FERTILITY ASSESSMENT OF SOILS ON THREE GEOLOGICAL MATERIALS FOR PRODUCTION OF SELECTED HORTICULTURAL CROPS IN NSUKKA AREA OF SOUTH EAST NIGERIA

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A THESIS SUBMITTED TO THE DEPARTMENT OF SOIL SCIENCE, UNIVERSITY OF NIGERIA, NSUKKA IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE (MSc) IN SOIL SCIENCE AND LAND RESOURCES MANAGEMENT (REMOTE SENSING, ENVIRONMENTAL IMPACT ASSESSMENT AND LAND EVALUATION)

BY

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SUPERVISOR: PROF. C.L.A ASADU

FEBRUARY, 2020

CERTIFICATION

Umeugokwe, Chigozie Pascal, a post graduate student in the Department of Soil Science with registration number PG/MSc/17/00759 has satisfactorily completed the requirements for the Master of Science in Soil Science (Remote Sensing, Environmental Impact Assessment and Land Evaluation).

The work embodied in this thesis is original and has not been published or submitted in part or full for any diploma or degree of this or any other university.

____________________________	____________________________
Prof. C.L.A. Asadu **(Project Supervisor)**	Date
____________________________	____________________________
Dr. S.E. Obalum **(Head of Department)**	Date

DEDICATION

To God Almighty

for His loving kindness and mercy

towards me and my family

ACKNOWLEDGEMENT

In earnest, I give all the glory to God for sustaining my life through all the challenges on the way to the accomplishment of this project and beyond. May His name be praised forever.

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May God bless you all.

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ABSTRACT

This study assessed the fertility of soils of three geological materials in Nsukka Area of Eastern Nigeria for horticultural crops (pepper, turmeric, ginger and tomato) production. The three geological materials are Upper Coal Measure (Agu-Ibagwa), False Bedded Sandstone (Nkpologwu) and Nkporo Shale (Opi-Agu). A total of three profile pits were dug and 14 core and auger samples were collected from the diagnostic horizons of the three pedons. Also, 36 auger samples (i.e. 18 top and subsoil) were collected from the locations. The samples collected were analyzed for their physical and chemical properties. The data obtained were subjected to descriptive statistics and two way ANOVA using genstat discovery software. The limitation method, parametric method and Multi-Criteria Decision Analysis (MCDA) were used to evaluate the suitability of soils for the production of horticultural crops. Morphologically, all the soils were very deep (> 150 cm) and well drained. The Agu-Ibagwa soils were dark reddish brown (2.5 YR 4/3) in Ap horizon, orange (2.5 YR 6/6) in Bt_1, and bright brown (2.5 YR 5/8) in Bt_2 and Bt_3 horizons; the Opi-Agu soils were brown (7.5 YR 4/4), dark reddish brown (2.5 YR 5/4), bright reddish brown (5 YR 5/8) and red (10R 4/8) in Ap, A_1, Bt and C horizons respectively whereas the Nkpologwu soils were very dark reddish brown (2.5 YR 2/3) in Ap horizon, over dark reddish brown (2.5 YR 3/6), red (10R 4/6), reddish brown (2.5 YR 4/8) and brown (10 YR 4/6). The structure varied from very fine weakly developed structure to fine medium massive granular in Nkpologwu soils; granular to sub-angular blocky structure in Opi-Agu soils and sub-angular blocky structure in Agu-Ibagwa soils. Generally, the horizon boundaries varied from clear smooth, gradual smooth, gradual wavy, diffuse smooth, abrupt smooth and gradually diffuse. Sand, silt and clay fractions range from 640 to 920 g kg^{-1}, 50 to 270 g kg^{-1} and 30 to 170 g kg^{-1} respectively for the three locations. Soil texture varied from sand to sandy clay loam in all the soils. The bulk density ranged from 1.40 to 1.80 g cm^{-3}, 1.40 to 1.70 g cm^{-3} and 1.70 to 1.80 g cm^{-3} at Agu-Ibagwa, Opi-Agu and Nkpologwu soils respectively. The macro, micro and total porosity ranged from 11.20 to 20.10%, 24.20 to 45.00% and 40.40 to 57.10% respectively with values varying irregularly down the depth in all the soils. The saturated hydraulic conductivity ranged from 1.70 to 13.90 cm h^{-1}, 11.60 to 16.80 cm h^{-1} and 33.90 to 87.70 cm h^{-1} at Agu-Ibagwa, Opi-Agu and Nkpologwu soils respectively with highest values in the Ap horizons. Soil reaction ranged from very strongly acidic to neutral as their pH values in H_2O ranged from 5.0 to 7.0 at Agu-Ibagwa, 6.0 to 7.30 at Opi-Agu, and 6.0 to 6.30 at Nkpologwu soils. The Soil Organic Matter (SOM), Total Nitrogen (TN), and Available Phosphorus (Av.P) were low with decreasing trend down the profiles. The exchangeable Na, K, H, Al and CEC, were generally low in all the soils. Also, exchangeable Ca and Mg, and BS ranged from moderate to high with the values of Ca decreasing down the profile and that of Mg and BS varying irregularly down the profile. The soils of the study area were classified as Typic Hapludalfs, Eutric Acrudox and Arenic Kanhapludults at the USDA classification and correlated to Loamic Lixisols and Arenic Acrisols at the WRB classification. Statistically, geological materials (location) significantly ($p \leq 0.05$) influenced particle size distribution and some soil chemical properties (soil pH, OM, TN, exchangeable Ca and Mg, and TEA. Agu-Ibagwa significantly ($p \leq 0.05$) recorded highest values of OM, TN, exchangeable cations and acidity; Opi-Agu significantly ($p \leq 0.05$) recorded highest values of pH, Av. P and CEC whereas Nkpologwu significantly recorded the lower values. Soil depth significantly ($p \leq 0.05$) influenced OM, exchangeable Na and Mg, and TEA with higher values occurring in the subsoil than the topsoil. Silt and sand contents, soil reaction, OM, TN, exchangeable cations, TEB and BS were not significantly ($p \geq 0.05$) influenced by the interaction of geological materials (location) and soil depth. Using the aggregate suitability class, the three locations are highly suitable for the four test crops except Nkpologwu which was moderately suitable for ginger and tomato production. Using the Multiple-Criteria Decision Analysis (MCDA), the Agu-Ibagwa and Opi-Agu soils were highly and moderately

suitable whereas Nkpologwu soils were moderately and marginally suitable for the four test crops.

CHAPTER ONE

INTRODUCTION

Soil is a complex system comprised of minerals, soil organic matter (SOM), water, and air (Vishal *et al*., 2009; Flores-Magdaleno *et al*., 2011). Its properties vary spatially and temporally from a field to a larger region scale, and are influenced by both intrinsic (soil formation factors, such as soil parent materials) and extrinsic factors (soil management practices, fertilization and crop rotation) (Cambardella and Karlen, 1999). Soil quality includes mutually interactive attributes of physical, chemical and biological properties, which affect many processes in the soil that make it suitable for agricultural practices and other purpose (Rakesh *et al*., 2012). These properties play important role in soil fertility and its determined after soil testing (Brady and Weil, 2002).

Fertility of the soil refers to its capacity to supply sufficient quantities and proportions of essential plant nutrients required for optimal growth of specified plants as governed by the chemical, physical and biological attributes of soil. It is a scientific discipline that integrates the basic principles of soil biology, soil chemistry, and soil physics to develop the practices needed to manage nutrients in a profitable and environmentally-sound manner. Thus, soil fertility is a major factor in determining soil productivity. Fertile and productive soils are vital components of stable societies because they ensure growth of plants needed for food, fibre, animal feed and forage, medicines, industrial products, energy and for an aesthetically pleasing environment (Sims and McGrath, 2012).

Nutrient management practices formulated to achieve economically optimum plant performance as well as minimal leakage of plant nutrients from the soil-plant system can only be optimized after soil fertility evaluation. The fundamental purpose of soil fertility evaluation is to quantify the ability of soils to supply nutrients for plant growth (Sims and McGrath, 2012). The evaluation of soil fertility includes the measurement of available plant essential nutrients and estimation of capacity of soil to maintain a continuous supply of plant nutrients for a crop (Khadka *et al.,* 2017).

Describing the spatial variability of soil fertility across a field has been difficult until new technologies such as Global Positioning Systems (GPS) and Geographic Information Systems (GIS) were introduced. The GIS is a tools for collecting, storing, retrieving, transforming and displaying spatial data (Burrough and McDonnell, 1998). Various authors have reported the applications of GIS in soil fertility evaluation (Adornado and Yoshida, 2008; Khadka *et al.*, 2017) and other soil resource applications such as soil resource inventory (Dobos *et al*., 2000; Dwivedi 2001), land capability classification (USDA, 1973; Rosser *et al*., 1974; Panhalkar, 2011), soil suitability assessment (Boonyanuphap *et al*., 2004; Srivastava and Saxena, 2004; Velmurugan and Carlos, 2009), land productivity assessment (ASD, 1995; Nizeyimana *et al*., 1998 and Patil *et al*., 2010) and quantification of soil loss (Karale *et al*., 1988; Lal, 1998; Olson *et al*., 1998; Reddy *et al*., 2004).

The problem of soil fertility in the most sub-Saharan African countries is driven by a wide range of factors. The first one is the geologic origin of the parent material on which the soils have developed (Yusuf and Yusuf, 2008). Parent material refers to the geology or superficial or drift deposit in which soil horizons form. Properties of the parent material that exert a profound influence on soil development include texture (physical property), mineralogical composition and chemical properties as well as the soil morphology (Maribeng, 2007). O'Hare (1997) reported that most soil nutrients originate as chemical salts which are released by rock weathering. Thus, the nature of the parent material has a decisive consequence on soil properties of soils they give rise to (Akamigbo and Asadu, 1983) and plant growth (Kosmas *et al.,* 1993). The chemical properties that make up the chemical basis of soil fertility are classified into two main groups: organic sources (Nitrogen, Phosphorus, Sulphur, Soil Organic Matter etc) and inorganic sources (Calcium, Magnessium, Sodium). However, minerals inherited from the soil parent materials overtime release chemical elements that go through different changes and transformations within the soil. This in turn may influence the properties of the soil (Orobator and Odjugo, 2015). The second cause of low soil fertility is nutrient depletion. Nutrient balances are negative for many cropping systems indicating that farmers are mining their soils (Yusuf and Yusuf, 2008).

Horticultural crops are directly used by man for food, for aesthetic uses and for medicinal purposes. They are an important source of carbohydrates, proteins, organic acids, vitamins and minerals for human nutrition. When humans use the plants or plant parts, whether for food or for aesthetic purposes, there is always a postharvest component that leads to soil nutrient loss (Fallik, 2004). Additionally, fresh horticultural crops are diverse in morphological structure (roots, stems, leaves, flowers, fruits, and so on), in composition, and in general physiology. (Kader, 1992). Horticultural crops include fruits (banana, guava, pineapple), nuts (almond, coconut), vegetables (tomato, onion, cabbage), culinary herbs and spices (pepper, ginger, turmeric), beverage crops (coffee, tea, sugarcane) and medicinal (ginger) as well as ornamental plants.

The study areas have been under arable crops production such as cassava (*Manihot esculenta*), maize (*Zea mays*), yam (*Dioscorea* spp), cocoyam (*Colocasia esculenta*), pumpkin (*Telferia occidentalis*) and cowpea (*Vigna unguiculata*). Some of the areas within Nsukka zone have been under horticultural crops production such as pepper (*Capsicum annuum* L.), tomato (*Lycopersicon esculentum* Mill.), turmeric (*Curcuma domestica* Val.), etc. However, studies on soil fertility evaluation for horticultural crop production in Southeastern Nigeria on different geological materials have been scanty. On this basis, it then becomes necessary to evaluate the fertility of some soils of Nsukka area in Southeastern Nigeria for their potentials for horticultural crop production.

The general objective of this study was to assess the fertility of the soil in three locations on different geological materials for selected horticultural crops production: pepper (*Capsicum annuum* L.), tomato (*Lycopersicon esculentum* Mill.), ginger (*Zingiber officinale* Rosc.) and turmeric (*Curcuma domestica* Val.). The specific objectives of the study were to:

- characterize and classify the soils;
- evaluate the influence of different geological materials on the soils of three locations; and
- evaluate the suitability of the soils for common horticultural crops (pepper, tomato, ginger and turmeric), and produce land/crop suitability map for the crops.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of Parent Materials

Variation in soil properties (morphological, physical and chemical) within or across different agroecological regions is inherent in nature due to geologic and pedologic soil forming factors, but some of the variability may be induced by anthropogenic activities (Iqbal *et al.,* 2005) such as tillage and management practices. These variation in soil properties has long been a subject of interest amongst many researchers globally. Many studies relate the variability of soil properties overtime to many factors as land use (Eden *et al.,* 1991; Amusan *et al.,* 2002; Langley-Turnbaugh and Keirstead, 2005; Ezeaku and Iwuanyanwu, 2013), slope disposition (Huand *et al.,* 2001), small changes in topography which affects the transport and storage of water across and within the soil profile and wetlands (Bruland and Richard, 2005). Nevertheless, the soil forming factors that influence the variability of soil properties include parent material, topography, climate, time and organisms (Soil Survey Staff, 2006). These factors interact with each other either spatially and temporally (Iqbal *et al.,* 2005) and parent material is considered by Jenny (1980) as an important factor in soil formation.

