slope (SFS)

Horizon	Depth	Sand (%)	Clay (%)	Silt (%)	Texture	SCR	LL (%)	PL (%)	PI (%)	BD g/cm3	TP (%)
Crest											
A	0-13	77	14	9	LS	0.64	Np	Np	Np	1.17	55.84
E	13-27	78	17	5	LS	0.29	Np	Np	Np	1.19	55.09
Bt1	27-50	79	19	2	S	0.11	23.6	18.7	4.9	1.32	50.19
Bt2	50-70	77	20	3	SCL	0.15	27.3	19.7	7.6	1.41	46.79
Bt3	70-150	72	22	5	SL	0.23	39.5	26.5	13.1	1.51	43.02
	mean	76.8	18.4	4.8	-	0.28	30.13	21.63	8.53	1.32	50.19
	AV	5.78	16.6	-	-	74.3	-	-	-	-	-
	CV	LV	LV			HV					
Midslope											
A	0-05	76	14	10	LS	0.71	Np	Np	Np	1.31	50.57
E	05-20	80	11	9	SL	0.82	Np	Np	Np	1.34	49.43
Bt1	20-60	72	18	10	SL	0.55	22.3	18.8	3.5	1.41	46.79
Bt2	60-90	72	20	8	SL	0.41	39.1	28.2	10.9	1.45	45.28
Bt3	90-150	77	19	5	SL	0.26	39.5	28.2	11.3	1.47	44.53
	mean	75.4	16.4	8.4	-	0.55	33.63	25.06	8.56	1.40	47.32
	AV	4.55	23.4	-	-	40.87	-	-	-	-	-
	CV	LV	MV			MV					
Footslope											
A	0-10	79	11	10	LS	0.91	Np	Np	Np	1.22	53.96
E	10-30	90	10	10	S	1	Np	Np	Np	1.37	48.30
Bt1	30-50	77	15	8	SL	0.53	22.1	16.5	5.6	1.51	43.02
Bt2	50-95	76	12	11	LS	0.92	Np	Np	Np	1.72	35.09
	mean	80.5	12	9.75	-	0.84	22.1	16.5	5.6	1.45	45.09
	AV	8.02	18.0	-	-	25.07	-	-	-	-	-
	CV	LV	LV			MV					

BD=Bulk density, LL =Liquid limit, PL =Plastic limit, PI =Plasticity index, NP =Non plastic, TP= Total porosity, CV= Coefficient of variation, AV=Absolute value of CV, LV= Low variation, MV= Moderate variation, HV=High variation

The percent silt value also decreased with depth at the crest (9-5%), midslope (10-5%) and then increased at the footslope (10-11%) at a very minimal rate. The mean percent silt increased down the slope from crest to footslope at the South facing physiographic position. The percent mean silt values were 4.8, 8.4 and 9.75% for crest, midslope and footslope respectively.

Furthermore, clay decreased generally at the North and South facing slopes from crest to footslope having mean values of 18.25 – 11% for NFS and 18.4 – 12% for SFS respectively. This may be as a result of the nearly flat nature of the crest when compared to the steep midslope and undulating footslope. There is also greater force of attraction due to the tenacity of cohesion between clay particles which tend to repel agents of detachment and transportation.

Generally the values of sand were higher at the valley bottom compared to the crest and midslope in both the NFS and the SFS. It ranged from Crest (75.75%) – midslope (73.8%) – footslope (77.3%) for NFS and crest (76.8%) – midslope (75.4%) – footslope (80.5%) for SFS. This sequence may be due to the pedogenesis of immature soil which encouraged the transport and deposit of sand through illuviation and runoff.

The silt/clay ratio has mean values which increased down the slope in both the north and south facing slopes and have values that are generally low. The silt/clay values are as follow; crest – 0.37, midslope – 0.51, footslope – 1.05% for north facing slope (NFS) and crest – 0.38, midslope – 0.55 and footslope – 0.84% for south facing slope (SFS). The low silt/clay ratio, according to Nuga *et al*. (2008) indicated feralitic pedogenesis. This also implies that the soils were made of young parent materials with low degree of weathering.

Furthermore, the textural class of the toposequence can be said to be generally of sand composition with a lesser loamy concentration. At the pedon A, texture ranged from loamy sand (LS) at the top horizons to sandy clay loam (SCL) at the lower horizon. Pedon B showed a similar trend but indicated a sandy clay loam texture at the Bt_1 horizon while loamy sand (LS) was seen at the following horizons. Pedon C showed loamy sand (LS) texture in all the horizons of the pit. Profiles D, E and F also indicated preponderance of sand composition with little loam. Pedon D had just the same textural class with that of the A counterpart. Pedon E indicated a little change as it gradually turned from loamy sand (LS) to sandy loam (SL) from the top of the horizon down the profile pit. This sandy nature of soils being investigated may be attributed to the Eze-aku sandstone and shale parent material from which these soils were formed. These parent materials are believed to constitute sedimentary fluvial stratification which formed the soils (Obi *et al.,* 2001).

In both the NFS and SFS, there was movement of clay down the B-horizon in an increasing order though this occurrence did not continue in all the pedons. Pedons A, D and E showed a regular clay increase down the profile. Argillation may have occurred at the Bt_1 horizon of pedon B and F as the highest value of clay were indicated and decreased down the profile thereby leading to a lithic discontinuity in the argillation process. Nuga *et al.,* (2008) suggested that this higher clay content observed in the sub-surface horizon in the pedons can be as a result of illuviation and faunal activities taking place in the area.

The textural distribution of the crop based soils (Table 7) also indicated that the crop based soils were dominated by loamy sand and sandy loam textural composition. However, the mean sand was lower than values obtained from top horizons at all physiographic view of the toposequence. This same trend does not apply to clay and silt content of the CBS as all values obtained were higher than that of the surface horizons of the toposequence. This textural differences between the crop based soils and the toposequence is in line with Irvin (1996) that as water empties from a river slope, its velocity starts to decrease. The larger particle like sand begins to sediment first from the suspension. Fine clay particles can be further transported away from the foot of the slope before being deposited. This leads to the reason why coarse textured soils tend to be found near the base of the toposequence and fine textured soils located further away from the base of the slope.

Also the silt/ clay relationship was low in the crop based soils since mean values for 3 major crop soils were less than 1as shown in Table 7. The silt/clay content of the toposequence was generally low and their mean value increased gradually from crest to footslope (Tables 5 and 6). However, values obtained were less than 1 for all pedons at both North and South physiographic view except footslope of the NFS with mean value 1.05. This higher value at the NFS indicated that the soil is a young soil, probably an Inceptisol or Entisol because of its higher silt content compared to other pedons on the toposequence

Atterberg limit was another interesting parameter tested in this research work in order to have a clue to the rheological properties of the soils being investigated. As can be seen in Tables 5 and 6, almost all surface horizons at the toposequence had no values for Atterberg limit except the footslope on the NFS. The Np indicated in the columns showed that these horizons had clays that were non plastic since they could not be rolled with the palm to form wires. The three core factors of Atterberg limits (Liquid limit (LL), Plastic limit (PL) and Plasticity index (PI) are related and dependent on one another. Atterberg limit shows that LL-PL=PI. However, if the soil does not form wire, it signifies that there is not plastic limit and hence there will be no plasticity index even though it has liquid limit. Down the profile pits, values of Atterberg limits were recorded and the PI increased in pedons A, D and E. It shows no regular pattern in profile B while profiles C and F had PI only on each of their horizons. Furthermore, this Atterberg limit is a direct function of the type of clay mineral contained in soil.

The Atterberg limit obtained from the crop based soils (Table 7) on the surface sampling conducted showed that all the samples from the three crop based plots had plasticity characteristics when compared to the surface horizons of the toposequence. However, the plasticity indices of CBS were not high enough to qualify the clay content of these soils as 2:1 expanding clays such as smectitle or montmorillonite since their plasticity indices were less than 25 %. Therefore, management practices such fertilization, land preparation and the soil's fairly stable surface may have encouraged the farmers who subject it under continuous cropping.

This agreed with (Brady and Weil, 2007) which noted that soils with plasticity indices more than 25% contains expanding clays which make poor roadbeds or foundations. Soils with smectite clays have higher liquid limits and higher plasticity indices especially if saturated with sodium. Kaolinites and other nonexpanding clays have low liquid limit values. Therefore since all the values obtained were far below 25, it showed that the soils of this toposequence are made up of nonexpanding clay minerals such as kaolinite. The Atterberg test of this toposequence indicated that these soils can be put into a non agricultural use such as road or other engineering construction, recreational centres or quarry site for its best performance and utilization.

The bulk densities of pedons on the toposequence are as indicated in Tables 5 and 6. Both the NFS and the SFS showed a similar trend on their surface bulk density values with the midslopes recording the highest values. The NFS values were; 1.09, 1.27 and 1.12 g/cm^3 for crest, midslope and footslope respectively. In the same vein, SFS values were; 1.17, 1.31 and 1.22 g/cm^3 for crest, midslope and footslope respectively. Meanwhile, the midslope recorded the highest mean value at the NFS when compared to the crest and footslope; 2.29, 1.40 and 1.36 g/cm^3 for crest, midslope and footslope respectively, while at the SFS, the mean bulk density values increased from crest to footslope as follow; 1.32, 1.40 and 1.45 g/cm^3 for crest, midslope and footslope respectively. However, it is worthy to note that values of bulk density increased with depth in all the physiographic positions of the toposequence. These results on bulk density are consistent with the findings of Onweremadu *et al.* (2007b) and Akamigbo (1999) in soils of the same agroecology. However, values of bulk density were lower than critical limits for root restriction (1.75-1.80 g/cm^3) (Soil Survey Staff 1996).

Total porosity (TP) for the NFS and SFS (Tables 5 and 6) decreased with depth in all the pedons of the toposequence. The mean values of TP also decreased down the slope in all the physiographic positions of both NFS(crest- 51.28, midslope – 47.1, footslope – 48.43%) and SFS (crest – 50.19, midslope – 47.32, footslope – 45.09%) except at the North Facing footslope where TP slightly surpassed midslope value. This is as a result of greater sand particles deposited very close to the point of detachment while finer particles are further transported to the valley bottom by agents of erosion. However, total porosity values were similar to that obtained by (Onweremadu, *et al.,* 2007b) in soils of the same agroecology in southeastern Nigeria.

Similarly, the crop based soils (Table 7) recorded highest mean total porosity at the Cassava Plot (57.06%); followed by Yam Plot (50.49%) while the Rice Plot showed the lowest TP value (41.81%). This can be explained by a more concentration of finer clay particles at the Rice Plot which tend to reduce the soil pore spaces. As a result of this, the mean bulk density value of the CBS was higher at the Rice Plot (1.54g/cm^3) compared to Cassava and Yam Plots which recorded 1.13 and 1.31g/cm^3 respectively.

Table 7: Physical Properties of Crop Based Soils (CBS)

Location	Sand	Clay (%)	Silt (%)	SCR	TC	LL (%)	PL (%)	PI (%)	BD g/cm3	TP (%)
	73	16	11	0.69	LS	36.2	28.7	7.5	1.12	57.74
	70	18	12	0.67	LS	33.5	21.3	12.2	1.26	52.45
Cassava	72	18	10	0.55	LS	34.8	26.5	8.3	1.06	60.01
	74	14	12	0.86	LS	31.9	25.8	6.1	1.12	57.74
	71	16	13	0.81	LS	35.9	27.3	8.6	1.13	57.35
Mean	72	16.4	11.6	0.71	LS	34.46	25.92	8.54	1.138	57.058
	71	18	11	0.61	LS	28.2	25.9	2.3	1.68	36.61
	68	20	12	0.60	SL	24.6	18.7	5.9	1.39	47.55
Rice	67	19	14	0.73	LS	25.2	19.6	5.6	1.62	38.86
	70	17	13	0.76	LS	26.9	21.2	8.7	1.44	45.66
	72	18	10	0.55	LS	27.2	21.5	5.7	1.58	40.38
Mean	69.6	18.4	12	0.65	LS	26.42	21.38	5.64	1.542	41.812
	70	17	13	0.76	LS	30.8	22.8	8	1.52	42.64
	71	19	10	0.53	LS	32.4	25.6	6.8	1.24	53.21
Yam	69	18	13	0.72	LS	33.9	23.6	10.3	1.31	50.56
	70	18	12	0.67	LS	30.2	24.1	6.1	1.32	50.18
	72	17	11	0.65	LS	31.1	23.5	7.5	1.17	55.84
Mean	70.4	17.8	11.8	0.66	LS	31.68	23.92	7.74	1.312	50.486
G Mean	**70.7**	**17.5**	**11.8**	**0.67**		**30.9**	**23.74**	**7.31**	**1.33**	**49.79**
$LSD_{0.05}$	**2.21***	**1.13***	**2.24^{ns}**	**0.15^{ns}**		**2.35****	**3.31***	**3.28***	**0.165***	**6.24****

BD=Bulk density, LL =Liquid limit, PL =Plastic limit, PI =Plasticity index, NP =Non plastic, TP= Total porosity, TC= Textural Class, SCR= Silt/Clay ratio.

Table 7 indicated plasticity index (PI) values for all surface horizons sampled. The highest mean value (8.54) occurred at the cassava farm, followed by yam (7.74) and then rice (5.64).

4.3 Soil Chemical Properties

Tables 8 and 9 showed the chemical properties of the toposequence (NFS and SFS), while table 10 displayed the chemical properties of the Crop Based Soils (CBS). However, from Tables 8 and 9, the soil pH in H_2O were all moderately acidic and their values slightly decreased from crest to footslope and ranged from 5.26 – 5.04 at the NFS and 5.67 – 5.11 at the SFS. The pH in KCl was lower than that obtained in water due to the presence of reserved acidity in addition to active acidity which pH in water only measures. The values ranged from 4.76 – 4.53 for NFS and 4.91 – 4.36 for SFS. This pH values indicated that the soils were strongly acidic which characterizes most tropical soils particularly soils of South-eastern Nigeria (Udo, 1980). Also the trend of pH values in the toposequence indicated that the crests are more acidic compared to the valley bottom. Therefore, from the trend as seen in the table, acidity decreases down the slope. This situation may have resulted due to the leaching and runoff of finer soil particles and their deposition down the slope (Silver *et al.,* (1994).

The mean pH for the crop based soils was almost of the same trend with that of the surface of the toposequence. The mean pH values for Cassava, Rice and Yam plots were 5.28, 5.32 and 5.75 respectively in H_20. This sequence showed that the Cassava plot was however more acidic followed by Rice plot before Yam plot.

Table 8: Chemical Properties of North Facing Slope (NFS)

Depth	pH: H_2O	pH: KCl	OC	OM	TN	C:N	Avai. P:ppm	Na	K	Ca	Mg	TEB	H	Al	TEA	ECEC	Base Sat.(%)	Al Sat (%)
				%							Cmol/kg							
Crest																		
0-20	5.26	4.76	0.61	1.03	0.05	12.9	2.30	0.02	0.06	0.44	0.44	0.96	0.23	0.5	0.73	1.69	57	26
20-45	5.12	4.71	0.46	0.79	0.04	12.0	2.00	0.01	0.06	0.52	0.44	1.03	0.82	0.75	1.57	2.60	40	28
45-75	5.08	4.59	0.42	0.72	0.03	16.5	1.80	0.01	0.07	0.04	0.04	0.16	1.4	1.75	3.15	3.31	5	53
75-150	5.04	4.53	0.22	0.38	0.02	14.1	1.40	0.01	0.07	0.02	0.02	0.12	0.95	1.58	2.53	2.65	5	60
Mean	5.13	4.65	0.427	0.73	0.035	15.3	1.88	0.013	0.07	0.255	0.235	0.57	0.85	1.145	1.995	2.56	26.8	41.8
CV		LV		MV	MV												HV	
Midslope																		
0-15	5.21	4.98	1.41	2.41	0.13	10.8	4.51	0.02	0.09	0.68	0.44	1.23	0.21	0.03	0.24	1.47	86	5
15-35	5.3	4.61	0.52	0.89	0.04	11.6	3.01	0.02	0.07	0.32	0.58	0.99	1.65	2.13	3.75	4.77	21	45
35-82	5.64	4.55	0.36	0.62	0.03	14.5	2.61	0.02	0.05	0.42	0.34	0.88	1.45	2.38	3.83	4.71	19	51
82-105	4.88	4.52	0.18	0.31	0.01	16.2	1.68	0.02	0.07	0.44	0.71	1.23	0.7	1.75	2.45	3.68	33	48
105-165	4.72	4.46	0.16	0.28	0.01	16.7	1.52	0.02	0.06	0.66	0.34	1.08	1.18	2.03	3.21	4.29	25	47
Mean	5.15	4.62	0.526	0.90	0.044	13.96	2.67	0.02	0.068	0.504	0.482	1.08	1.038	1.664	2.696	3.78	36.8	39.2
CV		LV		HV	HV												HV	
Footslope																		
0-17	5.24	4.71	0.96	1.65	0.09	11.4	3.61	0.02	0.06	0.41	0.24	0.72	0.61	1.21	1.81	2.52	29	48
17-50	5.53	4.79	0.94	1.62	0.08	12.1	3.11	0.02	0.07	0.36	0.04	0.49	0.05	1.01	1.05	1.54	31	65
50-75	5.57	4.99	0.26	0.45	0.02	13.9	2.62	0.02	0.06	0.16	0.16	0.41	0.38	0.01	0.38	0.78	51	2
Mean	5.45	4.83	0.72	1.24	0.063	12.47	3.11	0.02	0.063	0.31	0.147	0.54	0.347	0.743	1.08	1.61	37	38.3
CV		LV		HV	HV												MV	

OC=Organic Carbon, OM=Organic Matter, TN=Total Nitrogen, Avail. P= Available Phosphorus, TEB= Total exchangeable bases, TEA= Total exchangeable acidity, ECEC= Effective cation exchange capacity, Base Sat.= Base saturation, Al Sat.= Aluminum saturation, CV= Coefficient of variation, LV= Low variation, MV= Moderate variation, HV=High variation

Table 9: Chemical Properties of South Facing Slope (SFS)

Depth	pH: H_2O	pH: KCl	OC	OM %	TN	C:N	Avai P:ppm	Na	K	Ca	Mg	TEB Cmol/kg	H	Al	TEA	ECEC	Base Sat.(%)	Al Sat (%)
Crest (D)																		
0-13	5.67	4.91	1.28	2.21	0.12	11.8	4.01	0.01	0.11	0.96	0.44	1.51	0.48	0.02	0.48	1.99	76	2
13-27	4.59	4.62	1.14	1.97	0.09	12.9	3.62	0.02	0.09	0.22	0.04	0.37	0.75	0.95	1.71	2.07	18	46
27-50	4.88	4.52	0.51	0.86	0.04	12.8	2.68	0.01	0.06	0.21	0.04	0.31	0.93	1.21	2.13	2.44	13	49
50-70	5.14	4.41	0.42	0.69	0.03	15.4	2.41	0.02	0.09	0.22	0.31	0.63	1.79	2.15	3.95	4.58	14	47
70-150	5.11	4.36	0.34	0.58	0.02	15.7	2.01	0.01	0.08	0.04	0.12	0.25	1.11	2.63	3.73	3.98	6	66
Mean	5.08	4.56	0.738	1.26	0.06	13.72	2.95	0.014	0.086	0.33	0.19	0.614	1.012	1.392	2.40	3.01	25.4	42
CV		LV		HV	HV												HV	
Midslope	(E)																	
0-5	5.11	4.76	0.92	1.58	0.08	12.4	3.23	0.02	0.08	0.56	0.46	1.12	0.05	0.41	0.45	1.57	71	26
05-20	5.11	4.66	0.62	1.07	0.04	14.3	2.82	0.02	0.08	0.26	0.61	0.96	0.41	1.29	1.71	2.66	36	49
20-60	4.94	4.57	0.46	0.79	0.03	16.8	2.21	0.02	0.08	0.42	0.04	0.56	0.81	2.01	2.81	3.36	17	60
60-90	5.41	4.61	0.31	0.52	0.02	16.7	1.62	0.02	0.06	0.21	0.12	0.41	2.28	4.05	6.33	6.73	6	60
90-150	5.61	4.65	0.16	0.28	0.01	15.8	1.44	0.02	0.07	0.21	0.04	0.33	2.32	4.18	6.48	6.81	5	61
Mean	5.24	4.65	0.494	0.85	0.036	15.2	2.26	0.02	0.074	0.332	0.254	0.676	1.174	2.388	3.56	4.23	27	51.2
CV		LV		HV	HV												HV	
Footslope	(F)																	
0-14	5.66	5.12	0.86	1.48	0.08	11.2	3.01	0.01	0.07	0.96	1.01	2.04	0.03	0.53	0.56	2.61	79	20
14-30	5.58	4.64	0.5	0.89	0.04	12.8	2.51	0.02	0.09	1.02	0.28	1.39	0.28	0.63	0.91	2.29	60	27
30-50	5.67	4.65	0.52	0.86	0.04	12.9	2.41	0.01	0.05	0.86	0.68	1.61	0.68	1.13	1.81	3.41	47	33
50-95	5.86	4.61	0.26	0.48	0.02	18.6	1.82	0.02	0.08	0.66	0.21	0.87	0.51	1.28	1.78	2.65	33	48
Mean	5.69	4.75	0.535	0.93	0.045	13.87	2.44	0.015	0.072	0.875	0.545	1.478	0.375	0.8925	1.265	2.74	54.75	32
CV		LV		MV	HV												MV	

OC=Organic Carbon, OM=Organic Matter, TN=Total Nitrogen, Avail. P= Available Phosphorus, TEB= Total exchangeable bases, TEA= Total exchangeable acidity, ECEC= Effective cation exchange capacity, Base Sat.= Base saturation, Al Sat.= Aluminum saturation, CV= Coefficient of variation, LV= Low variation, MV= Moderate variation, HV=High variation

The percent organic matter was generally low and showed a decrease down the horizon in all the physiographic position of the toposequence as can be seen on Tables 8 and 9. The mean value increased from crest to valley bottom at the NFS. The values were 0.73, 0.90 and 1.24% for crest, midslope and footslope respectively. Similarly, organic matter decreased down the horizon at the SFS but the mean value was highest at the crest (1.26%) followed by the footslope (0.93%) while the lowest occurred at the midslope (0.85%).

This situation can be attributed to the transportation and deposition of leached and eroded soil minerals down the slope which may have affected the NFS more compared to the SFS due to their differences in vegetation cover. The NFS being covered with grasses may easily be set on fire during the dry season. This situation encouraged erosion and leaching of materials from crest to the footslope thereby increasing their organic matter content downslope. The SFS is however more forested and therefore does not permit much material movement by agents of erosion such as wind and rainfall. Therefore, SFS showed more organic matter, slightly above its NFS counterpart on the toposequence. At the Crop Based Soils, yam plot recorded more mean percent organic matter (2.25%) just slightly above that of cassava (2.23%) while rice plot had 1.82%.

The relationship between the slope and the CBS as concerns organic matter behavior agrees with Quideau (2002), that organic matter accumulation is often favoured at the bottom of hills. There are two reasons for this accumulation: conditions are wetter than at mid- or upper-slope positions, and organic matter is transported to the lowest point in the landscape through runoff and erosion. Similarly, soil organic matter levels are higher on north facing slopes (in the Northern Hemisphere) compared with south-facing slopes (and the other way round in the Southern Hemisphere) because temperatures are lower.

Total nitrogen content was generally very low at both NFS and SFS, and the pattern of its distribution closely follows that of organic carbon as it decreases with depth (Tables 8 and 9). The mean total nitrogen at the NFS recorded (0.035%) for crest, (0.044%) for midslope and (0.65%) for footslope. However, at this physiographic view highest value of total nitrogen was obtained in footslope soils. At the SFS, highest value occurred at the crest (0.06%) followed by footslope (0.045%) and then the midslope (0.036%). At the CBS (Table 10), Cassava plot recorded highest total nitrogen (0.112%), followed by Yam (0.104%) while Rice recorded (0.084%). The low nitrogen status of these soils can be attributed to the lifting of crop harvest away from the crop land and subsequent land preparation through bush/residue burning as well as forest fires by hunters during dry season. This hastens volatilization of available nitrogen and thereby depletes the soil total nitrogen (Lal, 1974).

The C/N ratios of the entire toposequence ranged from 10.2 to 18.6 with higher values occurring at the lower horizons as can be seen in Tables 8 and 9. However, the mean C/N ratio for NFS decreased down the slope ranging from 15.30 (crest) to 13.96 (midslope) and 12.47 (footslope). At the SFS, mean does not follow the same trend as highest mean value occurred at midslope (15.20) followed by footslope (13.87) before topslope (13.72). This can be explained from the fact that pH decreases with depth creating a more acidic condition which makes it difficult for microbes that conduct mineralization to thrive. The crop based soils recorded mean values lower than the top horizons of the toposequence all except the Yam plot that indicated 13.0 mean value compared to Cassava (11.68) and Rice (12.30).