Parent material as defined by Esu (2010) as the material from which soil is assumed to have been derived. It is also defined as the unconsolidated, chemically weathered mineral or organic matter from which the A and B horizons (Solum) of soils may have developed by pedogenic processes (Brady and Weil, 2008). It is a key factor that in many cases determine the kind and contents of secondary minerals of soils, therefore determines its texture and chemical properties (IUSS working Group WRB, 2006). Under the same region, different parent materials affect the morphological and chemical properties of the soils (Brady and Weil, 1999; Akamigbo, 2001; Esu, 2005; Irmak *et al.,* 2007). Nutrient supply to plants is key to crop productivity and according to Gray and Murphy (2002), parent material is a major source of most soil nutrients necessary for plant growth, with the notable exceptions of some nutrients that are primarily derived from the atmosphere and organic matter which are oxygen, hydrogen, nitrogen and carbon. Also, it has been reported by Giesler *et al*. (2005) and Onweremadu (2007) of the great impact parent material exert on the nutrient content of soils.

The influence of parent materials on soil has been studied in several parts of the world and various observations highlighted: Brewer (1954) reported the important role of parent material in determining both the chemical and physical properties of soils. He concluded from his research that pedologist are not concerned with the age or geological relationships of rocks, but with those physical and chemical characteristics which affect soil formation. Westin (1976) observed that parent material of the soils in South Dakota, USA, has significant influence on potassium and phosphorus contents of the soils he studied. Ojanuga and Awujooba (1981) opined that exchangeable cations, CEC and clay contents are related to the kind of soil parent material in Jos plateau, northern Nigeria. Robenhorst (1982) also found that, Mg^{2+} rich soil in Maryland, USA, resulted from Mg^{2+} rich parent material. Akamigbo and Asadu (1983) observed a significant relationship between parent material and most important properties of soil such as colour, texture, reaction, exchangeable bases, total acidity, soil depth, profile drainage and gravel content. Irmak *et al*. (2007) studied the soils of the Arid region of Turkey and observed that different parent materials affect the morphology and chemistry of soils under the same agroecological conditions. The recent studies of Abam and Orji (2019) showed that the morphological features of the soils differed in terms of colour, texture, structure and consistency due to varied parent materials. Though, these and more studies not mentioned here have been carried out but, results produced did not draw out clear universal trends (Gray *et al.,* 2016).

Based on their mode of origin, parent materials can be classified into four main categories: Igneous, Sedimentary and Metamorphic rocks and Unconsolidated materials (Gray and Murphy, 1999). A diagram showing the dominant members within each of the four conventional geological categories is provided in Figure 1. Further details on the classification and characteristics of the major rock types can be found in most geological text books, including Krumbein and Sloss (1963), Pettijohn (1975), Ellers and Blatt (1982), Middlemost (1985), Duff (1993) and Asadu *et al.* (2002). This conventional method (mode of origin) of parent material classification has been regarded by Gray and Murphy (1999) as of lesser significance. However, parent material can be classified for pedologic purposes with respect to its chemical composition. The most useful chemical criteria are silica content (SiO_2) and selected basic cations (taken as Ca, Fe and Mg oxides) which usually have an inverse relationship with each other (Gray *et al.,* 2016). These classification scheme identifies ten major classes: extremely siliceous, highly siliceous, transitional siliceous/intermediate, intermediate, mafic, ultramafic, calcareous (non-siliceous), organic (non-siliceous), alluvial and sesquioxide (non-siliceous). From all indication, a parent material is assumed to belong to one of this class.

However, living organisms such as plants and animals also plays an important and notable role in a number of processes involved in soil formation which are but not limited to organic matter accumulation through litter fall, profile mixing by earthworm and biogeochemical nutrient cycling (Nkongolo and Plassmeyer, 2010).

Soils of Southeastern Nigeria are formed from diverse geological materials (parent materials) (Onweremadu *et al.,* 2007a). One third (80%) of the total land area is of sedimentary geologic deposits (which is made up of shales, coastal plain sand, false-bedded sandstone), and unconsolidated materials (alluvium), while the balance is composed of basement complex and igneous rocks (Akamigbo and Asadu, 1983). FDALR (1990); Edeth *et al.* (1994) opined that coastal plain sands, underlie the major part of the area and consist of unconsolidated yellow and white sand materials which are sometimes cross-bedded with clays, sand clays and sometimes pebbles.

Various studies on the influence of geological materials on the soil (morphological, physical and chemical) properties have been carried out in Nigeria (Akamigbo and Asadu, 1983; Asadu *et al.,* 2001; Onweremadu *et al.,* 2007a; Ndukwu *et al.,* 2012; Ndukwu *et al.,* 2015; Ahukaemere *et al.,* 2016; Onwuka *et al.,* 2016; Abam and Orji, 2019) but, Information on how these parent materials and their corresponding pedogenetic processes influence soil properties in Southeastern Nigeria is limited. There exist important relationships between parent materials and soil properties such as texture, soil reaction (pH), exchangeable bases (Ca^{2+}, Na^{+}, K^{+} and Mg^{2+}) and acidity (H^{+} and Al^{3+}), all are essential to soil fertility evaluation. (Akamigbo and Asadu, 1983). Non-utilization of available information on field/soil data could be responsible for the large number of land degradation observed in most area of Southeastern Nigeria (Ahukaemere *et al.,* 2016). The usefulness of soil studies lies in its land evaluation. Land evaluation aids in determining suitability and capability of the soils for various uses be it forestry, cultivated land, grazing and so on and also eventually serve as a guide to conservation practices and management of the areas being studied (Dent and Young, 1981).

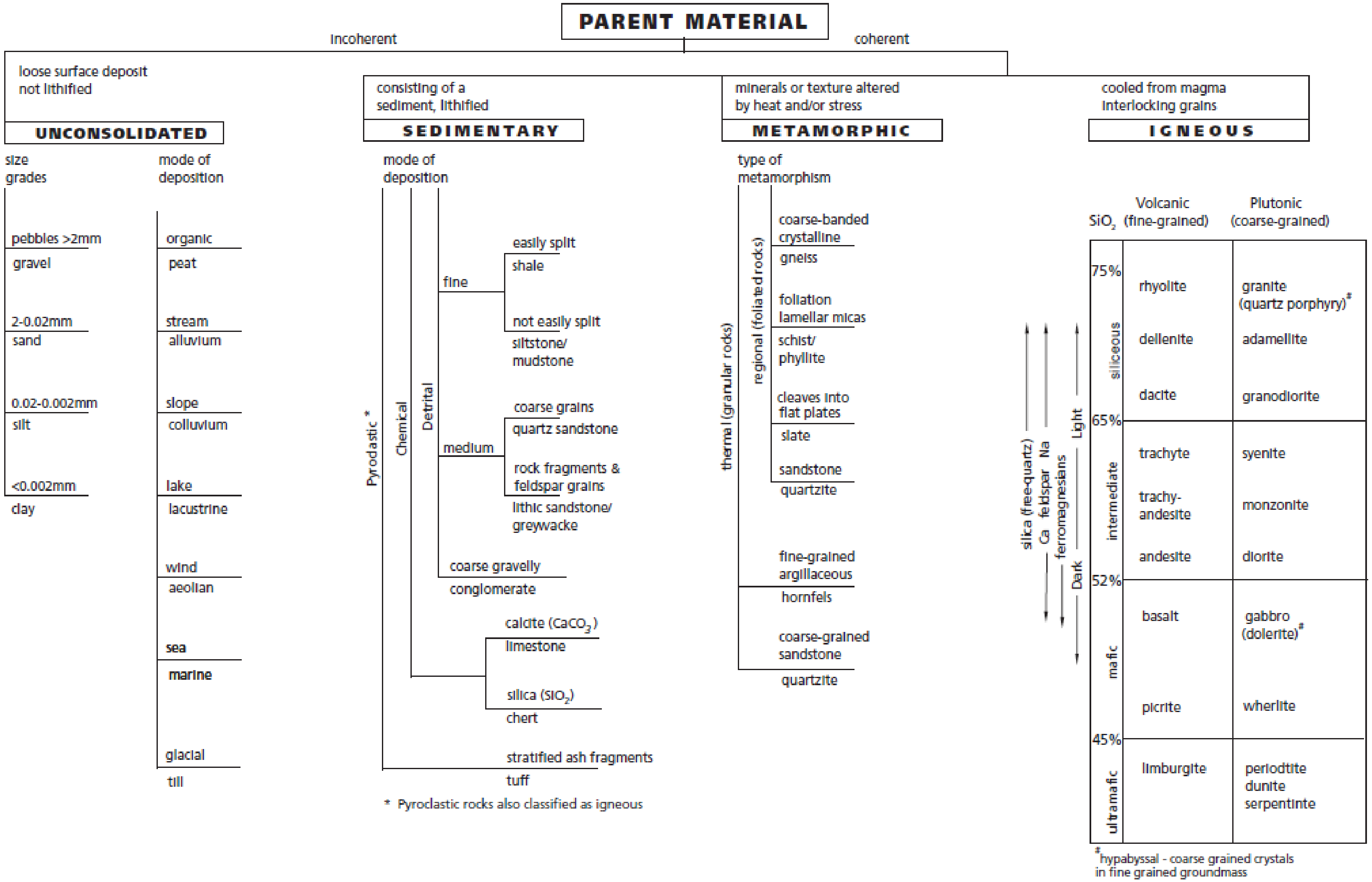


Figure 1: Standard Geological Classification of Parent Material

Source: Talent (1970)

2.2 Soil Physical Properties

The physical properties of soils such as colour, texture, density, hydraulic conductivity and so on. These properties determine the availability of oxygen in soils, mobility of water into or through soils, ease of penetration as well as other properties (Brady and Weil, 2002).

2.2.1 Soil colour

Colour could be referred to as the physical appearance that soils have as a result of the way in which they reflect light. It is an important characteristic of a soil pedon (Akpan-Idiok *et al.,* 2013) and also help us to predict mineral content, chemical composition, physical properties, and other important soil characteristics. Soil colour can indicate many soil features and which for example, difference in the soil's mineral origin (parent materials) or in soil development could be observed in a change in soil colour from adjacent soils (Miller and Donahue, 1995).

The ease with which one horizon is differentiated from each other (either above or below it) when the profile pit is dug during field studies is made possible by the colour of the soil (Brady and Weil, 2002). Though the component horizons in some soil profiles, either the colour are very distinct with sharp boundaries that can be easily seen or the colour changes between horizons may be very gradual making the boundaries more difficult to locate (Brady and Weil, 2002). An important chart (Munsell colour chart) in which a small chunk of soil is being compared to standard soil colour chips in the chart has been developed, to serve as a guide for standard system for accurate colour description. This emphasize the importance of colour in soil classification and interpretation. The chart has three components of colour: hue (usually redness or yellowness), chroma (intensity or brightness, a chroma of 0 being neutral gray), and value (lightness or darkness, a value of 0 being black) used to describe the colour chip (Brady and Weil, 2002). Thus, a colour chip of hue 2.5YR and value of 4/3 can be described as Dark Reddish Brown.

The variation in color change among the pedons and within a pedon could be attributed to climate (Buol *et al.,* 1973), difference in organic matter content, parent material, and drainage conditions (Ashenafi *et al.,* 2010; Buol *et al.,* 2011; Nahusenay *et al.,* 2014; Alem *et al.,* 2015). Brady and Weil (2002) in their work "the nature and properties of soils" stated that the major factors that have the greatest influence on the colour of a soil in addition to organic matter content are water content and the presence and oxidation states of Iron and manganese oxides. However, high water table encountered, especially around stream, lake, river and other water bodies, may have contributed to the slight changes in the soil colour adjacent to it and the profile depths. Thus, the profile characteristics observed by Asadu *et al.* (2001) around Opi Lake in eastern Nigeria could be a reflection of both the influence of lake and nature of the parent material of the area.

Across different landscapes, darker colours usually seen on the soil surface usually indicate higher organic matter contents. Nevertheless, Miller and Donahue (1995) stated that colour is not a good indicator of organic matter.

2.2.2 Soil texture

The relative proportion of sand, silt and clay particle sizes in soil is refers to as Soil Texture (Brady and Weil, 2002). It influences some other soil properties such as water-holding capacity, hydraulic conductivity, total porosity, resistance to pH change, base saturation and organic matter level and also behaviour of soils such as aeration, drainage rate, erodibility, tillage suitability, infiltration, among others (Akpan-Idiok, 2002; Tabor *et al.*, 2017). Three broad groups of soil textural class are recognized: sandy, clayey and loamy soils.

In Southeastern Nigeria, the major factor affecting the soil particle size distribution is parent materials (Akamigbo and Asadu, 1983). Variation of soil texture across different parent materials can due to differences in the composition of the parent rock, land use history and other soil forming factors (Akamigbo, 1999; Ahukaemere *et al.*, 2012). Abam and Orji, (2019) in their study on morphological and physicochemical properties of soils formed from diverse parent materials in Cross River State, Nigeria recorded Sandy Clay to Loamy Sand in Coastal Plain Sands and Sand Stones, Sandy Clay Loam to Sandy Clay in Shales and Basement Complex and Sandy Clay Loam in Basalt.