Available P was also low and decreased down the profile at all physiographic positions of the toposequence as shown in Tables 8 and 9. The NFS also showed a decrease down the slope as the lowest value occurred at the crest (1.88 ppm), 2.67ppm for midslope and 3.11ppm for footslope. However, at the SFS, highest value occurred at the topslope (2.95 ppm) followed by footslope (2.44 ppm) while the lowest occurred at the midslope (2.26 ppm). This can be explained to have occurred due to higher organic matter distribution at the footslope for NFS and at the crest for SFS. At the crop based soils (Table 10), highest mean available P was recorded at the Cassava plot (4.54 ppm), followed by Rice plot (3.51ppm) while the lowest was Yam plot (3.20 ppm). Therefore, the concentration of available phosphorus closely followed organic matter distribution of these soils generally and was suggested that some form of phosphates are of organic sources (Brady and Weil 2005).

The exchangeable bases values (Tables 8 and 9) showed that Potassium (K) and Sodium (Na) were low compared to Calcium (Ca) and Magnesium Mg contents. At the NFS (Table 8), Na decreased with depth at the crest with a mean value of 0.013 cmol/kg, constant at the midslope (0.02 cmol/kg) and footslope (0.02 cmol/kg). K increased with depth at the crest with a mean value of (0.07 cmol/kg). It however showed no particular pattern at the midslope and footslope with mean values of 0.068 cmol/kg and 0.063 Cmol/kg respectively. Ca and Mg decreased with depth at the crest with mean values of 0.255 cmol/kg and 0.235 cmol/kg respectively. At the midslope Ca and Mg showed no regular patter, 0.504 cmol/kg and 0.482 cmol/kg were their mean values respectively. Ca decreased down the horizon at the footslope while Mg showed irregular pattern. The mean values for Ca and Mg at the footslope were 0.310 cmol/kg and 0.147 cmol/kg respectively.

Exchangeable bases of SFS (Table 9) indicated an irregular pattern of decrease of Na, K, Ca and Mg down the horizon in all physiographic positions except Na that maintained steady values at the Midslope. Ca followed by Mg recorded the highest mean values, K followed, while Na registered the lowest at all physiographic positions of the toposequence. Na showed highest mean value at the midslope (0.02 Cmol/kg) followed by footslope (0.015 cmol/kg) and topslope (0.014 Cmol/kg). K decreased down the slope with values; 0.086 cmol/kg, 0.074cmol/kg and 0.072 cmol/kg for crest midslope and footslope respectively. Ca and Mg increased down the slope. Ca indicated mean values of 0.33 cmol/kg, 0.332 cmol/kg and 0.875cmol/kg for crest, midslope and footslope respectively whereas those of Mg were 0.19 cmol/kg, 0.254 cmol/kg and 0.545 cmol/kg for crest, midslope and footslope respectively. These highest values of Ca and Mg can be as a result of the pedogenic parent material which is of Eze Aku shale with intercalation of Amasiri Sandstone (Ofomata 1975, Obi *et al*., 2001). However mean total exchangeable bases at the NFS increased from crest to midslope (0.57-1.08 cmol/kg) and decreased at the footslope (0.54 cmol/kg). At the SFS mean total exchangeable bases increased down the slope recording 0.614, 0.676 and 1.478 cmol/kg for crest, midslope and footslope respectively.

Table 10: Chemical Properties of Crop Based Soils (CBS)

Location	pH: H_2O	pH: KCl	OC	OM %	TN	C:N	Avail. P:ppm	Na	K	Ca	Mg	TEB Cmol/kg	H -	Al	TEA	ECEC	Base Sat.(%)	Al Sat.(%)
	Cassava																	
1	5.16	4.48	1.61	2.75	0.16	10.2	5.81	0.01	0.12	1.54	2.58	4.25	1.15	1.98	3.13	7.38	58	27
2	5.38	4.47	1.34	2.31	0.11	11.7	5.22	0.01	0.15	2.56	0.74	3.46	1.15	2.01	3.15	6.61	52	30
3	5.33	4.52	1.16	2.01	0.09	12.4	4.62	0.01	0.21	2.18	1.32	3.72	1.25	1.95	3.21	6.92	54	28
4	5.21	4.51	1.16	1.82	0.11	11.6	3.81	0.01	0.15	2.48	1.01	3.64	1.35	2.23	3.58	7.22	50	31
5	5.31	4.44	1.06	2.19	0.09	12.5	3.24	0.02	0.13	2.96	0.71	3.81	1.75	2.75	4.51	8.31	46	33
mean	5.28	4.484	1.27	2.23	0.112	11.68	4.54	0.012	0.152	2.34	1.27	3.776	1.33	2.184	3.516	7.29	52	29.8
	Rice																	
6	5.21	4.68	1.16	2.01	0.09	11.9	4.11	0.02	0.13	1.31	0.46	1.91	0.62	0.55	1.15	3.06	62	18
7	5.48	4.84	0.94	1.62	0.07	13.2	3.62	0.02	0.11	1.62	0.48	2.22	0.21	0.45	0.65	2.87	77	16
8	5.53	5.02	0.94	1.62	0.07	12.4	3.41	0.02	0.11	1.44	1.36	2.92	0.08	0.48	0.56	3.48	84	14
9	5.22	4.91	1.16	2.01	0.11	11.3	3.01	0.02	0.09	1.42	1.02	2.55	0.13	0.45	0.58	3.13	82	14
10	5.14	4.89	1.06	1.82	0.08	12.7	3.42	0.02	0.14	1.41	0.84	2.41	0.31	0.05	0.31	2.71	89	2
mean	5.32	4.868	1.05	1.82	0.08	12.3	3.51	0.02	0.116	1.44	0.83	2.402	0.27	0.396	0.65	3.05	78.8	12.8
	Yam																	
11	6.21	5.57	1.24	2.13	0.09	13.5	3.52	0.01	0.11	2.76	0.78	3.65	0.48	0.05	0.48	4.13	88	4
12	5.75	5.11	1.32	2.27	0.11	12.6	2.89	0.01	0.13	1.81	2.71	4.64	0.23	0.05	0.23	4.87	95	2
13	5.63	4.69	1.21	2.06	0.11	12.6	3.21	0.02	0.13	2.41	1.06	3.61	0.21	0.73	0.93	4.54	80	16
14	5.55	4.83	1.43	2.47	0.12	11.8	3.39	0.01	0.12	1.61	2.31	4.03	0.31	0.42	0.73	4.76	85	9
15	5.6	4.99	1.34	2.31	0.09	14.5	3.01	0.02	0.19	3.48	0.81	4.49	0.25	0.05	0.25	4.74	95	3
mean	**5.75**	**5.038**	**1.31**	**2.25**	**0.104**	**13.0**	**3.20**	**0.014**	**0.136**	**2.41**	**1.53**	**4.084**	**0.296**	**0.26**	**0.524**	**4.61**	**88.6**	**6.8**
$LSD_{0.05}$	**0.30*** **	**0.29** **		**0.44*** **	**0.62*** **	**1.21*** **	**0.87*** **					**0.53*** **						**0.65*** **

OC=Organic Carbon, OM=Organic Matter, TN=Total Nitrogen, Avail. P= Available Phosphorus, TEB= Total exchangeable bases, TEA= Total exchangeable acidity, ECEC= Effective cation exchange capacity, Base Sat.= Base saturation, Al Sat.= Aluminum saturation

Furthermore, at the CBS (Table 10), Ca recorded the highest value followed by Mg, K and Na the lowest for all the plot. The mean total exchangeable bases indicated that Yam plot showed the highest value 4.084 cmol/kg, 3.776 cmol/kg for Cassava and 2.402 cmol/kg for Rice.

Exchangeable acidity was generally high at the toposequence with increasing depth of the profiles. Also the mean value of exchangeable Al was higher in all physiographic positions of the toposequece (Tables 8 and 9) than its exchangeable H counterpart. At the NFS (Table 8), exchangeable Al was highest at the middle horizons of pedons at the crest (3.15) and midslope (3.83 cmol/kg) as well as the surface of the footslope (1.81 cmol/kg) pedon. However, the mean total exchangeable acidity was highest at the midslope in both the NFS (2.69 cmol/kg) and SFS (3.56 cmol/kg). The mean total exchangeable acidity was higher than the mean total exchangeable bases in pedons A, B, C, D and E while pedon F recorded higher mean TEB compared TEA. This is because, the soil under study is highly acidic and its acidity increased with depth. There is however sufficient rainfall that may have leached out much of the base forming cations leaving the exchangeable complex dominated by H and Al ions (Donahue et al., 1990).

Similarly, mean ECEC was also higher at the midslope of both the NFS and SFS. It increased with depth up to the middle horizon then decreased again. This could be as a result of the higher concentration of TEA at the middle horizons. The mean ECECs at the NFS were 2.56 cmol/kg, 3.78 cmol/kg and 1.61 cmol/kg for crest, midslope and footslope respectively while at the SFS ECEC recorded 3.01, 4.23 and 2.74 cmol/kg at the crest, midslope and footslope respectively. The percent base saturation at the NFS was low and increased down the slope. The mean BS was; 26.8% (crest), 36.8% (midslope) and 37.0% at the footslope. At the SFS, mean percent base saturation followed a similar trend; 25.4% (crest), 27.0% (midslope) and 54.8% at the footslope. The gradual increase of Exchangeable bases down the slope was due the decreasing acidity down the slope making the bases to gain more exchange sites of the soil.

At the CBS, the mean TEA values were lower than their TEB counterparts for the cropped soils making their ECEC to be more dominated with basic cations. The mean ECEC values were 7.29 cmol/kg, 3.5 cmol/kg and 4.61 cmol/kg for Cassava, Rice and Yam respectively. The percentage base saturation for the crop based soils also recorded 52%, 78.8% and 88.6% for Cassava, Rice and Yam respectively. The base saturation of the CBS was very high and can be attributed to the downslope flow of cations through the deposition process of leaching and runoff and the decreasing acidity which provided more exchange sites for the bases (Miller and Donahue, 1996).

Also, the variability of the some selected properties at the NFS and SFS of the toposequence was considered as represented in Table 11. Percent sand recorded low variability generally and decreased down the slope at the NFS whereas the SFS decreased down the slope and increased at the footslope. This may have resulted due to local podogenic action leading to the deposition of eroded and runoff material from the upper slope at the footslope at the NFS. Furthermore, the SFS having more vegetation cover may have encouraged sort of more soil forming processes which led to more variability at the footslope compared to all other physiographic positions of the toposequence.

Table 11. Variability of Selected Soil Properties

Soil Properties	NFS (C.V. in %)	Ranking	SFS (C. V. in %)	Ranking
		Crest		
Sand	5.83	Low Variation	5.78	Low Variation
Clay	20. 7	Moderate Var.	16.6	Low Variation
pH	1.18	Low Variation	7.83	Low Variation
OM	36.77	Moderate Var.	60.79	High Variation
TN	36.88	Moderate Var.	71.68	High Variation
Base Sat.	97.4	High Variation	112.6	High Variation
SCR	50.3	High Variation	74.3	High Variation
		Midslope		
Sand	4.6	Low Variation	4.55	Low Variation
Clay	19.5	Low Variation	23.4	Moderate Var.
pH	7.02	Low Variation	5.14	Low Variation
OM	97.46	High Variation	59.5	High Variation
TN	113.18	High Variation	75.05	High Variation
Base Sat.	76.15	High Variation	102.13	High Variation
SCR	39.6	Moderate Var.	40.87	Moderate Var.
		Footslope		
Sand	2.0	Low Variation	8.02	Low Variation
Clay	24.5	Moderate Var.	18.0	Low Variation
pH	3.31	Low Variation	2.09	Low Variation
OM	55.19	High variation	44.51	Moderate Var.
TN	59.81	High Variation	55.93	High Variation
Base Sat.	32.88	Moderate Var.	35.74	Moderate Var.
SCR	29.9	Moderate var.	25.07	Moderate var.

C. V= Coefficient of Variation, NFS=North Facing Slope, SFS= South Facing Slope, OM= Organic Matter, TN= Total Nitrogen, SCR= Silt-Clay Ratio

Soil pH however, recorded the lowest variation in both the NFS and SFS of the Toposequence. This variability increased down the slope from crest (1.18%) to midslope (7.02%) and then decreased at the footslope (3.31%) at the NFS. There was however a continuous decreasing orders in pH variability downslope at the SFS. They are as follow; crest recorded 7.83%, midslope (5.14%) and footslope recorded 2.09%.

Furthermore, there was a moderate (greater than 20%) variability in percent clay at the crest (20.7%) and footslope (24.5%) of the NFS while the midslope (19.5%) indicated a low variability. The SFS had low variability in crest (16.6%) and midslope (18.0%) while the footslope (23.4%) showed a moderate variability. This is as a result of the downwards movement of fine particles to the foot of the toposequence where they are deposited as well as illuviation and colluvial deposition of particles.

Organic matter however, displayed high variability at the midslope (97.46%) and footslope (55.19%), while the crest (36.77%) recorded a moderate variability at the NFS. There was a general down slope decrease in the variability of organic matter at the SFS. The crest (60.79%) and midslope (59.5%) indicated high variability while that of footslope (44.51%) showed a moderate variability. This may have resulted due to the leaching, runoff and eluviations of soil minerals down the slope at the NFS while the SFS could be said to have more vegetation cover as well as organic debris at its upper slopes.

Moreover, percent total nitrogen recorded moderate variability at the crest (36.88%), very high variability at the midslope (113.18%) and high at the footslope (59.81%) at the NFS. While SFS indicated high variability in all physiographic positions; crest (71.68%), midslope (75.05%) and footslope (55.93%), therefore total nitrogen showed a closer trend in variability to that of organic matter in almost all the physiographic positions on the toposequence. This may have resulted due to the fact that most of the total nitrogen content of our soils is in the organic form (Obasi, 2005).

The base saturation recorded high variability at the crest and midslope, then moderate variability at the footslope of both the NFS and SFS physiographic positions and decreased down the slope. The NFS trend was crest (97.4%), midslope (76.15%) and 32.88% for footslope while at the SFS the trend was; crest (112.6), midslope (112.13%) and footslope (35.74%). The high variability upwards the slope showed that the soil under investigation is a typical highly weathered soil of the tropical region in the southeastern Nigeria. However the low variability at the footslope indicated that more soil minerals have been leached downslope due to runoff and eluviations.

The silt-clay ratio (SCR) recorded high variability at the crest, moderate at the midslope and footslope with a decreasing value down the slope at the both the NFS and SFS of the toposequence. This high variability at the crest indicated advanced weathering at the topslope compared to midslope and footslope that are at a lower level of pedogenesis.

Table 12. Correlation of Selected Soil Properties

	NFS		SFS	
Soil Properties	**Crest**			
	r	r^2	R	r^2
pH Vs. OM	0.93^{ns}	0.86	0.92*	0.84
pH vs. Avail. P	0.96*	0.93	0.94*	0.89
TN vs. pH	0.99*	0.97	0.96**	0.93
TN vs. OM	0.97*	0.94	0.99**	0.98
OM vs. Avail. P	0.99**	0.98	0.98**	0.97
OM vs. ECEC	-0.56^{ns}	0.31	-0.82^{ns}	0.66
	Midslope			
pH Vs. OM	0.99***	0.98	0.70^{ns}	0.49
pH vs. Avail. P	0.95*	0.91	0.65^{ns}	0.43
TN vs. pH	0.99**	0.98	0.78^{ns}	0.61
TN vs. OM	0.99***	0.99	0.98**	0.96
OM vs. Avail. P	0.97**	0.93	0.98**	0.96
OM vs. ECEC	-0.84^{ns}	0.70	0.93*	0.87
	Footslope			
pH Vs. OM	-0.97^{ns}	0.93	0.92^{ns}	0.85
pH vs. Avail. P	-0.97^{ns}	0.94	0.82^{ns}	0.67
TN vs. pH	-0.99^{ns}	0.98	0.95*	0.90
TN vs. OM	0.99^{ns}	0.98	0.99**	0.99
OM vs. Avail. P	0.89^{ns}	0.76	0.98*	0.96
OM vs. ECEC	0.84^{ns}	0.70	-0.10^{ns}	0.01

ns = not significant, *= Significant at 5% level, **= significant at 1% level, ***= significant at 0.1%level. NFS= North Facing Slope, SFS= South Facing Slope, r= Correlation coefficient, r^2 = Coefficient of determination, OM= Organic matter, Avail. P=Available Phosphorus, ECEC= Effective cation exchange capacity.

Table 12 recorded the results of correlation of some soil properties while the graph of relationships of soil properties are shown in appendix 1a-b.

At the NFS crest, pH had the following relationships; it correlated positively and insignificantly ($p>0.05$) with organic matter, correlated positively at $p=0.05$ with available P and total nitrogen. Total nitrogen correlated positively at $p=0.05$ with organic matter, organic matter had a high positive correlation ($p=0.01$) with available P and a negative and insignificant correlation with ECEC. At the SFS-crest; pH correlated positively at $p=0.05$ with organic matter and available P, highly positively at $p=0.01$ with total nitrogen. Organic matter had a very high positive correlation at $p=0.01$ with total nitrogen and available P. It however had a negative and insignificant relationship with the soil ECEC.

Furthermore, pH had a very high positive ($p=0.001$) and significant relationship with organic matter at the NFS-Midslope, also correlated positively and significantly at $p=0.05$ and $p=0.01$ with available P and total nitrogen respectively. At this physiographic position, organic matter also correlates positively and highly significantly with total nitrogen and available P at $p=0.001$ and $p=0.01$ respectively. It however does not correlate positively or significantly with ECEC at this midslope position. Meanwhile, at the SFS- Midslope; pH correlated positively but insignificantly with organic matter, available P as well as total nitrogen. Organic matter correlated positively and significantly at $p=0.01$ with both total nitrogen and available P while at $p=0.05$ with ECEC.

Conversely, at the NFS- footslope, pH correlated negatively and insignificantly with organic matter, available phosphorus and total nitrogen. Organic matter however correlated positively but insignificantly with total nitrogen, available P as well as effective cation exchange capacity. This negative and insignificant relationship that pH exhibited at this physiographic position could be attributed to the shallow water table which created a more alkaline condition and also increased pH down the profile at this footslope compared to other physiographic positions.

4.4 Taxonomic Classification of soils

The soils of the study were classified using USDA Soil Taxonomy System Soil Survey Staff (2003) and correlated with FAO/UNESCO Classification System (Ibanga, 2006). Pedons A, B, D, E and F had argillic (Bt) horizons and low silt/ clay ratio indicating advanced stage of weathering (Tables 2 and 3). Pedons A, D and E had mean percentage base saturation less than 35% and as such Ultisols. The soil has an Udic moisture regime an Iso-hyperthermic temperature regime, hence it belongs to the sub order udult, it also belongs to the great group of the soil kandiudult. Pedons B, C and F had their base saturation above 35% hence Alfisols. The soil has an Udic moisture regime an Iso-hyperthermic temperature regime, hence it belongs to the sub order udalf, and it also belongs to the great group of the soil kandiudalf. They do not have any lithic, paralithic or petroferric contact within 150cm of the mineral soil surface; they have CEC of less than 16 Cmol/Kg (by sum of bases extracted with 1N NH4OAc at pH7) and do not have their clay content decreasing with 20% clay than maximum clay content. They have clay increase of 3% or more in the fine earth fraction and so Pedons A, D and E belong to the great group of Kandiudults and sub group of Typic Kandiudults (Plinthic Acrisol) while Pedons B and F belong to the great group of Kandiudalfs and sub group of Typic Kandiudalfs (Albic Luvisol).

Pedon C has a cambic sub surface horizon that is illuvial horizon in which there has not been enough clay movement to qualify as argillic. The silt/clay ratio however higher (1.05) than other physiographic positions , has a base saturation above 35% and organic carbon decreases with depth it therefore belongs to the soil order Alfisol. Due to its aquic moisture regime it belongs to the sub-order Aqualfs. It also has Iso-hyperthermic temperature regime, it therefore belongs to the soil great group of Kandiaqualfs with sub-group of Typic Kandiaqualfs (Gleyic Luvisols).

Table 13. Geographical Coordinates of the study site in Amasiri Afikpo North, Ebonyi state

North Facing Slope (NFS)		South Facing Slope (SFS)	
a.	Elevation: 49m N 05^o 55’ 57.7’’ E 007^o 53’ 13.5’’	**d.**	Elevation: 49m N 05^o 56’ 01.3’’ E007^o 53’ 22.4’’
b.	Elevation: 38m N 05^o 55’ 58.8’’ E 007^{o}53’ 13.4’’	**e.**	Elevation: 39m N05^{o}56’ 01.3’’ E 007^{o}53’ 21.4’’
c.	Elevation: 32m N 05^o 56’ 00.3’’ E 007^o 53’ 13.4’’	**f.**	Elevation: 31m N 05^o 56’ 05.0’’ E 007^o 53’ 22.1’’

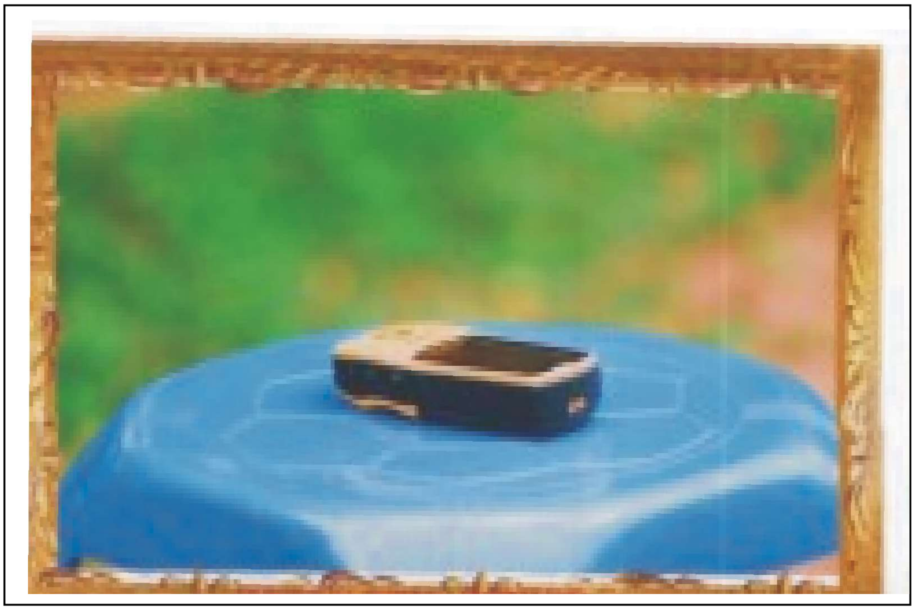

Plate 1: The GPS receiver used for the study

4.5 Digital elevation modeling (DEM)

Digital elevation modeling (DEM) of the area revealed both gentle and steep sloppy surfaces in the area but the place seems to have more steep slopes. This otherwise explains the reason why the place could be regarded as a place with rough terrain. The DEM also reveals the pathway of Cross river which flows through valleys and most of the roads (both secondary and main roads) pass through valleys. Majority of the settlements located are found on the gentle slope. All other settlements except Amizu is located on the steep slope.

However, at the study site the DEM also indicated that these soils fall within Class II – Class IV soils in the USDA land capability classification system (FAO 1983). Limitations ranging from gentle slopes, moderate susceptibility to erosion, less than ideal soil depth, occasional damaging overflow, wetness correctable by drainage, slight climatic limitation were evident. Soils in this class require more than ordinary management practices for obtaining optimum production and for maintaining productivity. The limitations were not so severe as to render the soil unsuitable for agricultural purposes but it can be clearly seen that certain crops will adapt better to a particular location at the study site.

The study site consisting of a toposequence where farmers often grow crop such as yam or cassava along the slopes, while the valleys are continuously used for rice (*Oryza sativa*) and sometimes yam and cassava cultivation or the intercrop of both. This study agrees with (Eshett 1985) who worked on soils of Northern Cross River State in the same agroecology in the South-eastern Nigeria.

Furthermore, the relatively stable terrain at the study site in Amasiri compared to other settlement has however encouraged rice farming prevalent in its inland valleys. This may be due to the lower elevation of the study site as can be seen on the Digital elevation model of the area. The study area generally is naturally endowed with mass body of rocks in some locations which also encouraged quarrying in the study site.

Fig. 5.1 represent the Digital elevation model (DEM) of the study area, Fig. 5.2 showed the DEM of the study site while Fig. 5.3 revealed the 3-dimensional surface view of the study area. Fig. 5.4 showed map of the study area with particular reference to elevations (contour lines). Fig. 5.5 showed the map of the study area.