A strong relationship exists between sand and silt, clay and organic carbon suggesting that an increase in sand leads to decrease in silt, clay and organic carbon. This finding is observed in the studies of Asadu *et al.* (2002); Irmak *et al.* (2007); Onweremadu *et al.* (2007a); Osujieke (2017). Though this is not in harmony with sustainable crop production since clay minerals play important role in soil fertility status of a given location (Abam and Orji, 2019).

2.2.3 Bulk density

Bulk density of a soil is the mass of soil divided by the total or bulk volume of soil (Koorevar *et al.*, 1999). Buol *et al.* (1973) expressed soil bulk density as the weight of a known soil volume compared to the weight of an equal volume of water per unit volume. Its values vary with the arrangement of the soil particles. Typically, sands pack more closely have a bulk density values of range 1.4 to 1.9 g cm^{-3}. Clays tend to bridge and cannot pack as tightly, giving values from 0.9 to 1.4 g cm^{-3} (Warrick, 2002). Thus, Sandy soils have higher bulk densities than fine silts and clays because they have larger, but fewer, pore spaces (Njoloma *et al.,* 2016).

Bulk density influences soil properties and behaviors and affects the activities of microorganisms. According to USDA-NRCS (2015), soil bulk density affects infiltration, rooting depth restrictions, available water capacity, soil porosity, plant nutrient availability and soil microorganism activity. White (1997) stated that values of bulk density ranges from < 1 g cm^{-3} for soils high in organic matter, 1.0 to 1.46 g cm^{-3} for well aggregated loamy soils and 1.2 to 1.8 g cm^{-3} for sands and compacted horizons in clay soils.

Bulk density plays a major role in the nutrient accessibility by the plant roots (Njoloma *et al.,* 2016). The minimum bulk density at which root restricting conditions will occur (1.75 – 1.80 g cm^{-3}) (Soil Survey Staff, 2003). The effects of soil compaction on plant growth are a complex interaction between many soil and plant properties, but for many situations there appears to be an upper limit or threshold soil bulk density value where resistance to root penetration is so high that plant root growth is essentially stopped (O'Connell, 1975). The ideal range of bulk density values for agronomic activities for most mineral soils and which permit easily penetration of most adventitious roots is the range of 1.0 to 1.7 g cm^{-3} (Wild 1993; Amalu, 2016).

Across different parent materials, variation in bulk density values might be attributed to changes in soil depth, moisture content and particle size distribution (Onweremadu *et al.,* 2007). The alluvial soils of the Niger-Ofu river floodplains at Ibaji had bulk density values of 1.12 to 1.70 g cm^{-3} (Ojanuga *et al.,* 2003). Ahukaemere *et al.* (2016) reported bulk density values of 0.96 – 1.62 g cm^{-3} for false bedded sandstone, coastal plain sand and shale parent materials in southeastern Nigeria. Their studies shown that bulk density increased with depth in all the soils studied (Sharu *et al.,* 2013; Fekadu *et al.*, 2018).

2.2.4 Saturated Hydraulic conductivity

Saturated Hydraulic conductivity, symbolically represented as K_{sat}, is a property of soils, that describes the ease with which a fluid (usually water) can move through pore spaces or fractures (Elango, 2011). It is considered one of the most important parameters for water flow and chemical transport phenomena beneath the ground surface, especially in soils and aquifers (Reynolds and Elrick, 2002; Li, 2014). Two of the most commonly measured soil physical properties associating hydraulic conductivity are the soil bulk density and porosity and these two soil physical properties are also essential to soil compaction and related agricultural management issues (Strudley *et al.*, 2008).

In the process of compaction, the macroporosity decreases, whereas the microporosity often increases. This results in larger water contents for a wide range of matric potentials in compacted versus uncompacted soil. Thereby subsequent higher unsaturated hydraulic conductivity of a compacted soil versus uncompacted soil (Van den Akker and Soane, 2005). This agrees with the findings of Ezeaku (2013) that reported hydraulic conductivity mean values of 7.43 cm h^{-1} and 6.27 cm h^{-1} for forest and arable crops respectively in Southeastern Nigeria. Thus, high litter falls and its decomposition may contribute to high K_{sat} value obtained in forest soils.

The soil hydraulic conductivity varies from one season to another. According to Strudley *et al.* (2008), this soil parameter varies in space and time. In the work of Azuka and Obi (2012), the highest mean value (16.1 cm h^{-1}) was obtained at the end of the first cropping season whereas the least mean value (7.01 cm h^{-1}) was obtained at the end of the second cropping season. Thus, values of K_{sat} decreased by almost 30 – 50% between the first and last sampling periods. A good knowledge of seasonal changes in soil saturated hydraulic conductivity is essential for optimal and sustainable management of our agroecosystem.

2.3 Soil Chemical Properties

The chemical properties of soils include the following characteristics: inorganic and organic matters in soil, colloidal properties of soil particles, soil reaction (pH) and buffering action (Balasubramanian, 2017). The interactions of the soil chemical properties with some other environmental factors (climate, topography, and so on) yields products that are valuable to the stability of the ecosystem (Brady and Weil, 2002).

2.3.1 Soil pH

Soil pH is the measure of degree of the acidity or alkalinity of soil, which is caused by particular chemical, mineralogical and/or biological environment. It is also called actual or active acidity (Sanaullah and Shamsuddin, 2010) or soil reaction. It provides many clues about other soil properties and greatly influence the solubility of minerals (Raymond and Roy, 1995).

Descriptively, the terms associated with pH ranges are extremely acidic (pH < 4.5), very strongly acidic (pH 4.5 - 5.0), strongly acidic (pH 5.1 - 5.5), moderately acidic (pH 5.6 - 6.0), slightly acid (pH 6.1 - 6.5), neutral (pH 6.6 - 7.3), slightly alkaline (pH 7.4 - 7.8), moderately alkaline (pH 7.9 - 8.4), strongly alkaline (pH 8.5 - 9.0), and very strongly alkaline (pH > 9.0) (Foth and Ellis, 1997; Soil Survey Staff, 1999).

Soil reaction influences several soil factors that affect plant growth; these include soil microorganism, nutrient leaching, nutrient availability, toxic elements and soil structure (Perry, 2015) because most of these soil factors operates on a certain pH range. For instance, most microorganisms operate best in the pH range of 5.5 to 7.0 (Perry, 2015). Plant nutrients are generally most available to plants in the pH range 5.5 to 6.5 (Gebhardt and Coleman, 1974), and Aluminum may become toxic to plant growth in certain soils with a pH below 5.0.

Soils become acidic as rainfall leaches away the exchangeable cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+) and many of them are replaced by H^+ and Al^{3+} (Brady and Weil, 2002) and thereby may have low pH values. Onwuka *et al.* (2016) reported low pH range of 4.8 to 5.3 from soils of three parent materials (alluvium, sandstone and shale) in southeastern Nigeria (Onwuka *et al.*, 2016). According to Landon (1991) pH range of 5.60 to 6.50 provides the most satisfactory plant nutrient levels for most crops. Abua *et al.* (2010); Iwara *et al.* (2011); Ahukaemere *et al.* (2016) reported the acidic nature inherent in the soils of Southeastern, Nigeria irrespective of their parent materials. Non-leached soils (low rainfall areas) may have pH values 6.0 - 8.0. Sharu *et al.* (2013) recorded pH range of 6.1 to 8.2 in the soils of an agricultural landscape in Dingyadi District, Sokoto State, Nigeria. It was recorded that this range of pH has a significantly positive correlation with calcium ($r = 0.65$) and effective cation exchange capacity ($r = 0.58$) (Amhakhian and Osemwota, 2012a).

On the other hand, soils of high acidity were observed to influence negatively the activities of plant and animal as well as the performance of most arable crops. Ande *et al.* (2008) observed low yield of cassava in the acidic soils of Southwestern Nigeria and similar observations were made by Udo and Ogunkule (2012) for maize production in the southeastern Nigeria. However, the low performance in these soils could be attributed to phosphorus fixations which is predominant in soils of low pH (Enwezor *et al.* 1989).

2.3.2 Soil organic matter

Soil organic matter (SOM) is important for healthy plant growth as it maintains favourable conditions supporting soil moisture retention, temperature, nutrient, pH, and aeration (Njoloma *et al.*, 2016). It is formed from the remains of plants, and animal residues and excreta that are deposited on the surface and mixed to a variable extent with the mineral component (White, 1997). Soil organic matter is one of the major sources of carbon (Donahue and Herren, 1991) and contains about three times as much carbon as is found in all the world's vegetation (Brady and Weil, 2002). Its quantity in the soil can be reduced by incessant burning of plant residues and removal of crop residues through harvest from the fields (Lal, 2000) and high rate of organic matter degradation made possible by relatively high temperature (Asadu *et al.*, 2001).

Enwezor *et al.* (1989) classified soil organic matter as very low (< 4.0 g kg^{-1}), low (4.0 – 10.0 g kg^{-1}), moderate (11.0 – 14.0 g kg^{-1}), and high (> 14.0 g kg^{-1}). Ideally, an agricultural soil should have an organic matter level greater than 2% (Ojomah and Joseph, 2017) and according to Chude *et al.* (2011) critical level of amounts of soil organic carbon in Nigerian soils is 2% (20 g kg^{-1}). Also, the soils classified generally in the *ultisol* order of soil taxonomy are low in organic matter (Enwezor *et al*., 1990) and practices that enriched soil organic matter should be encouraged because decline in soil organic matter would make it difficult for these soils to obtain crop yields equivalent to those expected from rich soils.

Irrespective of landforms, organic matter content of the soils decreases with depth. Brady and Weil (2002) stated that the reason for higher values of organic matter in the upper part of the pedon could be attributed to the fact that most organic residues are incorporated or deposited on the surface horizons than in the lower horizons. In the studies of Ndukwu *et al.* (2012, 2015), the values of soil organic matter were reported to decrease with depth in the soils underlain by three parent materials and river slope in Amaigbo all in Southeastern, Nigeria.

Also, in less severely eroded site where illuviation and leaching had taken place, organic carbon has been found to move downward, thereby making it difficult for plants (arable crops) to access it. Similar findings were reported by Onyekanne *et al.* (2012) in the soils of Ideato North Local Government Area of Imo State, Nigeria, Umeugochukwu *et al.* (2012) in the palm oil polluted soils of Uga, Southeastern Nigeria and Sharu *et al.* (2013) in some soils on an agricultural landscape in Dingyadi District Sokoto State were organic matter has been recorded to increase with depth.

2.3.3 Total nitrogen

Nitrogen is the fourth plant nutrient taken up by plants in greatest quantity next to carbon, oxygen and hydrogen, but it is one of the most deficient elements in the Tropics for crop production (Sanchez, 1976; Mengel and Kirkby, 1987; Mesfin, 1998; Akpan-Idiok *et al.* ,2013). The major store house of nitrogen in soils is organic matter (Brady and Weil, 2002). It is a major determinant of crop yield under field condition and its lowest level is capable of limiting crop yield. Such risk might be attributed with improper management of the resource and inherent volatility nature of the element in tropical soils (Belachew and Abera, 2010).

Shehu *et al.* (2015) classified total nitrogen as < 0.05 (0.5 g kg^{-1}), 0.06 – 0.10 (0.6 – 1.0 g kg^{-1}), 0.11 – 0.15 (1.1 – 1.5 g kg^{-1}), 0.16 – 0.20 (1.6 – 2.0 g kg^{-1}), and > 0.20 (2.0 g kg^{-1}) for very low, low, moderate, high and very high respectively. Uzoho *et al.* (2014) reported in their study that soils of the humid tropical rainforest in southeastern Nigeria have soil organic nitrogen content of 88 – 92% out of the total nitrogen. Generally, total nitrogen contents of tropical soils are rated low to medium using the rating of Shehu *et al.* (2015). Abam and Orji (2019) recorded the mean values of 1.7, 1.6, 1.2, 1.3 and 1.1 g kg^{-1} total nitrogen contents in the soils formed from diverse parent materials (Shale, Basalt, Coastal Plain Sands, Basement Complex Rocks and Sandstone) in Cross River State, Nigeria. Ndukwu *et al.* (2015) reported the lowest mean values (0.2 g kg^{-1}) for soils of a River Slope in Amaigbo, Southeastern Nigeria. Also, Ojomah and Joseph (2017) reported the low values of total nitrogen (0.2 g kg^{-1}) for soils of Kogi East Agroecological Zone of Kogi State.

Soil Nitrogen status differs depending on certain natural and anthropogenic factors, with the later often very important (Hope *et al.*, 2005). Critical anthropogenic factors include those related to land use types and crop management systems (Guggenberger *et al.*, 1994, 1995; Onweremadu *et al.*, 2011). Aberra and Belachew (2011) reported that changes in land use and cropping systems influences soil organic matter and its indices especially the organic carbon, humus, organic and inorganic nitrogen. Nega (2006) reported an increase in total N from cultivated to grazing and forest land soils, which again decrease with increasing depth. The considerable reduction of total N in the continuously cultivated fields could be attributed to the mineralization of the organic substrates derived from crop residue whenever added following intensive cultivation (McDonagh *et al.*, 2001).