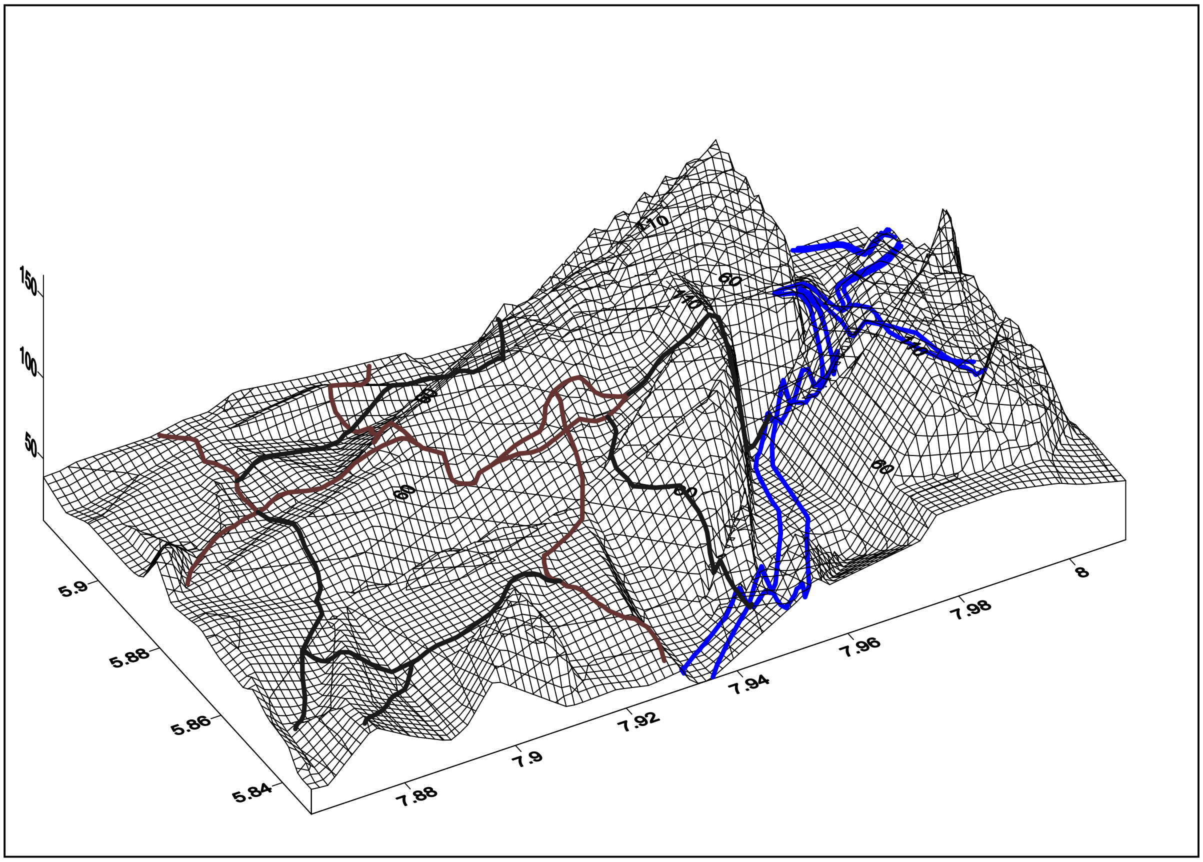

Fig. 5.1: Digital Elevation Model of Study Area

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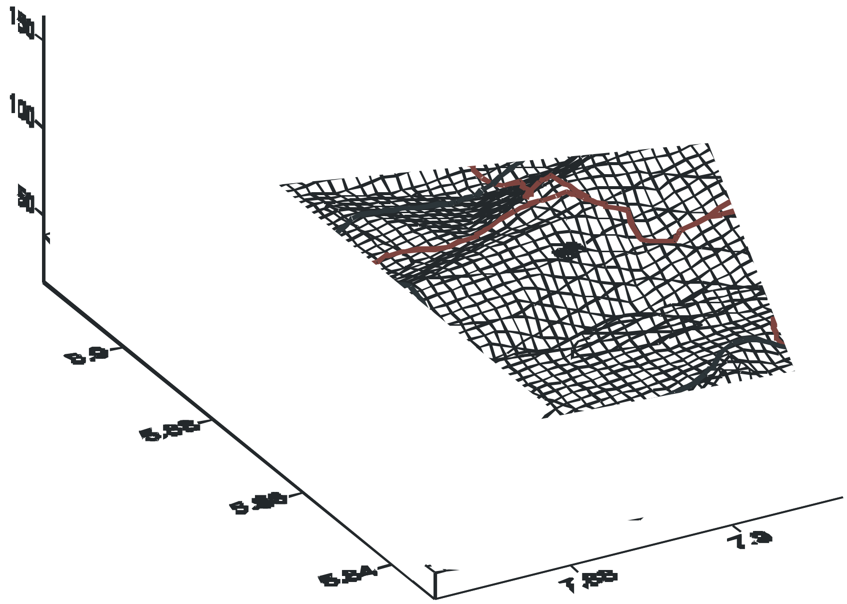

Fig. 5.2 Digital elevation model of study site

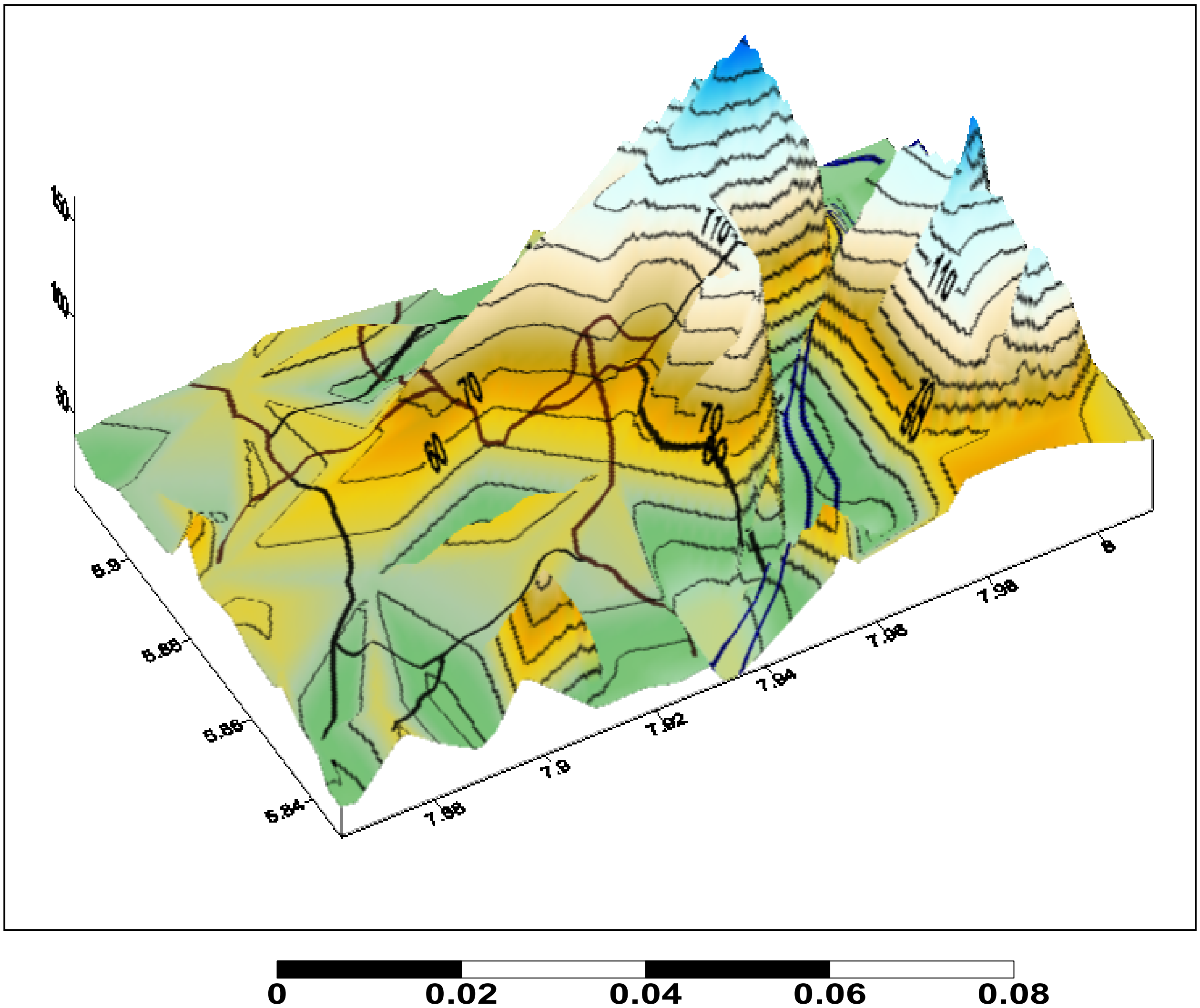

Fig.5.3: 3D- Surface Representation of the Study Area

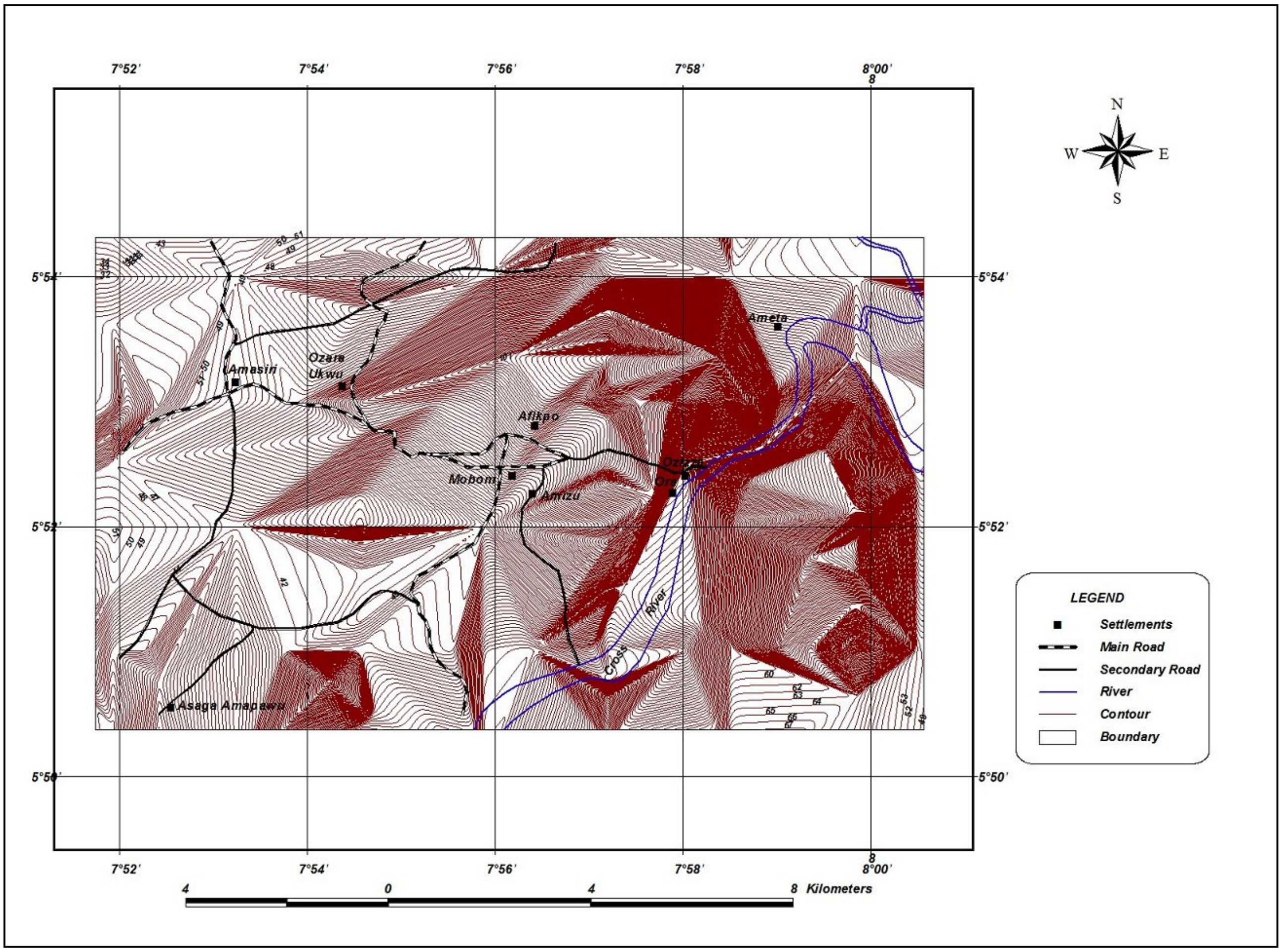

Fig 5.4 Map of Study Area showing elevation (contour lines).

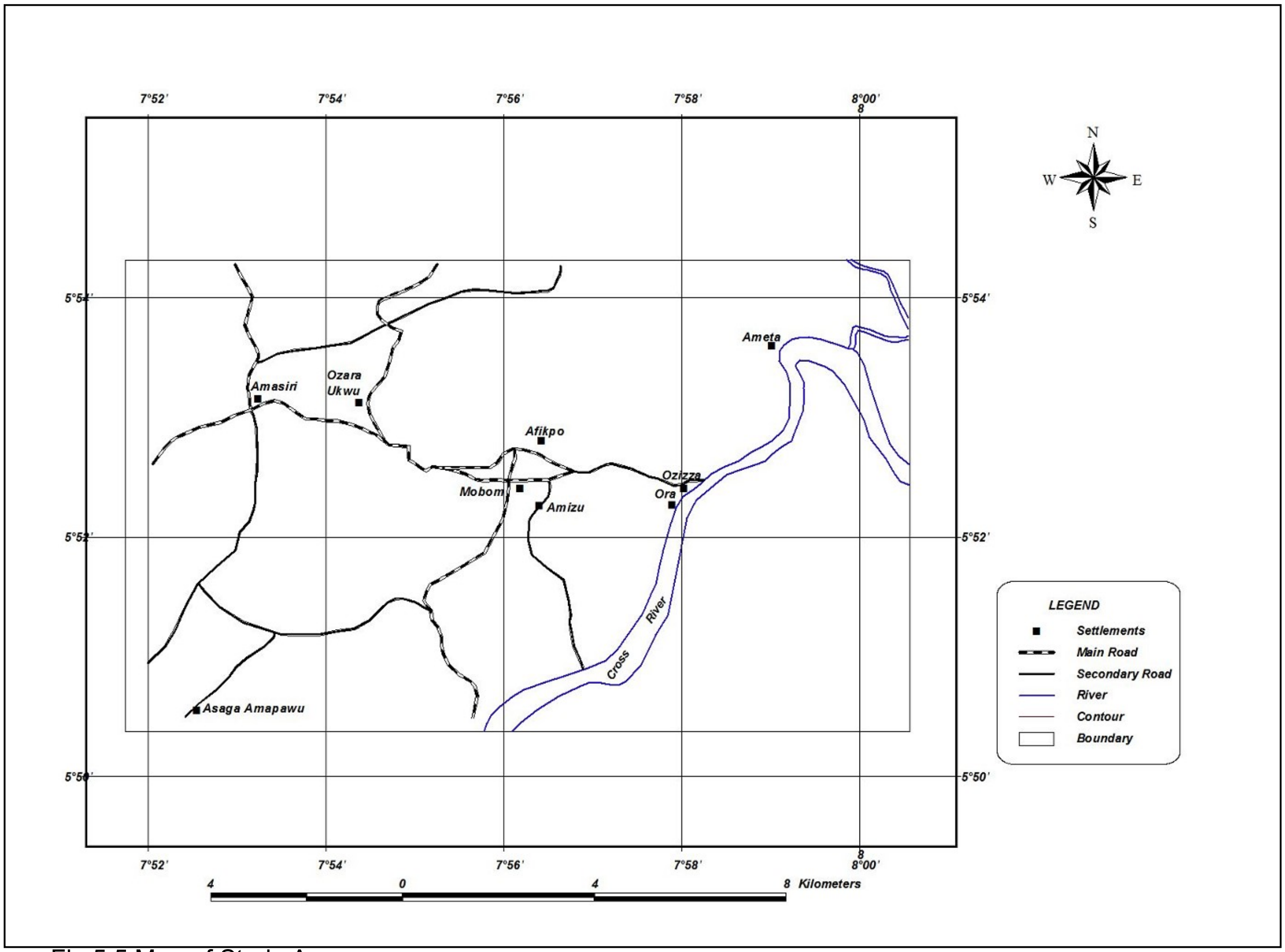

Fig 5.5 Map of Study Area

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4.6 Depth Functions of Selected soil Properties

From Fig. 6.1a At the NFS crest, it can be seen that ECEC increased with depth from A to Bt_1 and then decreased at Bt_2. At the midslope, it increased with depth but decreased at Bt_2 and then increased again at Bt_3. However at the foot slope, there was a decrease down the profile. Fig. 6.1b indicated an increase at the SFS crest from A to Bt_2 and then decreased at the Bt_3. At the midslope, ECEC increased across the profile while there was an irregular trend at the footslope. ECEC was highest at the midslope physiographic positions of the NF and SF slopes.

Fig. 6.2a showed that pH decreased down the profile at the NFS crest, midslope and footslope at all physiographic positions. The same trend applied at the SFS (Fig. 6.2b) except midslope where pH increased at Bt_2.

Fig. 6.3a-b indicated a consistent decrease in organic matter across the profile from top to bottom at all physiographic positions of NF and SF slopes. Fig. 6.4a-b and Fig. 6.5a-b also showed that Total N and Available P followed a decreased trend down the profile at all positions of NF and SF slopes.

Fig. 6.6a showed that percent base saturation decreased with depth at the NFS crest, midslope but increased at Bt_2 and then decreased at Bt_3 of the midslope. Base saturation decreased however at the footslope of SF physiographic position. Fig. 6.6b indicated a decrease at the crest, midslope and footslope positions of SFS.

Fig. 6.7a revealed that percent Al saturation increased down the profile at the NFS crest, midslope though it decreased slightly after Bt_1 at this midslope physiographic position. Percent Al saturation increased at the

AB horizon of NF footslope. It however decreased at the Bg_1. At the SFS (Fig. 6. 7b) percent Al saturation increased down the profile at crest, midslope and footslope physiographic positions.

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Chapter Five

5.0 **Summary, Conclusion and Recommendations**

The results revealed that there was more percent sand at the footslope than all other physiographic position at both the NFS and SFS constituting a common textural class of loamy sand in majority of the pedons. Percent clay was higher at the crest at both the NF and SF slopes. The SCR was low at the crest and midslope which signifies advanced stage of weathering compared to the footslope with a relatively higher SCR which may have been made of younger soils at lower stage of weathering. The Plasticity index (PI) values were all less than 25% which indicated that the soils can also be put to other uses other than agriculture. Bulk density was less than the critical level of 1.85g/cm^3 in all the pedons examined on the toposequence as well as the crop based soils.

The soil pH in water was higher than that measured in 0.1NKCl. This is due to the fact that water measures only the already dissociated hydrogen ion (H^+) while the salt measures in addition to that, the H^+ in the soil complex. Organic matter decreased with depth in the pedons in all physiographic positions. It however increased down the slope at the NFS and showed an irregular pattern of distribution at the SFS. Calcium had the highest value of the exchangeable bases followed by Magnesium on the toposequence as well as the crop based soils. Ca and Mg increased downslope at the SFS whereas at the NFS they were however higher at the midslope due to the aquic condition experienced at the footslope. This increase downslope resulted to a reduced acidity dowslope since Calcium and Magnesium are major component mineral of the basement complex of Eze-Aku shale which form part of the parent material of the region.

The variability of soil properties went as follow; percent sand showed low variation in all physiographic position of the NFS and SFS. Percent clay showed moderate variation at the crest and footslope of the NFS and low variation at the midslope. At the SFS, the midslope recorded moderate variation in the percent clay content while the crest and the footslope showed low variation. Organic matter varied moderately at the crest and footslope of the NFS while the midslope indicated a high variation. However, at the SFS, OM showed high variation at the crest and midslope but the footslope recorded moderate variation. Base saturation indicated high variation at the crest and midslope of both NFS and SFS while their footslopes recorded moderate variation.

The correlation between soil properties indicated positive relationship (r=0.001, r=0.01 and r=0.05) between selected soil properties at the crest and midslope of NFS and SFS compared to their footslopes. The aquic condition at the footslope affected the correlation between soil properties. This relationship however does not apply to all the physiographic positions.

Conclusively, adopting good and adequate management measures on the soil under investigation will certainly improve agricultural production especially at the footslope and valley bottom generally with higher organic matter and certain other nutrient elements. The Digital elevation modeling (DEM) of the area revealed that it also consists of geological features such as high elevations, with rough terrain and presence of huge mass of rocks. This large body of rocks has attracted rock miners who recently established quarrying sites in large locations of the study site. Soils were classifies based on United States Soil Taxonomy Systems and correlated with FAO/UNESCO Soil Classification System as Typic Kandiudults (Plinthic Acrisols) for Pedons A, D and E, Typic Kandiudalfs (Albic Luvisols) for Pedons B and F, while Pedon C as Typic Kandiaqualfs (Gleyic Luvisols).

Recommendations

Due to the increasing demand for food security to meet up with the country's population growth and the vulnerability of our soils generally to agents of degradation, it is however necessary in this study to suggest measures to be taken to achieve optimal utilization of soils of Amasiri. Therefore, for effective management of these soils, the following practices should be adopted.

1. The farmers are encourages to supplement the soil nutrients by the use of organic and inorganic fertilizers. This is because these soils are subjected to continuous farming and it is necessary to replenish the nutrients taken by crops.
2. Bush burning by hunters and farmers should be discourages. This does not only destroy the natural habitat causing and imbalance in the ecosystem but it also exposes the soil to agents of degradation such as; wind or water erosion and the direct heating of soil surface by sunlight leading to loss of nutrients through evaporation.

3. Farming on the toposequence should be across the slope rather than along the slope. This will reduce surface runoff and invariably reduce the loss of nutrients by agents of erosion.
4. There should also be improvement in the organic matter status of these soils to increase soil aggregation, structural stability, lower the bulk density for easy root penetration and increase soil water holding capacity.
5. The use of heavy machines at the quarry sites should be discouraged as it does not only affect the top soils which constitute the highest organic fraction but also subject these soils to compaction. This will render the soils perpetually useless with respect to agriculture even after many years of quarrying.
6. The use of crop rotation, alley cropping, shrub fallow and mixed cropping can sustain the productivity of these soils irrespective of the topography and high population growth.

REFERENCES

Akamigbo FOR (1999). Influence of land use on soil properties of the humid tropical agro-ecology of southeastern Nigeria Agric J., 30:59-76.

Alexander, M. (1977). Advances in Soil Microbiology. Pleum Press, N.Y., pp 190-385.

Aregheore, E.M. (2006). Nigeria: Country pasture/Forest resource profile. Apia: Animal Science Department, School of Agriculture, The University of the South Pacific, Alafua Campus, SAMOA.

Aubest, G. and R. Taverina. (1972). Soil survey. In: Soils of the humid tropics. U.S. Washington: National Academy of Sciences.

Avery B.W. (1980) Soil Classification for England and Whales, Soil Survey Technocal Monograph No.14 Harpenden Soil.

Aweto, A. O. (1982). Variability of Upper Slope Soils developed on sandstone in South western Nigeria. The Nig. Geogr. J.25:27-37.

Baldwin, M., C.E. Kellogg, and J. Thorp (1938). Soil classification. In *Soils and men: Yearbook of agriculture.* Washington D.C.: U.S. Department of Agriculture. pp. 979-1001.

Bennett, O.L., E.L. Mathias, and P.R. Henderlong. (1972). Effects of north and south facing slopes on yield of Kentucky Bluegrass (*Poa pratensis* L.) with variable rate and time of nitrogen Application. Agron. J. 64:630–635

Birkeland, P. W. (1999) Soils and Geomorphology, Oxford University Press, New York pp 450

Blake, G. R. and Hartge, K. H. (1982); Bulk Density. In A Klute (Ed.) Method of Soil Analysis, part 1. 2nd ed. Am. Soc. Agron., Inc. Madison.

Bouyoucos, G. H. (1951): A Recalibration of hydrometer for making mechanical analysis of soils; Agron. Journal 43 pp 434-438.

Brady, N.C. and Weil, R.R (1999): The Nature and Properties of Soil. 12th ed. Prentice Hall, Inc. New Jersey 07458.

Brady, N.C. and Weil, R.R (2005): The Nature and Properties of Soil. 13th ed. New Jersey, Prentice Hall, Inc.

Bremner, J. M. and Milvaney, C. S. (1982). Nitrogen-total. In Methods of Soil Analysis, Part 2, ed. A. L. pg. Miller and D. R. Keeney (eds.). American Society of Agron. Madison WI, pp 593-624.