2.3.4 Available phosphorus

The second most limiting nutrients in the Tropical soil after Nitrogen (Dibabe, 2000). It is one of the essential nutrient requirements for plant growth (Unamba Oparah, 1985). The ability of a soil to supply potassium to a crop depends on its forms and distribution as influenced by soil physicochemical properties (Chandra and Singh, 1985). Phosphorus plays an important role in plants: increased resistance to diseases, improvement of crop quality in forages and palatability of vegetables, root development, flowering and fruiting including seed formation, formation of fat and albumin, cell division and multiplication and so on (Agbede, 2009).

The major sources of phosphorus in soil are parent material, plant and animal residues and inorganic fertilizers. Phosphorus is taken up by plants from soil solution as orthophosphate anions, $H_2PO^-{}_4$ or $HPO^-{}_4$, depending on the pH of the soil. Its P contents vary considerably over a wide range and depends on the organic matter content, parent material, degree of weathering, soil pH, mineralogy, presence of hydrous oxides of aluminum and iron, carbon dioxide (CO_2), redox potential and degree of phosphorus status of the soil (Agbede, 2009). Soil available phosphorus contents of less than 3.0, 3.0 – 7.0, 7.1 – 20.0 and greater than 20.0 mg kg^{-1} are very low, low, moderate, high and very high respectively (Enwezor *et al.*, 1989).

Onyekanne *et al.* (2012) observed an average total phosphorus contents of 2.08 mg kg^{-1} in the soils of Ideato North Local Government Area of Imo State. Also, Amhakhian and Osemwota (2012a) observed an average total phosphorus content of 7.58 mg kg^{-1} in the soils of the Guinea Savanna Zone of Nigeria. They stated that the low phosphorus content of some Tropical soils has been attributed from the low SOM content and possible lack of abundant native phosphate – bearing rocks in the geological materials of the area. (Asadu *et al.*, 2001). The higher range (34 – 87 mg kg^{-1}) of available phosphorus reported in the work of Umeugochukwu *et al.* (2012) in degraded site in Uga, Southeastern Nigeria could be attributed to inorganic fertilization by farmers.

2.3.5 Exchangeable cations

Cations are positively charged ions and the exchange of one positive ion by another is called cation exchange (Ogeleka *et al.* 2017). Traditionally, these cations are sodium, potassium, calcium and magnesium. They do not hydrolyze as Al^{3+} and H^+ do, and therefore are not acid-forming cations (Brady and Weil, 2002). The critical values of exchangeable calcium, magnesium, potassium and sodium are reported to be 4, 0.5, 0.3 and 0.2 cmol kg^{-1} respectively

(Bellamy, 1986). Soils with a low CEC values are more likely to be deficient in potassium, magnesium and other cations while high CEC soils are less susceptible to leaching of these cations (CUCE 2007).

In acid soils of the humid Tropics, base cations tend to be in lesser amount (Amberger, 2006). The lesser amount of these cations might be attributed to leaching/sedimentation effects, which thereby reduce the quantity of the exchangeable nutrients (Asadu *et al.,* 2001; Effiong and Akpan, 2013). Also, the prevalence of low exchangeable cations can be as a result of effect of parent materials (Akamigbo and Asadu, 1983), high mineralization rate of the soil organic matter content (Asadu, 1990; Igwe and Okebalama, 2006) and the dominance of low activity clay soils which poses low CEC caused by low values of exchangeable cations which occurs in areas of high intensive rainfall (Asadu and Bosah, 2002; Igwe *et al.,* 2004).

The soils of southeastern Nigeria have been reported to be dominated by calcium and magnesium. This is similar to the findings of Okenmuo (2015) of the soils of lower Niger floodplain at Ogbaru, Anambra State; Nwokocha *et al.* (2003) in the soils of Umuahia-North, Abia State; Ukaegbu and Akamigbo (2003) in the soils of University of Nigeria, Nsukka in Enugu State; Asadu *et al.* (2001) in the soils around lake Opi in Eastern Nigeria; Ndukwu *et al.* (2012) in soils underlain by three lithologies in Abia State of Southeastern Nigeria. Umeugochukwu *et al.* (2012) in the soils of Uga, Southeastern Nigeria. The dominated calcium and magnesium in the Tropical soils of Southeastern Nigeria might be attributed to the chemical constituents of their parent materials (Irmak *et al.,* 2007).

2.3.6 Exchangeable acidity

Exchangeable acidity (EA) is the measure of the H^+ and Al^{3+} ions retained or fixed on soil colloid after the active acidity is measured (McCarty *et al.,* 2003). They are easily replaceable by other cations in soils (Brady and Weil, 2002). This type of acidity is primarily associated with exchangeable aluminium and hydrogen ions that are present in large quantities in very acid soils, which can be released into the soil solution by cation exchange (Brady and Weil, 2002). Enwezor *et al.* (1989) classified the EA of Tropical soils as low (< 2.00 cmol kg^{-1}), moderate (2.10 – 5.00 cmol kg^{-1}) and high (> 5.00 cmol kg^{-1}).

When the exchangeable acidity of the soil is high with a resultant low pH, it affects the soil condition and many processes in the soil (Onwuka *et al.,* 2016). Igwe *et al.* (2004) reported that high leaching rate favours the development of acidity which inversely gives rise to the high exchangeable aluminium and hydrogen when compared with the exchangeable base forming cations. The ultimate influence of exchange acidity to the acidity of Tropical soils had been attributed to presence of aluminum ions (Fageria *et al*., 1988) though exchangeable hydrogen has been used as synonymous with exchangeable acidity by many researchers (Coleman and Thomas, 1967). The concentration of aluminum ion > 1 cmol kg^{-1} in the soil solution could result to aluminium toxicity (Amberger, 2006).

Across different location, land uses and parent materials, the values of exchangeable acidity vary. Abam and Orji (2019) recorded in the soils formed from diverse parent materials in Cross River State, Nigeria variation of exchangeable acidity from 4.3 at Odukpani Shale to 7.7 cmol kg^{-1} at Calabar coastal plain sand. Though, hydrogen ions rather than aluminum ions dominated the exchange acidity. Amalu (1998) opined that H^+ rather than Al^{3+} dominates in majority of soils with pH less than 5. Amhakhian and Achimugu (2011) reported mean exchangeable acidity of 0.72 cmol kg^{-1} for soils of derived guinea savanna across Dekina Local Government Area of Kogi State. The general low levels of exchangeable acidity in the soils were attributed to the sandy nature of the soils and the low clay contents. Ogukunle (2013) observed in the soils of three land uses (savannah, forest and swamp) in the coastal areas of Badagry that the exchangeable acidity mean values are 0.77, 1.70 and 0.83 cmol kg^{-1} respectively. Although, there were no significant differences among them.

2.3.7 Cation exchange capacity

Cation exchange capacity (CEC) is the dominant factor in measuring soil fertility which affects exchange of ions on the clay surface (Abera and Belachew, 2010). AFSS (2015) defined cation exchange capacity as the capacity of soils to hold exchangeable cations (calcium, magnesium, potassium and sodium). These cations are held by the negatively charged clay and organic matter particles in the soil through electrostatic forces (Ukabiala, 2019). Also, the cations on the CEC of the soil particles are easily exchanged with other cations and as a result, they are readily available to plants.

In most soils of the humid regions, sodium is not present or less available in sufficient quantities to occupy a significant amount of the CEC whereas in dry climates, sodium can occupy an important portion of the CEC (AFSS, 2015). This is similar to the findings of Akpan-Idiok *et al.* (2006) who reported in the soils of Abini in southeastern Nigeria that low contents of Na^+ (0.07 – 0.13 cmol kg^{-1}) which occupied no significant amount of the CEC (15.69 – 31.88 cmol kg^{-1}). Moreover, similar results were reported by Nwite *et al.*, (2014) and Idoga *et al.* (2005).

The CEC of the soil is influenced by the clay content of the soils and organic matter. According to Irmak (2007) and Abera and Belachew (2010) stated that higher or lower CEC values in the soil might be attributed to higher or lower clay content and organic matter content. Thus, the higher or lower the clay or organic matter content the higher or lower the CEC of the soil. This was similar to the findings of Ahukaemere *et al.* (2016b) of the soils of coastal plain sands for rain-fed maize production in acid sands of Southeastern, Nigeria and Umeugochukwu *et al.* (2012) of degraded soil of Uga Southeastern Nigeria. Also, the CEC of the soil depends on the pH of the soil (Brady and Weil, 2002). Similar findings were reported by Udotong *et al.* (2008) of wetland soils in Eket Nigeria that pH (5.4) showed CEC value of 6.68 cmol kg^{-1}. However, Enwezor *et al.* (1989), proposed that soil with CEC of > 40 cmol kg^{-1}, 25.1 – 40.0 cmol kg^{-1}, 12.1 – 25.0 cmol kg^{-1}, 6.0 – 12.0 cmol kg^{-1} and < 6.0 cmol kg^{-1} are classified as very high, high, medium, low and very low respectively.

2.3.8 Percentage base saturation

Percent base saturation (PBS) is the percentage of the CEC occupied by the basic cations Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} (Sonon *et al.*, 2017). In this definition, basic cations are distinguished from the acid cations H^{+} and Al^{3+}. FAO (1985) classified percentage base saturation of soils as low (< 20%), medium (20 – 60%) and high (> 60%). Base saturation is an important soil measurement that help determine how a soil is managed and fertilized (Culman *et al.*, 2019). Thus, its knowledge is necessary when calculating fertilizer requirements for crop and amendment applications (CRI, 2015).

The percentage base saturation of soil is highly dependent on soil pH. Melich (2014) opined that the PBS and pH are of considerable practical importance in relation to liming, nutrient conservation and plant growth. Soils with high percent base saturation have a higher pH; therefore, they are more buffered against acid cations from plant roots and soil processes (nitrification, acid rain, etc.) that acidify the soil (Sonon *et al.*, 2017). The soils of Eastern Kogi State Nigeria showed moderate values of PBS (> 20%) which increases as soil pH increases (Ukabiala, 2019).

In the soils of central Nigeria, the mean percentage base saturation was 70% with very strongly acid soil pH with low values of calcium and magnesium (Okusami *et al.*, 1987). The soils of Abini in Cross River State Nigeria have percentage base saturation mean values of 92% (surface) and 95% (subsurface) and were classified as *Inceptisols* (Akpan-Idiok *et al.*, 2006). The soils of two toposequences formed over different parent materials in Imo State have a mean value of 18.15% and 6.43% of PBS (Osujieke, 2017) and the low values indicate the leaching of bases due to the high rainfall in the study area (Fekadu *et al.,* 2018). In the *Ultisols* of Nsukka semi-humid area of Nigeria, the mean percentage base saturation recorded was 52.80% with very strongly acidic soils (Ezeaku *et al.,* 2015).

2.4 Soil Suitability Evaluation

Characterizing the soils in a given area for specific land use type using a set of specified guidelines/procedures is defined as soil suitability evaluation (Ande, 2011). Khan and Khan (2014) defines soil suitability evaluation as grouping of specific areas of land in terms of their suitability for defined agricultural use. Also, FAO (1976) defines suitability as a measure of how well the qualities of a soil unit match the requirements of a particular form of soil use/land use. Thus, the suitability of a given piece of land is its natural ability to support a specific purpose.

For assessing the suitability of soils for crop production, soil requirements of crops must be known, prevailing soil conditions and applied soil management practices. It is a function of crop requirements and soil characteristics (Khan and Khan, 2014). Matching the soils characteristics with the crop requirements provides suitability (Akamigbo, 2010). In other words, soil suitability evaluation quantifies in broad terms to what extent soil conditions match crop requirements under defined input and management circumstances (FAO, 1976). Also, land evaluation identifies the most limiting land qualities and provides a good basis for advising farmers for optimum production (FAO, 1976).

There are different methods of soil suitability evaluation which are categorized into qualitative (limitation) and quantitative (parametric) methods (Akamigbo, 2010; Ezeaku, 2011b) which are presented / summarized in a table. In the table, there are five land quality groups: climate (c), soil physical characteristics (s), wetness (w), fertility status (f) and toxicity (t). Moreover, on the basis of soil parameters provided by harmonized World Soil Database, seven key soil qualities important for crop production have been derived: nutrient availability, nutrient retention capacity, rooting conditions, oxygen availability to roots, excess salts, toxicities and workability (Fischer *et al.,* 2002). The identified soil units are placed in suitability classes (highly suitable (S1), moderately suitable (S2), marginally suitable (S3), or not suitable (N)) by matching the characteristics with the requirements of the test crops.

The usefulness of soil studies lies in land evaluation as it aids in determining suitability and capability of our soils for various uses and eventually as a guide to conservation practices and management of the areas under study (Dent and Young, 1981). Several studies on soil suitability evaluation have been reported by various authors. Udoh *et al.* (2011) evaluate the suitability of eight pedons for rice and cocoa cultivation in soils developed from alluvial deposit using conventional (non-parametric) and parametric methods. By the conventional method, all the soils were marginally suitable (S3) whereas 87 % were not suitable (N1) for rice cultivation.

Raji (2016) assess the Basement Complex soils in Kwara State for cassava production. The findings revealed that 36% of the soils on lower and middle slope positions landscape were classified as marginally suitable with moderate limitations of soil physical and fertility problems whereas another 43% on middle to upper slopes have in addition topographic problems to the soil physical and fertility problems.

Ande (2011) evaluate the soils of derived savanna area of Southwestern Nigeria for cassava production. The findings indicated that Apomu series was moderately suitable ($S2_f$), Gbemi series was marginally suitable ($S3_g$), while Matako series was not suitable for cassava production (N) due to susceptibility to water logging during the 5-6 months of raining season in the area.

Ahukaemere *et al.* (2015) evaluate the soils derived from dissimilar lithological materials for maize and groundnut production in Owerri agricultural zone, Southeastern Nigeria. The result showed that none of the parent material was highly suitable for maize production. The limiting factor is available phosphorus. For groundnut production, Imo clay shale were highly suitable whereas alluvium and coastal plain sands were only moderately suitable.

Udoh and Ogunkunle (2012) assess the soils of Humid tropical area of Southeastern Nigeria for Maize cultivation using the non-parametric method. The findings reported that 76% of the pedons were moderately suitable (S2), 14% were marginally suitable (S3) and 10% were not suitable (N1) for maize production. However, by the parametric method (potentially and currently), there was neither S1 and S2 land for maize cultivation in the area.

Ahukaemere *et al.* (2016) evaluate the soils of the Coastal Plain Sands for Rain-Fed maize production in acid-sands of Southeastern Nigeria. The overall suitability ratings of the soils indicated that soil units 1, 3 and 4 were not suitable (N_f) for rain-fed maize production because of fertility (pH) limitation. Soil unit 2 was rated marginally suitable ($S3_f$) for maize production with fertility (total nitrogen, pH, CEC) constraint as the major limitation.

Ezeaku and Anikwe (2003) investigated a rainfed agricultural land use in Southeastern Nigeria. The results showed that the *Typic Haplaustults* (*Ferric Alisols*) of Awgu, Enugu State were moderately suitable (S2) and marginally suitable (S3) for maize production.

Also, Multi Criteria Decision Analysis (MCDA) or Multi Criteria Evaluation (MCE) using Geographical Information System (GIS) or Remote Sensing (RS) has been developed to improve spatial decision making when a set of alternatives need to be evaluated on the basis of conflicting and incommensurate criteria for soil suitability. MCDA is an effective tool for multiple criteria decision-making issues (Malczewski, 2006) and aims to investigate a number of choice possibilities in light of not only multiple criteria but also multiple objectives (Carver, 1991). GIS enables the computation of assessment factors, while MCE aggregates them into a land suitability maps (Mustafa *et al.*, 2011).

Various criteria are considered during Multi Criteria Decision Analysis (MCDA) for crop/land suitability. The criteria are called layers and it is considered as the main drivers for land suitability. They are soil (physical properties (depth and texture) and chemical properties (organic matter and pH)), climate (precipitation and temperature), topography (slope) and current land use/cover (cultivated land, forest, grassland and so on) (Lupia, 2012). This is usually obtained by assigning a weight to each criterion. The derivation of weights is a central step in defining the decision maker's preferences.

In the land suitability evaluation through GIS, each pixel in the database is taken as an alternative to be evaluated in its quality or appropriateness for a given end, and each thematic layer represents a criterion for the process or evaluation (Pereira and Duckesstien, 1993). Each criterion is generally rated with five classes: highly suitable, moderately suitable, marginally suitable, currently not suitable, and permanently not suitable (FAO, 1985; 1993).

The combination procedure of the layers follows the conventional scheme for GIS-based MCDA (Malczewski, 1996). It involves three main steps:

- Criterion maps are standardized/reclassified using Spatial Analyst Reclassify tool. This step is necessary because the criterion maps contain the ordinal values (high, medium and low) that indicate the degree of land suitability with respect to a particular criterion (criteria standardization).

- Derivation of the of relative criterion importance using the pairwise comparison method. The criterion weights are automatically calculated once the pairwise comparison matrix is entered in Analytic Hierarchy Process (AHP) weight derivation module in ArcMap.
- The criterion weights and the standardized criterion maps are combined /aggregated by means of weighted overlay technique and vector overlay analysis.

Integration of the GIS and MCE can help land-use planners and managers to improve decision-making processes (Malczewski, 1999). It is a useful tool for integration of socio economic and environmental data and identifying the strength and limitation of land (Baniya, 2008). Multi-criteria evaluation for land use issues is not a new concept and several studies globally has been reported. However, MCDA studies in Nigeria is scanty or limited.

Baniya (2008) evaluated land suitability for vegetable crops in Nepal. The result from the analysis showed that no land units are highly suitable (S1) and 31 percent and 66 percent area fall in the category of S2 and S3 respectively. Kanlaya *et al*. (2009) evaluated the land suitability for cultivation of sugarcane and cassava crops in Kanchanaburi province, Thailand. The proportion of the area highly suitable or moderately suitable for cultivation of sugarcane was 2%, and for cultivation of cassava, 45%. Only a small percentage of the area was not suitable. Khoi and Murayama (2010) delineated the suitable cropland areas by applying a GIS based multi criteria evaluation approach in the Tam Dao National Park Region, Vietnam. The results indicate the location and extent of crop farming areas at different suitability levels, i.e., most suitable (28.10%), moderately suitable (23.96%), marginally suitable (28.77%), and least suitable (19.17%).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Physical Environment of the Study Area

3.1.1 Location of study

The study was conducted in three locations in Nsukka area of Enugu State. Enugu State is located at the South Eastern part of Nigeria and lies within geographical coordinates of latitude (6° 30' 0"N and 7° 0' 0"N) and longitude (7° 0' 0"E and 7° 50' 0"E). Benue and Kogi states are located in its northern axis while Anambra State is in the west; on the south is Abia State whereas on the east is Ebonyi State (Figure 2). The three locations, their geographical coordinates and elevation are presented in Table 1.

Table 1: Geographical coordinates and elevation of the study sites

Location	Latitude (DMS)	Longitude (DMS)	Elevation (m)
Agu Ibagwa	6° 57' 8.13"N	7° 19' 14.91"E	294
Nkpologwu	6° 44' 47.38"N	7° 17' 6.17"E	255
Opi-Agu	6° 41' 52.44"N	7° 33' 2.86"E	183

3.1.3 Climate

The selected study locations fall within the region of humid Tropics and hence enjoys humid tropical environment marked by two distinct seasons namely the rainy season and dry seasons. The climate of Eastern Nigeria is characterized by uniformly high temperature and a seasonal distribution of precipitation with humidity being generally high, except during the desiccating weather of “Harmattan”. The mean relative humidity is 60 % (Asadu, 2000). The two major seasons are the wet and dry seasons with the former lasting for eight months (March – October) and the later for four months (November – February) (Jungerius, 1964 and Inyang, 1975). The rainy season in Nsukka area peaks during the months of July and September. There is usually a short dry spell in August which is referred to as “August break”. The mean annual rainfall is 1550 mm and the temperature is uniformly high throughout the year. It rarely falls below 21^{0}C except during the ‘Harmattan’ period when temperature below 21 ^{0}C may be recorded. However, annual mean temperature does not exceed 35 ^{0}C (Akamigbo and Asadu, 1983).

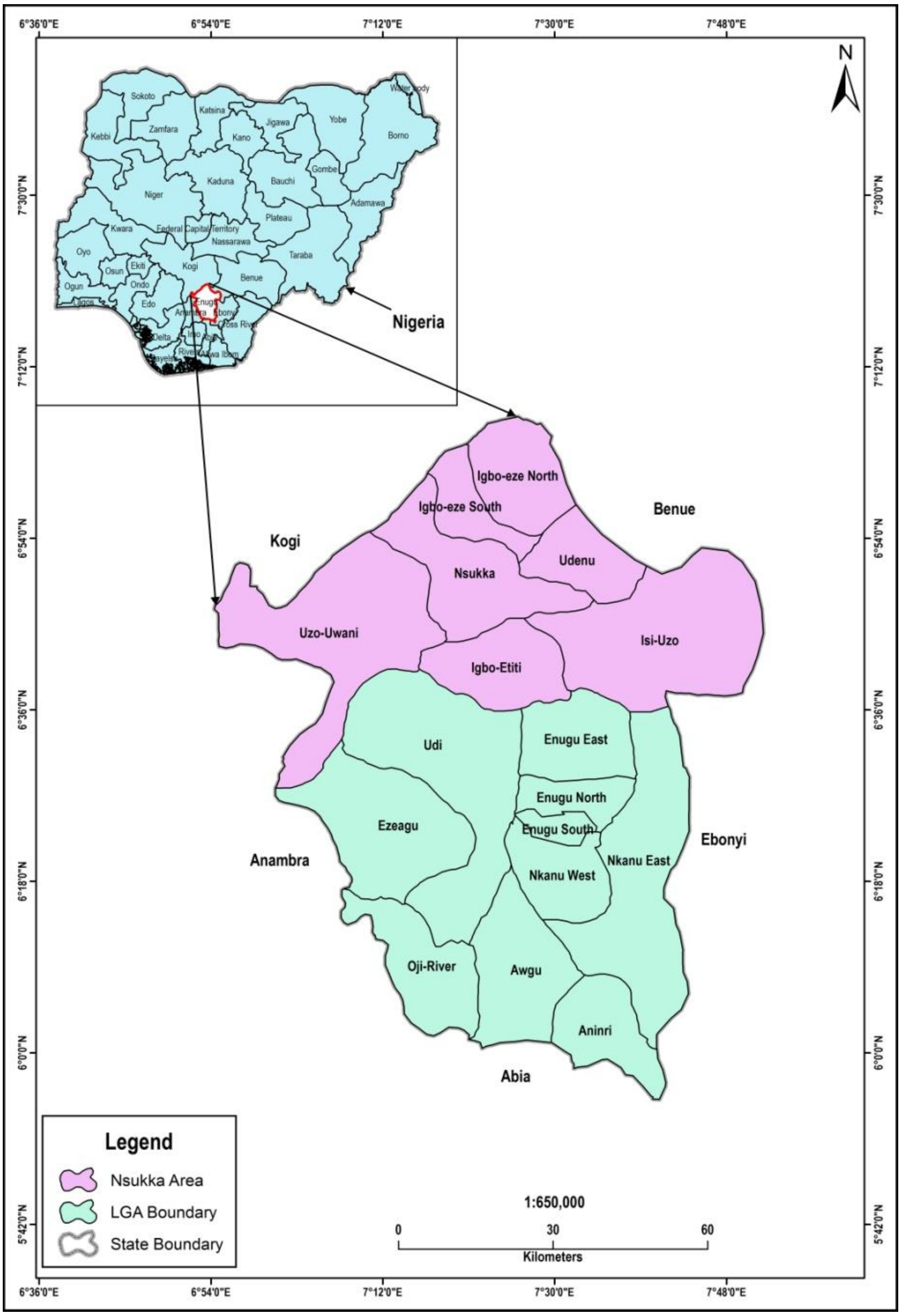


Figure 2: Map of Enugu State showing the Nsukka Area

3.1.3 Geology

Most of the rocks of eastern Nigeria are of Precambrian complex with such rocks as granite, gneisses and the like dominating (Jungerius, 1964). According to Akamigbo and Asadu (1983), over 80% of Eastern Nigeria is of sedimentary geologic deposits, made up of shales, coastal plain sands, false bedded sandstones and alluvium. The upper coal measure occupies the upper slopes and top of residual hills within the area but residues from them are often transported by fluvial, colluvial and/or erosion processes to the lower plain to form soils. The soils of the lowlands show strong mottling of gray and red colour due to periodical water logging. They have a dominance of sandy materials due to the nature of the alluvial parent materials (Ofomata, 1975).

The geology of the study area consists of false bedded sandstones for Nkpologwu, upper coal measure for Agu Ibagwa and Nkporo shale for Opi-Agu (Figure 3) (Nigerian Geological Survey Agency, 2006).

3.1.4 Vegetation and land use

Due to human influences, the vegetation of the study areas is largely secondary because of the cut and burn system of land preparation often adopted by the farmers for agricultural activities. The general vegetation can be best described as a "derived savannah". It is characteristically green and is complemented by typical grassy vegetation (Asadu, 2000). The plant species in the area include timber trees for examples Iroko (*Chlorophora excelsa*) and Obeche (*Triplochiton sleroxylon*); tree crops include oil palm (*Elaeis guineesis*), native pear (*Dacryodes edulis*), mango (*Mangifera indica*), arable crops include cassava (*Manihot esculenta*), maize (*Zea mays*), yam (*Dioscorea* spp), cocoyam (*Colocasia esculenta*), pumpkin (*Telferia occidentalis*) and cowpea (*Vigna unguiculata*); Grasses such as giant star grass (*Cynodon nlemfuensis*) and elephant grass (*Pennisetum purpureum*).

The predominant land uses in Nsukka zone are forestry, arable crop production, plantation and grazing land (Ezeaku *et al.*, 2015). The land use types are farming, grassland, grazing and oil palm plantation. Some areas share adjacent boundary with lake or river. For example, the farm at Opi share adjacent boundary with Ozhi Ugwuozioko Lake while Agu Nkpologwu share adjacent boundary with Adada River.