Burrough, P. A. (1986) Principles of Geographical Information Systems for Land Resources Assessment, New York: Oxford University Press.

Chang, K. (2006) Introduction to Geographical Information Systems, Boston: McGraw Hill Higher Education, Third Editions.

Ciha, A.J. (1984). Slope position and grain yield of soft white winter wheat. Agron. J. 76:193–196.

Cleaver, K.M. and Shreiber, A.G. (1994) Reversing the Spiral. Washington, D.C.: World Bank.

Cottenie, A., Kang, B.T., Kiekens, L. Sajjapongse, A. (1981). Micronutrient status. pp. 149-163. In: Greenland, D.J. (ed.). Characterization of soils in relation to their classification and management for crop production: Examples from some areas of the humid tropics. London: Oxford University Press.

Cowen, D. J., (1990) GIS versus CAD Versus DBMS: What are the differences? In Peuquet, D. J. and Marble, D. F. (Eds.) Introductory Readings in Geographic Information Systems, New York: Taylor & Francis, pp 52-61.

Daniels, R.B., J.W. Gilliam, D.K. Cassel, and L.A. Nelson., (1985) Soil erosion class and landscape position in the North Carolina Piedmont. Soil Sci. Soc. Am. J. 49:991–995

Donahue, R. L., Miller, R. W., Schickluna, J. C. (1990). An Introduction to Soils and Plant Growth, 5th Edition, Prentice Hall of India, New Delhi. 689pp

Eshett, E. T. (1985). Soil Characterization and Farming Systems in Northern Cross River State of Nigeria, Unpublished Ph.D. Thesis Department of Agronomy, University of Ibadan, Nigeria

Eshett, E. T. (1991) Socio-economic and Edaphic Factors of Small Scale Arable Crop Production in Southeastern Nigeria: A Case Study of Eziobodo Farming Community, Agronomie Africaine 111(1): 23-33.

Eshett, E. T. (1993), The Wetland Soils of Nigeria: Properties, Classification and Traditional Land Use Practices. In Gopal B., Hillbricht-Ilkowasko, and Wetzel, R. G. (eds.) Wetlands and Ecotones: Studies of Land-Water interactions, New Delhi National Institute of Ecology in conjunction with International Scientific Publications. Pp 227-240.

Eshett, E. T. (1996). Characteristics and Management Problem of Humid and Sub-humid Tropical Soils with Special Reference to Southeastern Nigeria, Agronomie Africaine VIII(1): 21-35

Environmental Systems Research Institute (ESRI), (1991) A Glossary for GIS and ARC/INFO Terms, Redlands: Environmental Systems Research Institute, Inc.

Fanning, D.S. (2004), University of Maryland Soil Monolith Collection and Some Associated History. Soil Surv. Horizons 45: 7-13.

FAO/UNESCO, (1974) FAO/UNESCO Soil map of the world, 1:5,000,000 Vol. 1 Paris: UNESCO.

FAO (Food and Agriculture Organization). (1983). Guidelines: Land evaluation for rainfed agriculture. Soils Bulletin No. 52. Rome: FAO.

FAO (Food and Agriculture Organization). (1986). Atlas of African Agriculture. Rome: FAO.

FAO(Food and Agriculture Organization) (1995) Land and water integration and river basin management. In: Proceedings of an FAO Informal Workshop Rome, Italy, 31 January - 2 February 1993. Rome: Food and Agriculture Organisation of the United Nations

FAO (Food and Agriculture Organization). (1998) Guidelines for Soil Description (2th ed.) Rome: Food and Agriculture Organization of the United Nations. Rome, pp:66.

FAO (Food and Agriculture Organization). (2002), Gateway to land and water information: Nigeria national report. Rome: Food and Agricultural Organization of the United Nations Available from: http://www.fao.org/landandwater/swlwpnr/reports/ rc_codes.htm

Federal Department of Agricultural Land Resources (1985), Reconnaissance Soil Survey of Imo State Nigeria Soil Report, F.S.A.L.R. Kaduna, Nigeria

Fiez, T.E., B.C. Miller, and W.L. Pan. (1994). Winter wheat yield and grain protein across varied landscape positions. Agron. J. 86:1026–1032

Franzmeier, D.P., E.J. Pedersen, T.J. Longwell, J.G. Byrne, and C. Losche. (1969). Properties of some soils in the cumberland plateau as related to slope aspect and position. Soil Sci. Soc. Am. Proc. 33:755–761.

Foth, H.D., (1984).Fundamentals of Soil Science (7th ed). John Willey and Sons inc., New York. 234 pp

Foth, H.D. (1990), Fundamentals of Soil Science (8 ed.). New York: John Wiley and Sons INC. 360 pp.

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

Grossman, R.B., Reinsch, T.G.(2002). Bulk density and linear extensibility, In: Dane, J.H., Topp, G.C. (eds). Methods of soil analysis, part 4 physical methods. Soil Sci. Soc. Am. Book Series No.5 ASA and SSSA, Madison WI 2002; 201-228

Holdren, J. P., G. C. Daily and P. R. Ehrlich, (1995). The Meaning of Sustainability: Biogeography aspects. In Munasinghe, M and W. Shearer, (Eds) Defining and Measuring Sustainability: The Biogeophysical foundations. The United Nations University (UNU) and The World Bank, pp: 141.

Hurn, J. (1993) Differential GPS Explained: An expose of the surprisingly simple principles behind today's most advanced positioning Technology, Trimble Navigation Limited.

Huxhold, W. F. (1991) An Introduction to Urban Geographic Information Systems, New York, Oxford University Press.

Ibanga, I. J. (2006) Soil Studies: a pedological approach. Maesot Printing, Calabar, Nigeria.

International Institute of Tropical Agriculture (1979). Selected methods for soil and plant analysis. IITA Manual Series No 1: IITA Ibadan, Nigeria. 71pp.

International Institute of Tropical Agriculture (IITA). (1984). Farming system program research highlights 1981-1984. Ibadan, Nigeria. IITA.

International Soil Reference and Information Centre (ISRIC) (2005) Updated global and national soils and terrain digital databases (SOTER).

Irvin, B. J. (1996) Spatial Information Tools for Delineating Landform Elements to Support Soil/Landscape Analysis, Ph.D. Thesis, University of Wisconsin: Madison 432pp.

IUSS Working Group WRB (2006) World reference base for soil resources 2006. World Soil Resources Reports No. 103. Rome, FAO.

Izak, A. M. N., Swift, M.J. and Andriesse, W. (1990) A strategy for inland valleys agro-ecosystems research in West and Central Africa. Resource and Crop Management Programme, Research Monographs No. 5. International Institute of Tropical Agriculture, Ibadan. 24 pp.

Jaiyeoba, J. O. and Ologe, K. O. (1995). Soil Degradation in Nigeria Semi-arid Region: in G.E.O. Omuta et al., (eds). Goegraphy and sustainable development; Abstract of Papers: 30th Ann. Conf. N. G. A. 28th -31st May 1995 pp:70.

Jenkinson, D.S., (1981) The Chemistry of Soil Process. Ed. D.J Greenland and M.H.B. Hayes, Willy, Chichester. 505 pp.

Jones, C. (1997) Geographical Information Systems and Computer Cartography, Essex: Addison Wesley Longman Limited.

Juo A.S.R. and Adams, F. (1986). Chemistry of LAC Soils. pp. 37-62. In:Proceedings of Symposium on Low Activity Clays (LAC) Soils. SMSS Technical Monograph No. 14. Washington DC.

Jungerus, P. D. and Leveli T.W.M. (1964) Clay Minerallogy of Soils Over Sedementary Rocks in Eastern Nigeria, Science Vol. 97 No.2

Jungerus, P. D. (1964) The Soils of Eastern Nigeria, Publication Services Geological du Luxembeurg XII:185-198

Kampen, J., and Burford, J. (1980). Production systems, soil related constraints and potentials in the semi-arid tropics with special reference to India. pp. 141-165. In: International Rice Research Institute (IRRI) (ed.). Priorities for alleviating soil-related constraints to food crop production in the tropics. Los Banos, Philippines: IRRI.

Kang, B.T. and Fox, R.L. (1981). Management of soils for continuous production and controlling nutrient status. pp. 202-213. In: Greenland, D.J. (ed.). Characterization of soils in relation to their classification and management for crop production. Examples of some areas of the humid tropics. London: Oxford University Press.

Kang, B.T. and Juo, A.S.R. (1983). Management of low activity clay soils in tropical Africa for food crop production. pp. 450-470. In: Beinroth, FH, Neel H., Eswaran H. (eds.). Proceedings of the Fourth International Soil Classification Workshop, Kigali, Rwanda. Brussels, Belgium: ABOS-AGCD.

Kang, B.T. and Juo, A.S.R. (1986). Effect of forest clearing on soil chemical properties and crop performance. pp. 383-394. In: Lal, R. Sanchez, P.A., Cummings, R.W. (eds.). Land clearing and development in the tropics., Rotterdam, Netherlands: A.A. Balkema.

Kang, B.T. and Spain, J.M. (1986). Management of low activity clays with special reference to Alfisols, Ultisols and Oxisols. pp. 107-131. In: Proceedings of Symposium on Low Activity Clays (LAC) Soils. SMSS Technical Monograph No. 14. Washington DC.

Kang, B.T., and VandenBeldt, R. (1990). Agroforestry systems for crop production in the tropics with special reference to West Africa. pp. 13-34. In: Moore, E. (ed.). Agroforestry land-use systems. Waimanalo, Hawaii: NFTA.

Kasianchuk, P and Taggart, M. (2004) Introduction to ArcGIS I, Redlands: Environment Systems Research Institute (ESRI). Kevany, M. J. (n.d) GIS and CADD: Relationship in a Local Gorverment Utility, Mimeograph, Plan Graphics, Inc., Maryland.

Kilian, J. (1974). Etude du milieu physique en vue de son amenagement. Conceptions de travail. Methods cartographiques L'Agronomic Tropicale, Vol. 29, 2-3.pp 141-153.

Klingebiel, A.A. and Montgomery, P.H. (1961). Land capability classification. Agriculture handbook no 210. Soil conservation service, Washington D.C. US Department of Agriculture (USDA).

Krall, L., Lee C.E. (2004). Keeping the link: Soil survey inventory and technical service. Soil Surv. Hor. 2004, 45 (1): 35-36

Kravchenko, A.N., and D.G. Bullock. (2000). Correlation of corn and soybean grain yield with topography and soil properties. Agron. J. 92:75–83

Kreznor, W.R., K.R. Olson, W.L. Banwart, and D.L. Johnson. (1989). Soil, landscape, and erosion relationships in a northwest Illinois watershed. Soil Sci. Soc. Am. J. 53:1763–1771.

Krivoruchko, K. (URL) GIS and Geostatistics: Spatial Analysis of Chemobyl's Consequences in Balarus, http://www.ncgia.ucsb.edu/conf/sa_workshop/papers/Krivoruchko_old.html

Lal, R. (1974). Role of mulching techniques in tropical soils and water management. Technical Bulletin I. Ibadan, Nigeria: IITA.

Lekwa, M. U. (1998), Soil Survey and Land Evaluation for Irrigated Rice Paddy at Igwu River Flood Plane, Abia State. University of Nigeria Research Publications

Leonard, D. (1986) Soils Crops and Fertilizer Use: A Field Manual for Developing Workers Peace Crops of the United States of America: 205pp.

McCraken, R. J and Southard, R.J., (1997) Soil Genesis and Classification, 4th eds. Ames, Iowa: Iowa State University Press.

McKeague, J.A. (ed.) (1978) Manual on soil sampling and method of analysis. Canadian Society of Soil Science, 66-68.

Miller, M.P., M.J. Singer, and D.R. Nielsen. (1988). Spatial variability of wheat yield and soil properties on Complex Hill. Soil Sci. Soc. Am. J. 52:1133–1141

Mooman, F. R. (1981). Representative of toposequence of soils in Southern Nigeria and their Pedology. In: Characterization of Soils in Relation to their Classification and management for Crop production. D.J Greenland (ed). Clarendo Press Oxford. pp. 10-29.W1 pp: 960-1000.

Moore, I.D., P.E. Gessler, G.A. Nielsen, and G.A. Peterson. (1993). Soil attribute prediction using terrain analysis. Soil Sci. Soc. Am. J. 57:443–452

Munsell. (1975). Standard soil color charts.