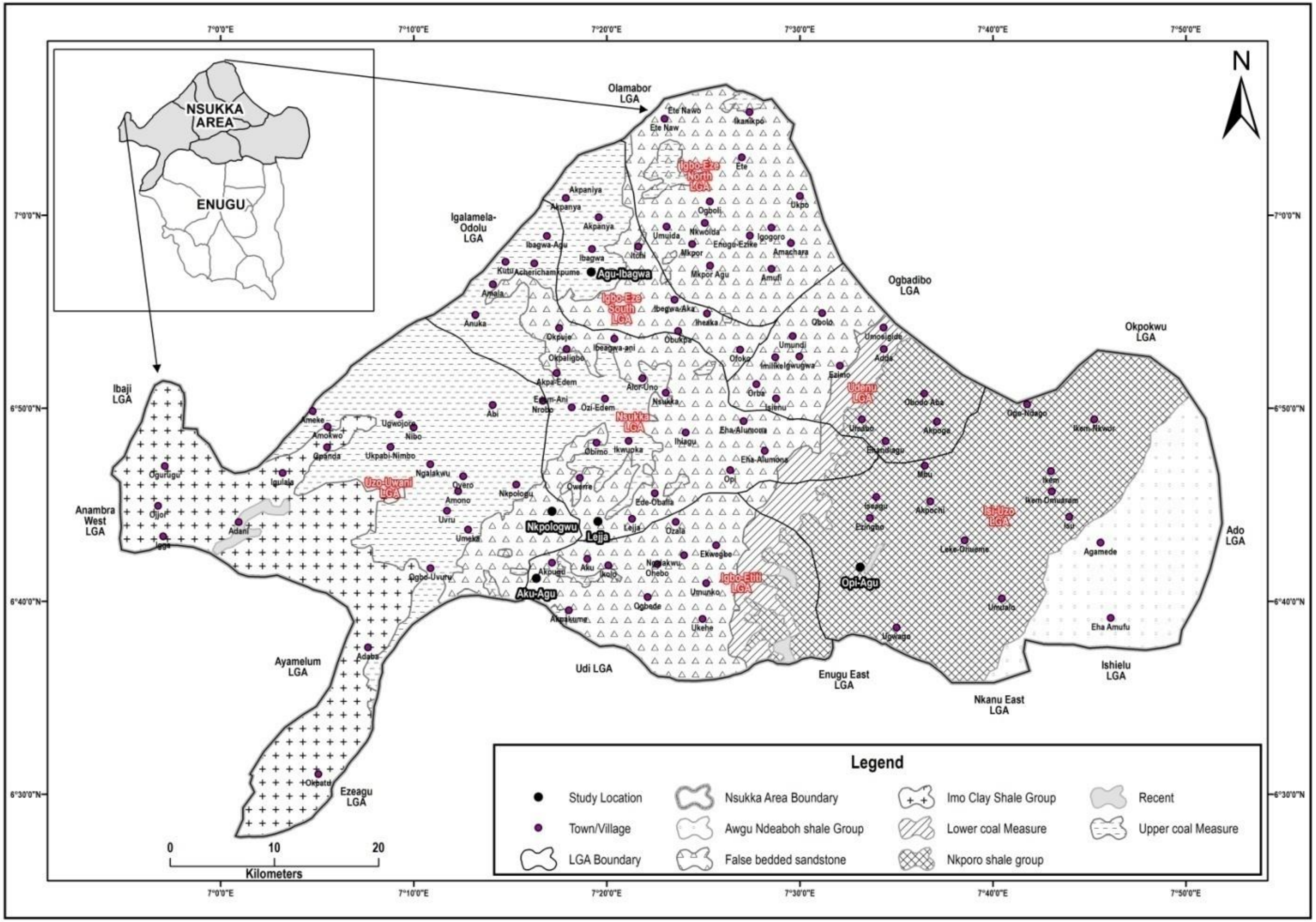


Figure 3: Map of Nsukka Area showing the Geology of the Area

3.1.5 Soils

The soils of the Nsukka area have been investigated, described and in some cases classified at varying degree of intensity. Akamigbo and Asadu (1983) taxonomically classified some of the soils into four orders as follows: *ultisols*, *inceptisols*, *entisols* and *alfisols*. Earlier, Jungerius (1964) morphologically studied and classified the soils of south-eastern Nigeria into five classes: ferallitic soils, ferruginous tropical soils, lithosols, hydromophic soils and young soils which are derived from recent deposited materials, this classification was adapted from D'Hoore's soil map of Africa (1964). Akamigbo (1984) has noted that silt content of soils of Eastern Nigeria within which the study site falls is very low.

3.2 Field Work

The study was carried out on three different farms of different sizes located on three (3) different geological materials. The size of the farms were as follows Opi-Agu (60 hectare), Agu-Ibagwa (48 hectare) and Nkpologwu (140 hectare). The measurement of the farm was captured using GPS following a field visit between the researcher, my supervisor and the members of Nsukka Chambers of Commerce Industry, Mines and Agriculture (NCCSIMA).

A 2 m × 2 m × 2 m profile pit were dug in each of the three locations at the centre of the field that represent the three geological materials and was georeferenced with a Global Positioning System (GPS). Steps were constructed for easy access into the pits. Collection of samples from each horizon was done using knife from bottom to up to avoid contamination. The pedons were described insitu following the procedures in the guidelines for soil profile description (FAO, 2006) and horizon designations of the Soil Survey Staff (2006). Soil colours were described using Munsell soil colour charts (Munsell Soil Colour Chart, 2009). A total of 14 core and auger samples were collected from the diagnostic horizons of the three pedons.

Auger samples were collected at 200 m intervals from the 0 – 20 cm depth and 20 – 40 cm depth. In all, a total of 36 soil samples were collected from the three study areas. Thus, 12 auger soil samples (six 0 – 20 cm and six 20 – 40 cm depth) were collected from each of the location. The exact locations of the samples were recorded using a handheld GPS receiver whixh are presented in Figure 4, 5 and 6.

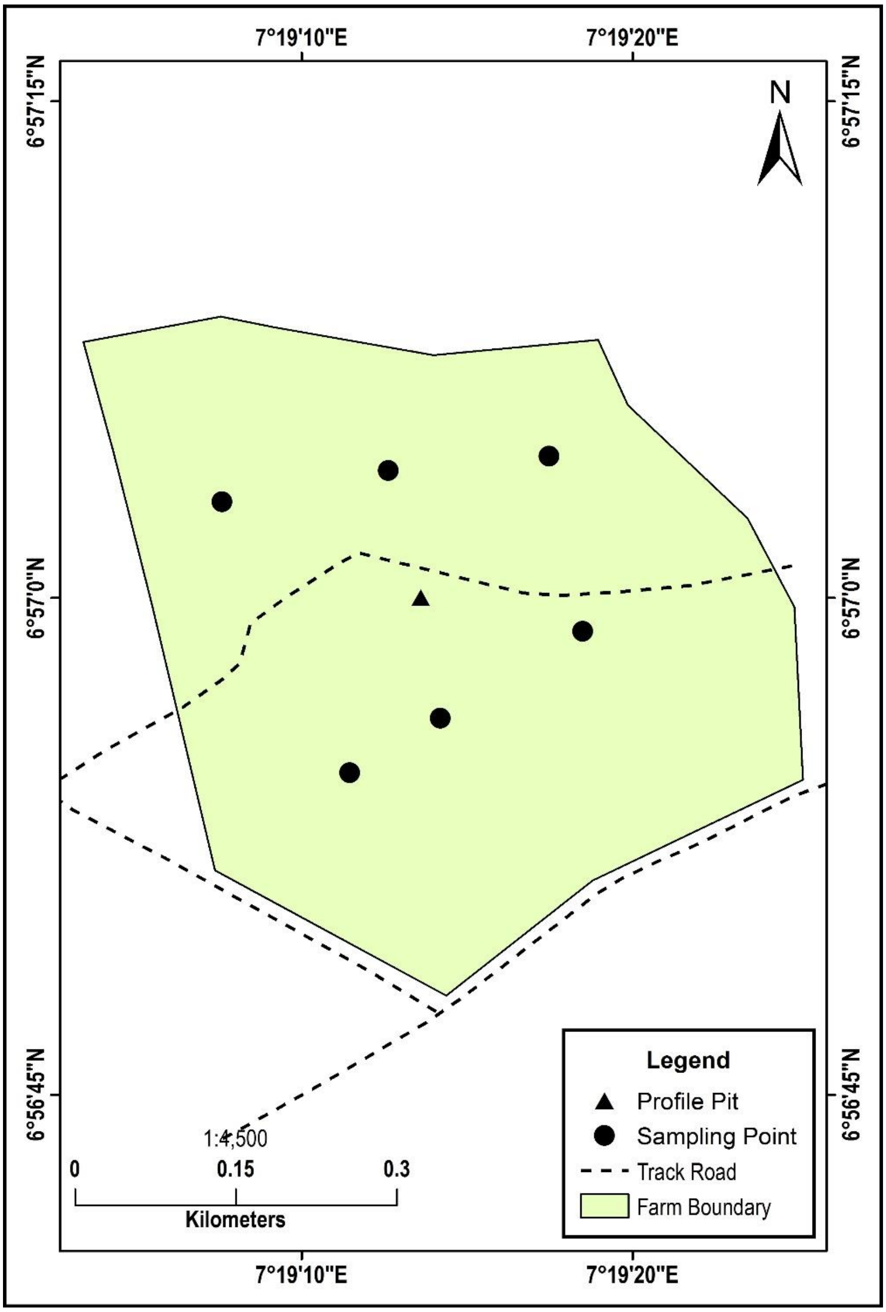


Figure 4: Perimeter map of Agu Ibagwa Farm

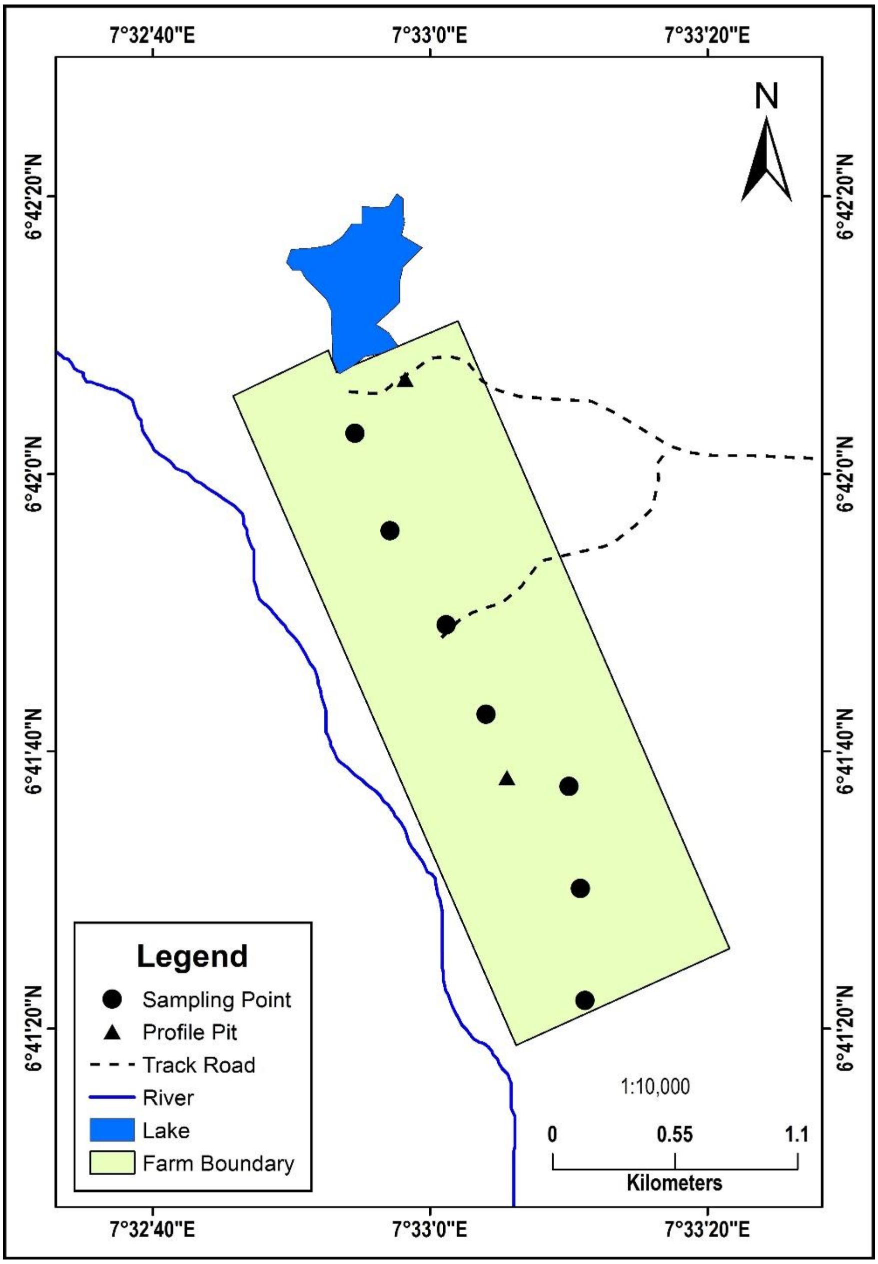


Figure 5: Perimeter map of Opi-Agu Farm

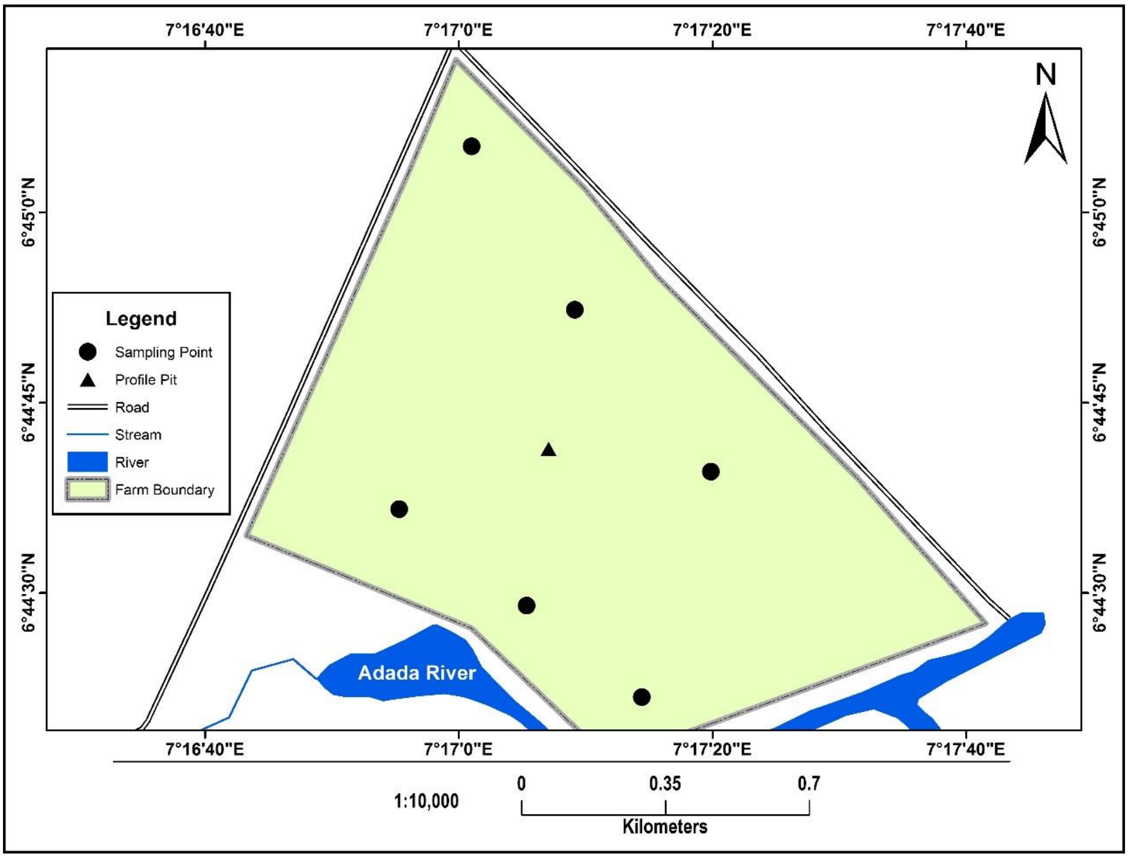


Figure 6: Perimeter map of Nkpologwu Farm

3.3 General Flow of Analysis by GIS for Land/Crop Suitability Map

3.3.1 Land/crop suitability mapping

To generate a crop/land suitability map for a given area is based on processing and combination of a set of layers that are considered as the main drivers for crop/land suitability: soil, climate, topography and current land use/cover (Lupia, 2012). The combination procedure of the four layers is a used and accepted method for GIS-based Multiple-Criteria Decision Analysis (MCDA) (Malczewski, 1996). The following layers: soil physical properties [texture and soil depth] and chemical properties [organic matter (OM) and pH], climate [precipitation and temperature], topography (slope) and current Land use/cover when combined were used to produce crop/land suitability map. The combination procedure was achieved using the following steps:

1. Criterion maps are standardized/reclassified using ArcGIS Spatial Analyst Reclassify tool. This step is necessary because the criterion maps contain the ordinal values that indicate the degree of land suitability with respect to a particular criterion. Each criterion is generally rated with four classes according to FAO, 1985; 1993: highly suitable, moderately suitable, marginally suitable and non-suitable.
2. The standardized criterion maps are combined /aggregated by means of weighted overlay technique using ArcGIS Spatial Analyst Weighted Overlay tool.

The above technique can be represented schematically below (Figure 7):

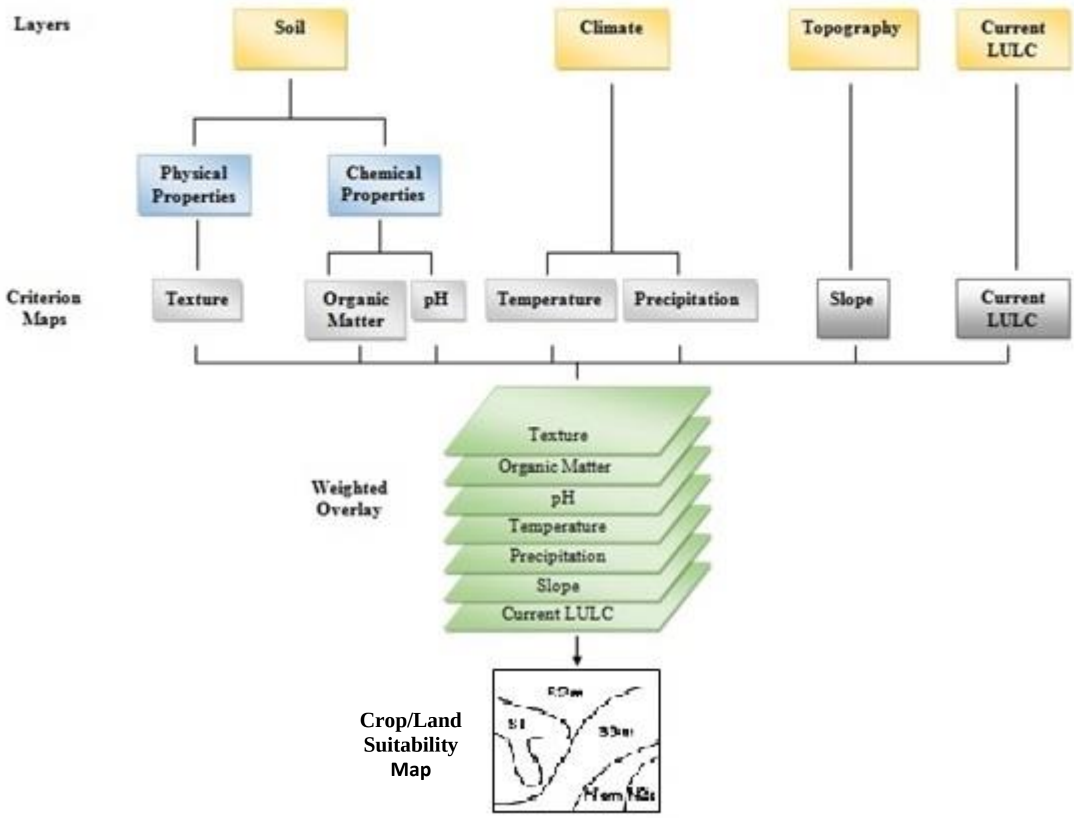


Figure 7: Schematic chart of GIS application for Land Suitability

3.3. Laboratory Analyses

The soil samples collected from the field were air-dried, crushed and passed through a 2 mm sieve for analysis of selected soil physical and chemical properties through specific procedures in the Department of Soil Science laboratory. The critical limits for interpreting fertility levels of soil analytical parameters are presented in Table 1.

3.3.1 Determination of the soil physical properties

Particle size distribution of the soils were determined on the < 2 mm soil properties using the Bouyoucous hydrometer method (Gee and Or, 2002), with 0.1N NaOH as dispersant. Total porosity were calculated from the relationship between bulk density and particle density using equation (1):

$$TP = \left(1 - \frac{\ell b}{\ell s}\right) \times 100; \qquad (1)$$

where ℓb = bulk density (g cm^{-3}) and ℓs = particle density (2.65g cm^{-3}).

Bulk density were determined using core method (Grossman and Reinch, 2002). Saturated hydraulic conductivity (K_{sat}) were determined using a set of undisturbed core samples collected with metallic core cylinders (Reynolds, 1993b) and computed from the equation (2) below:

$$K_{sat} = \frac{QL}{At.\Delta H}; \qquad (2)$$

where Ksat = Saturated hydraulic conductivity (cm l^{-1}), Q = volume of water (cm^3), L = height of water above soil column, A = cross sectional area of sample (cm^2), ΔH = hydraulic head difference (1 + h), cm and t = time (min).

3.3.2 Determination of chemical properties of the soils

The soil pH was determined in duplicates both in distilled water and in 0.1N KCl solution using soil to liquid ratio of 1:2.5. The solutions were stirred for about 30 minutes and corresponding pH values read using a glass electrode pH meter (McLean, 1982). Organic carbon was determined using the method described by Nelson and Sommers (1996) while organic matter was calculated by multiplying the value of organic carbon with 1.724 (Van Bermelen factor) which is based on the assumption that soil organic matter contains 58% carbon (Allison, 1982). The CEC were determined titrimetrically using ammonium acetate (NH_4OA_C) displacement method (Rhoades, 1982). The following exchangeable base: Calcium (Ca^{2+}), Sodium (Na^+), Potassium (K^+), and Magnesium (Mg^{2+}) were determined by complexometric titration method, described by Chapman (1982). Potassium (K^+) and Sodium (Na^+) were extracted using 1N ammonium acetate (NH_4OA_C) solution and will be determined by flame photometry, and the exchangeable acidity by titration method after extraction with 1N KCl (McLean, 1982). The total nitrogen was determined by the Kjeldahl digestion and distillation method (Bremmer and Mulvaaney, 1982). The available phosphorus of the soil samples was determined using Bray-2 method as described by Olson and Sommers (1982). The percentage (%) base saturation were calculated thus (equation 3):

$$\% \text{ Base Saturation} = \frac{\text{Total Exchangeable Base}}{\text{Effective Cation Exchange Capacity}} \times \frac{100}{1} \qquad (3)$$

3.4 Land Suitability Evaluation

In this study soils of three (3) different geological materials were evaluated and assessed for its suitability for the production of pepper, turmeric, ginger and tomato using the principle of limiting condition and parametric method (Ezeaku and Tyav, 2013). The qualitative approach involved the matching of the crop requirements with the soil characteristics. The most limiting characteristics dictated overall suitability for each soil. On the basis of the degree and number of limitations identified, the suitability class were established: highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and not suitable (N) for the four test crops. The limitations were indicated by lower-case letters with mnemonic significance. The parametric approach to this evaluation was the numerical rating of some selected land qualities on a scale of 0 to 100 (Table 2) and was computed using the Linear Additive Model by Ezeaku (2011a) in equation 4:

$$\text{Li} = \text{A} + \frac{\text{B}}{100} + \frac{\text{C}}{100} + \frac{\text{D}}{100} \text{.........} + \frac{\text{F}}{100}; \qquad (4)$$

where Li is the Land Suitability Index (%), A is the overall lowest characteristics ratings (%) and B, C, D ..... F are the different ratings for each property (%). The value of the land suitability index was used to determine the resulting suitability class. The land and soil requirements for the four test crops according to Naidu *et al*. (2006) are presented in Tables 3 – 6.

Table 1: Critical limits for interpreting fertility levels of soil analytical parameters

Parameter	**Very Low**	**Low**	**Moderate**	**High**	**Very High**
*Ca^{2+} (cmol kg^{-1})		<2.0	2.1-5.0	>5.0	
*Mg^{2+} (cmol kg^{-1})		<0.30	0.31-1.0	>1.0	
*K^{+} (cmol kg^{-1})		<0.15	0.16-0.3	>0.3	
*Na^{+} (cmol kg^{-1})		<0.10	0.11-0.3	>0.3	
**CEC (cmol kg^{-1})	<6.0	6.0-12.0	12.1-25.0	25.1-40.0	>40.0
**EA (cmol kg^{-1})		<2.0	2.1-5	>5	
**Org. C (%)	<0.4	0.4-1.0	1.1-1.4	1.5-2.0	
*Total N (%)	<0.05	0.06-0.10	0.11-0.15	0.16-0.20	>0.20
**Av. P (mg kg^{-1})	<3.0	3.0-7.0	7.1-20.0	>20.0	
**BS (%)	<20	20-40	41-60	60-80	80-100

Interpretation	**Soil reaction pH**
***Extremely acid	< 4.5
***Very strongly acid	4.5 – 5.0
***Strongly acid	5.1-5.5
***Moderately acid	5.6-6.0
***Slightly acid	6.1-6.5
***Neutral	6.6-7.3
***Slightly alkaline	7.4-7.8
***Moderately alkaline	7.9-8.4
***Strongly alkaline	8.5-9.0
***Very strongly alkaline	>9.0

Sources: *Shehu *et al.* (2015), **Enwezor *et al.* (1989), ***Foth and Ellis (1997)

Table 2: Quantitative land suitability classes for the different land indices

Symbol	Definition	Land index
S_1	Highly suitable	75.0 – 100
S_2	Moderately suitable	50.0 – 75
S_3	Marginally suitable	25.0 – 50
N_1	Currently not suitable	12.5 – 25
N_2	Permanently not suitable	0.0 – 12.5

Source: FAO (1985; 1993)

Table 3: Soil-site suitability criteria for pepper (*Capsicum annuum* L.)