Myers, D.E. (URL) What is Geostatistics? http://www.u.arizona.edu/-donaldm/homepage/whatis.html

Nelson, D. W and Sommers L. E. (1982). Total Carbon, Organic Carbon and Organic Matter in: Sparks, D. L. (Eds.), Methods of Soil Analysis. Part 3. SSSA Books Series No 5 SSSA Madison,

Nuga, B. O., Eluwa, N. C., and Akinbola, G. E. (2008). Characterization and Classification of Soils Along a Toposequence in Ikwuano Local Government Area of Abia State Nigeria: *Electronic journal of Environment, Agriculture and Food Chemistry*. Pp: 2779-2788.

NAP (National Academy Press). (1982). Ecological aspects of development in the humid tropics. Washington D.C.: National Academy Press.

Nicholaides III, J.J., Bandy D.E. Sanchez, P.A., Villachienea, J.H., Coutou, A.J., Valverde, C. (1984). From Migratory to continuous agriculture in the Amazon basin. pp. 141-168. In: Improved production systems as an alternative to shifting cultivation. Soils Bulletin No. 53. Rome: FAO.

Obasi, S. N., (2005) Organic carbon, nitrogen and phosphorus in cultivated and uncultivated soils of Ebonyi and Imo States of Nigeria. Final year project, Soil Science Department FUT-Owerri, Imo State.

Obi, G.C., Okogbue, C.O., Nwajide, C.S., (2001). Evolution of the Enugu Cuesta: A tectonically driven erosional process. Global Journal of Pure Applied Sciences 7, 321–330.

Obihara C. H. (1961), The acid sands of Eastern Nigeria Part 1: Extent. Nigerian Scientist 1:57-64.

Odenerho F. O. (1980). Catenary sequence and agricultural productivity in the tropic. Paper presented at the conference of the 8th joint annual national soil correlation committee. *Soil Sci. Soci. Of Ng* 1980 pp 15

Ofomata, G.E.K. (1975) Eastern states of Nigeria: Hydrology. In: G.E.K. Ofomata (ed.) Nigeria in maps. Benin City: Ethiope Publishing House. Pp. 13-15.

Ogunkunle, A. O. (1995) Nigerian Soils and their Capacity for Crop Production, Green Magazine.

Ohieri, G.E.C. (1961) Soil Observation in Eastern Nigeria

Ojanuga, A. G. and A. I. Awujoola, (1971) A Study of Soils and Genesis in the South Western Upland of Nigeria, Ph.D. Thesis, University of Wisconsin, Mandison WIS, USA.

Ojo-Afere, J. O. and O. M. Oladimeji, (1977) Classification of Soils in S.W. Nigeria and Correlation with US Soil Taxonomy and the FAO Soil Unit. Paper Presented at Joint Conference SSSN and NSCC at Nsuka 1977.

Okusami, T. A., Rust, R. H., and Juo, A. S. R. (1985). Characterization and classification of some Soils formed on Post-cretaceous sediments in

Southern Nigeria. Soil Sc. 140: 110-119.

Olson, S. R. and Sommers, L. E. (1982). Phosphorus in: Methods of Soil Analysis. A. L. Page, R. HMiller and D. R. Keeney (eds). Maidson, W. I Americal Sciety of Agronomy: 1572pp.

Oluwatosin G. A., J. O .Ojo-Atere; O. Osiname and J. A. Adediran. (2001). Influence of topographic position on crop responses to different rates of fertilizer in southwestern Nigeria. *Moor journal of Agricultural research* 2: 1-7. 2001

Onweremadu, E.U., (2006). Application of geographic information systems (GIS) on soils, land use and soil-related environmental problems in Southeastern Nigeria. Ph.D. Thesis of the University of Nigeria, Nsukka, Nigeria. 330Pp

Onweremadu, E.U., Osuji, G.E., Eshett, E.T., Opara, C.C., Ibeawuchi, I.I. (2007a) Characterization of Soil Properties of Owner Managed Farms of Abia and Imo States, for Sustainable Crop Production in Southeastern Nigeria. Journal of American Science, 3(1): 28-37.

Onweremadu, E.U., Eshett, E.T., Osuji, G.E., Unamba-Oparah,I., Obiefuna J.C., Onwuliri, C.O.E.,(2007b). Anisotropy of Edaphic Properties in slope soils of a University Farm in Owerri, Southeastern Nigeria. Journal of American Science, 3(4): 52-62.

Onweremadu, E.U.; Eshett, E.T.; Osuji, G.E., (2007c). Temporal variability of selected heavy metals in automobile soils. Int. J. Sci. Tech., 4(1), 35-41.

Onweremadu, E.U., Asiabaka, C.C., Adesope, O.M., Oguzo, N.S. (2007d). Application of indigenous knowledge on land use activities among farmers in central Southeastern Nigeria. Online Journal of Earth Science 1(1): 47-50.

Oparandi, O. A., and Oranekwulu S.C.(1988), Liming and Organic Matter Interaction in Nigerian Ultisols. Effect on pH, Organic Carbon and Early Growth on Maize In: O. Babalola (Ed.) Proc. Of The 16th annual Conference of Soil Science Society of Nigeria, Minna, Nov. 27th -30th pp177-198

Pennock, D. J. and De Jong, E. D. (1987) The Influence of of Slope

Curveture on Soil Erosion and Deposition in Hummocky Terrain, Soil Science 144: 209-217.

Pennock, D.J., Anderson, D.W., and De Jong E.D., (1994). Landscape Scale Change in indicators of soil quality due to cultivation in Saskatchewan, Canada. Geoderma 64:1-19.

Quideau, S.A. **(**2002). Organic matter accumulation. *In: Encyclopedia of soil science,* pp. 891-894. New York, USA, Marcel Dekker Inc

Ramadan, K. (URL) The use of GPS for GIS Applications, http://www.geogr.muni.cz/lgc/gis98/proceed/ KRCMAR.html.

Rashid, A. Ryan, J. and Estefan, G. (2007) Soil and Plant Analysis Laboratory Manual (2nd ed.) Islamabad: International Center for Agricultural Research in the Dry Area and National Agricultural Research Center, Islamabad, Pakistan.

Richards, L.A. (1954) Diagnosis and improvement of saline and alkali soils. USDA Agriculture Handbook 60, Washington, DC.

Robert, P. C., (1988). Land Evaluation at farm level using soil survey information systems. Proc. Internal Symp. Land Qualities in Space and Time, Wageningen, pp 299-311.

Rueker, G. R., Park, S. J., Sali T and Pender J (2003), Strategic Targeting of Development policies to a Complex region: A GIS-Based Stratification Applied to Uganda. ZEF-Discussion Paper on Development Policies.

Russel E.U. (1988) Soil Conditions and Plant Growth 11th Ed. Longman Group. U.K Ltd, 565 pp.

Scherr, S. J. and Yadav S. (1996), Land Degradation: A Threat to Developing Country Food Security by 2020. Food, Agriculture and Environment. Discussion Paper 2. Int. Food Policy Res. Inst. Washington D. C. pp 36.

Schlichting, E., Blume, H.P. and Stahr, K. (1995) Bodenkundliches Praktikum (2nd edition) Berlin, Vienna, Blackwell. 295pp.

Silver, W.L., Seatena, F.N. Johnson, A.H., Siccama, T.G. and Sanchez, M.J., (1994). Nutrient availability in a Montane wet tropical forest:

spatial patterns and methodological considerations. Plant and Soil 184: 129-145.

Simmons, F.W., D.K. Cassel, and R.B. Daniels. (1989). Landscape and soil property effects on corn grain yield response to tillage. Soil Sci. Soc. Am. J. 53:534–539.

Smith, T. R., Menon, S., Stars, J.L., and Estes, J. E. (1987) Requirements and Principles for the implantation and Construction of Large-scale Geographic Information Systems, International Journal of Geopgraphical Information Systems, 1(1), pp 13-32

Smyth, A.J and Montgomery, (1962) Soil and land Use in Central and Western Nigeria. Govt. Printer, Ibadan.

Soil Survey Staff, (1975). Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys. U. S Government printing office, Washington D. C., U.S.A.

Soil Survey Staff, (1978). Soil Taxonomy. Agriculture Handbook no. 436. Washington D.C.: USDA, Soil Conservation Service

Soil Survey Staff, (1993). Soil Survey Manual. Agriculture Handbook,18, Washington D.C. US Government Printing Office.

Soil Survey Staff (1996), Soil quality information sheet; soil quality indicators Aggregate stability National Soil Survey Center in collaboration with NRCS, USDA and the national Soil Tilth. Laboratory, ARS, USDA.

Soil Survey Staff, (1999). Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys. Agric Handbook 435, USDA Washington D. C., U.S.A.

Soil Survey Staff, (2003). Keys to Soil Taxonomy: 9th Edition, USDA Natural Resources Conservation Service Washington D. C., U.S.A.

Stone, J.R., J.W. Gilliam, D.K. Cassel, R.B. Daniels, L.A. Nelson, and H.J. Kleiss.(1985). Effect of erosion and landscape position on the productivity of Piedmont soils. Soil Sci. Soc. Am. J.49:987–991.

Stoop, W.A. 1978. Adaptation of sorghum maize and sorghum pear millet intercrop to the toposequence land types in North Sudanina zone of West Africa Savannah . *Field Crops Research* 16: 255-272.

Tomer, M. D. and Anderson, J. H. (1995) Variation of Soil Water Storage Across a Sand Plain Hill Slope, Soil Science Society American Journal. 38: 109-110.

Tripathl, B.R. and Psychas, P.J. (eds.) (1992) The AFNETA alley farming training manual: Source book for alley farming research (Vol. 2). Ibadan: Alley Fanning Research Network for Africa Institute of Tropical Agriculture.

Udo, E. J. 1980. Profile distribution of Iron sesquioxides contents in selected Nigeria soils. *Journal Agricultural Science of Cambridge* 95: 191 – 198.

Uluocha, N.O, (1999) The Application of Geographic Information Systems (GIS) to Property Rate Administration in Lagos Mainland, Nigeria, Unpublished Ph.D. Thesis, Department of Geography, University of Lagos, Nigeria.

Uluocha, N.O. (2004) Geoinformation: Manure for Sustainable Agricultural Development and Management, in R. E. Ekpenyong and N.Uluocha (eds.) Cartography, GIS and Agricultural Development, A Special Publication of the Nigerian Cartographic Association, pp 119-134.

Uluocha, N.O. (2007) Elements of Geographical Information Systems, Sam Iroanusi Publications, 29A Tejuosho Street, Surulere, Lagos, Nigeria

Unamba-Oparah I. (1985), The Potassium Status of the sandy soils of Northern Imo State, Nigeria. Soil Sci. 139 (5): 437.

Unamba-Oparah I., M. J. Wilson and B. F. L. Smyth (1987) Exchangeable Cation and Mineralogy of Some Selected Nigerian Soils. Applied Clay Science: 2: 105-125.

University of Texas (2004) Geotechnical Engineering Laboratory Test Procedure: Lecture Note 5 - Atterberg Limit Tests (LL & PL). Arlington: University of Texas.

Vine H. (1954) Latosols of Nigeria and Some Related Soils. Proc. 2nd Inter-African Soils Conference (Leopoldville) 1: 295-308.

Wahua, T.A.T. (1999) Applied Statistics for Scientific Studies. Africa Links Books, Nigeria.

Walker, P.H., G.F. Hall, and R. Protz. (1968). Relation between landform parameters and soil properties. Soil Sci. Soc. Am. Proc. 32:101 104.

Walkley, A. and Black, C. A. (1934): An Examination of methods of Determining Soil Organic Matter and a Proposed Modification of Chromic Acid Titration Method. Soil Sci. 120; pp 212-218.

Wigwe, G.A. (1975) Eastern states of Nigeria: Drainage. In: G.E.K. Ofomata (ed.) Nigeria in maps. Benin City: Ethiope Publishi ng House. Pp. 10-12.

Wikipedia (2003) FAO Soil Classofication http://wikipedia.or/WIKI/FAO-Soil Unit Classification Scheme

Wild A. (1993), Soils and the Environment, An Introduction, Global Journal Journal of Pure and Applied Science Vol. 6 No. 4 September 2000: 603-607.

Wright, R.J., D.G. Boyer, W.M. Winant, and H.D. Perry. (1990). The influence of soil factors on yield differences among landscape positions in an Appalachian cornfield. Soil Sci. 149:375–382.

Yang, C., C.L. Peterson, G.J. Shropshire, and T. Otawa. (1998). Spatial variability of field topography and wheat yield in the Palouse region of the Pacific Northwest. Trans. ASAE :17–27.

Zinck, J. A., and C.R. Valenzuela. (1990). Soil geographic database: Structure and application examples. ITC Journal 990:270–294