Soil-site characteristics	Highly suitable S1	Moderately suitable S2	Marginally suitable S3	Not suitable N
Climatic regime				
Mean temperature in growing season (^{0}C)	28-35	20-27 36-38	18-19 39-40	<18 >40
Total Rainfall (mm)	2000-3000	1200-1500	800-1200	<800
Topography				
Elevation (m)	200-1200	1200-1500	1500-1800	>1800
Oxygen availability to roots				
Soil drainage (class)	Well drained	Mod. well drained	Imperfectly drained	Poorly drained
Physical property				
Texture (class)	SCL, L, CL, SC	CL, SL, C	C (55%)	S, LS, C (>60%)
Chemical property				
Organic Carbon (%)	>2	1-2	0.5-1	<0.5
Rooting conditions				
Effective soil depth (cm)	>100	100-50	50-25	<25

SCL = sandy clay loam, L = loamy, CL, clayey loam, SC = sandy clayey, SL = sandy loam, C = clayey, S = sandy, LS = loamy sand

Source: Naidu *et al*. (2006)

Table 4: Soil-site suitability criteria for turmeric (*Curcuma domestica* Val.)

Soil-site characteristics	Highly suitable S1	Moderately suitable S2	Marginally suitable S3	Not suitable N
Climatic regime				
Mean temperature in growing season (^{0}C)	28-32	20-27 33-37	10-19 38-40	<10 >40
Total Rainfall (mm)	1500-2000	1000-1500	800-1000	<800
Topography				
Elevation (m)	500-1000	1000-1500	1500-2000	>2000
Oxygen availability to roots				
Soil drainage (class)	Well drained	Mod. well drained	imperfectly drained	Poorly drained
Physical property				
Texture (class)	L, CL, SCL, SL	SC, SiC, SiCL	C (40-60%), LS	Stony, Heavy Clay>60%
Soil Acidity				
pH (1:2.5)	5.8-7.0	4.8-5.7 7.1-7.5	4.7-4.5 7.6-8.5	<4.5 >8.5
Rooting conditions				
Effective soil depth (cm)	>75	50-75	25-50	<25
Erosion hazard				
Slope (%)	<3	3-8	8-15	>15

SCL = sandy clay loam, L = loamy, CL = clayey loam, SC = sandy clayey, SL = sandy loam, C = clayey, S = sandy, LS = loamy sand, SiC = silty clay, SiCL = silty clay loam

Source: Naidu *et al*. (2006)

Table 5: Soil-site suitability criteria for ginger (*Zingiber officinale* Rosc.)

Soil-site characteristics	Highly suitable S1	Moderately suitable S2	Marginally suitable S3	Not suitable N
Climatic regime				
Mean temperature in growing season (^{0}C)	28-32	33-37 27-24	38-40 23-20	>40 <20
Total Rainfall (mm)	>3000	2500-3000	2000-2500	<2000
Topography				
Elevation (m)	200-1000	1000-1500	1500-1800	>1800
Oxygen availability to roots				
Soil drainage (class)	Well drained	Mod. Well drained	Imperfectly Drained	Poorly Drained
Physical property				
Texture (class)	L, CL, SCL, SL	SC, S, CL, C	S, C (>40%), LS, SS	C (SS) >60%
Soil Acidity				
pH (1:2.5)	6.8-7.5	6.0-6.7 7.6-8.0	5.6-5.9 8.1-8.5	<5.5 >8.5
Chemical property				
Organic Carbon (%)	>2	1-2	0.5-1	<0.5
Rooting conditions				
Effective soil depth (cm)	>75	75-50	50-25	<25
Erosion hazard				
Slope (%)	1-3	3-5	5-10	>10

SCL = sandy clay loam, L = loamy, CL, clayey loam, SC = sandy clayey, SL = sandy loam, C = clayey, S = sandy, LS = loamy sand

Source: Naidu *et al*. (2006)

Table 6: Soil-site suitability criteria for tomato (*Lycopersicon esculentum* Mill.)

Soil-site characteristics	Highly suitable S1	Moderately suitable S2	Marginally suitable S3	Not suitable N
Climatic regime				
Mean temperature in growing season (^{0}C)	25-28	29-32 20-24	15-19 33-36	<15 >36
Total Rainfall (mm)	600-750	500-600 750-1000	400-500 >1000	
Rainfall in growing season (mm)	>150	120-150	90-120	
Moisture availability				
Length of growing period (Days)	>150	120-150	90-120	
Oxygen availability to roots				
Soil drainage (class)	Well drained	Mod. Well drained	Imperfectly Drained	Poorly Drained
Physical property				
Texture (class)	L, CL, SCL, SL	SIC, SICL, SC, C (M/K)	C (SS)	LS, S
Soil Acidity				
pH (1:2.5)	6.0-7.0	5.0-5.9 7.1-8.5	<5; >8.5	<5.5 >8.5
Nutrient availability				
Cation Exchange Capacity (CEC) (cmol kg^{-1})	>15	10-15	<10	
Rooting conditions				
Effective soil depth (cm)	>75	50-75	25-50	<25
Coarse fragments (vol %)	<15	15-35	>35	
Soil toxicity				
Salinity (EC saturation extract) (dS m^{-1})	Non-saline	Slight	Strongly	
Sodicity (ESP) (%)	Non-sodic	Slight	Strongly	
Erosion hazard				
Slope (%)	1-3	3-5	5-10	>10

SCL = sandy clay loam, L = loamy, CL, clayey loam, SC = sandy clayey, SL = sandy loam, C = clayey, S = sandy, LS = loamy sand, ESP = exchangeable sodium percentage

Source: Naidu *et al*. (2006)

3.5 Data Analyses

The data collected were subjected to two way analysis of variance (ANOVA) for Randomised Completely Block Design (RCBD) using a Genstat Discovery Software statistical package (Edition 4) (Genstat, 2012). Means that were statistically significant between the geological materials (location) and soil depth were separated using the Fisher's Least Significant Difference (LSD) at $p \leq 0.05$ respectively as described by Steel and Torrie (1981).

Descriptive statistics (mean, range and coefficient of variance) was used to determine the variability in soil physicochemical properties data obtained from samples collected from profile pit using Microsoft Excel (2016) software. The crop/land suitability map were produced using ArcGIS 10.3.1 software (ESRI, 2020).

The Coefficient of variation was used to estimate the extent of variability in soil properties within each location. This is calculated as shown in equation 5:

$$CV\ (\%) = \frac{S}{Z} \times \frac{100}{1}; \tag{5}$$

where S is the standard deviation and Z is the mean of sample population.

A coefficient of variation value of (i) 0-15, (ii) 16-35 and (iii) > 36 represents little (group i), moderate (group ii) and high variability (group iii), respectively (Wilding and Dress, 1983).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Soil Morphological, Physical and Chemical Properties of Soils of the Study Area

4.1.1 Morphological properties

Table 7 and Plate 1, 2 and 3 show the summary of the morphological characteristics of the soils. The details are presented in Appendix 1. The soils of Agu-Ibagwa, Opi-Agu and Nkpologwu were very deep (>150 cm) (Soil Survey Staff, 1999). The colour of Nkpologwu soil was very dark reddish brown (2.5YR 2/3) at the 'Ap' horizon over dark reddish brown (2.5YR 3/6), reddish brown (2.5YR 4/8) and brown (10 YR 4/6) coloured horizons. Opi-Agu soils have brown (7.5 YR 4/4) 'Ap' horizon underlain by dull reddish brown (2.5YR 5/4), bright reddish brown (5YR 5/8) and Red (10R 4/8) horizons (Table 7). The variations in colour within and among the pedons could be attributed to differences in OM content, parent material and drainage conditions (Ashenafi *et al*., 2010; Buol *et al*., 2011; Nahusenay *et al*., 2014; Alem *et al*., 2015). The reddish colours indicated the presence of oxidized and hydrated forms of iron oxides while the dark reddish brown, reddish brown and brown colours suggests the influence of organic matter as colouring agent in Tropical soils (Brady and Weil, 2002; 2006).

The texture of the soils were sand at Nkpologwu, loamy sand (Ap horizon) and sandy clay loam (subsoils) at Agu-Ibagwa and sand (Ap horizon), sandy loam (A_1 and C horizons), sandy clay loam (Bt horizon) at Opi-Agu soils suggesting that upper coal and Nkporo shale parent materials have finer texture when compared with soils of false-bedded sandstone. The structure varied from very fine weakly developed crumb to fine medium massive granular in Nkpologwu soils; strong coarse granular to moderately coarse granular and sub-angular blocky structures in Opi-Agu soil and fine moderately developed sub-angular blocky to medium moderately developed sub-angular blocky structure in Agu-Ibagwa soils. This structural variation among pedons might be attributed to differences in textural characteristics. The variations in soil consistence from very friable to friable (moist) and non-plastic (wet) at Nkpologwu, friable to very firm (moist) and plastic (wet) at Opi-Agu soils and friable (moist) and non- plastic at Ap horizon over friable (moist) and slightly plastic (wet) in sub horizons of Agu-Ibagwa may be attributed to the influence of clay content. Abay *et al*. (2015) reported that high clay content is responsible for slightly plastic, plastic and very plastic consistencies. The soils of Nkpologwu and Opi-Agu are perfectly drained and the higher clay contents at the lower horizons of the Agu-Ibagwa and Opi-Agu accounted for the imperfect drainage. The presence of the roots is an indication of biological activities in the soils. The horizons boundary varied from clear smooth and gradual smooth ‘Ap’ horizons to clear smooth, diffuse smooth, gradual smooth, gradual wavy subsurface.

4.1.2 Physical properties

Table 8 shows the physical characteristics of soil profiles of the study area. The clay content ranged from 50 g kg^{-1} to 270 g kg^{-1} across the profile with the mean values of 226, 165 and 62 g kg^{-1} for Agu-Ibagwa, Opi-Agu and Nkpologwu soils respectively. Generally, clay content showed an increased with depth in all profiles. The increase in clay content with depth recorded in all profiles indicated clay elluviation from the soil surface layer into the subsurface horizon, giving rise to pronounced argillic horizons as reported by Esu (1987) and Maniyunda (1999). The silt content ranged from 70 to 90 g kg^{-1} in Agu-Ibagwa profile and from 30 to 170 g kg^{-1} in Opi-Agu profile while for Nkpologwu, the mean value was 30 g kg^{-1}. The silt content varied irregularly with depth in Agu-Ibagwa and Opi-Agu profiles. The fine sand ranged from 430 to 600 g kg^{-1} with the mean value of 530 g kg^{-1}, 570 to 820 g kg^{-1} with the mean value of 642.50 g kg^{-1} and 260 to 360 g kg^{-1} with the mean value of 318 g kg^{-1} for Agu-Ibagwa, Opi-Agu and Nkpologwu soils respectively. The coarse sand content ranged from 50 to 640 g kg^{-1} across the profiles with the mean values of Agu-Ibagwa (174 g kg^{-1}), Opi-Agu (82.50 g kg^{-1}) and Nkpologwu (590 g kg^{-1}). Nkpologwu soils were sandier than soils of Opi-Agu and Agu-Ibagwa and this could be attributed to the nature of their parent materials and is a reflection of the characteristics of the acid sands of Southeastern Nigeria (Enwezor *et al*., 1989). In addition, the fine and coarse sand were irregularly distributed in all the profiles. The inconsistent distribution of coarse sand with profile depth in the three locations might have been influenced by pedogenic factors such as erosion which is responsible for irregular removal, transportation and redepositing of soil materials at the surface soils (Babalola *et al.*, 2007). The clay and fine sand content have CV (< 30%) in Agu-Ibagwa and Nkpologwu soils while Opi-Agu soils have CV (> 30 %) except for the fine sand content which has < 30% CV.

Soil texture in Agu-Ibagwa soils were loamy sand in Ap horizon and sandy clay loam in the subsurface horizons, for Opi-Agu the soils were sand in Ap horizon, sandy loam in A_1 and C horizon and sandy clay loam in Bt horizon while Nkpologwu soils were predominantly sand. The variations in textural classes in all the location might have resulted from differences in the parent materials.

Bulk density values ranged from 1.40 to 1.80 g cm^{-3} in all profiles and varied irregularly with depth in all the profile. The mean values were 1.60 g cm^{-3} for Agu-Ibagwa soils, 1.61 g cm^{-3} for Opi-Agu soils and 1.75 g cm^{-3} for Nkpologwu soils. Based on the rating by Wilding and

Dress (1983), there was little variation in bulk density values across the profiles. The bulk density values were lower than 1.85 g cm^{-3}, a value considered by Veparaskas (1988) to impede root penetration. Therefore, bulk density will not be a retarding factor for crop cultivation in the study area.

The values of macroporosity ranges of Agu-Ibagwa and Nkpologwu soils were similar being from 11 to 15% whereas for Opi-Agu soils, the range was 15 to 20%. The microporosity values ranged from 24% in Opi-Agu to 45% in Agu-Ibagwa. The macroporosity were irregularly distributed across the soil profiles with microporosity following the same trend. From all indications, microporosity values was greater than macroporosity values which might be as a result of compaction from tree loggers and animal grazing. For the total porosity, the mean values were 52.30, 45.32 and 44.33% for Agu-Ibagwa, Opi-Agu and Nkpologwu respectively. Fetter (1998) and Rieu and Sposito (1991) recommended that soils having porosity of over 50 and 45-50% of volume are good agricultural soils. Therefore, the values of total porosity recorded for soils in this study shows that they are good agronomic soils. Also, the total porosity values decreased gradually with depth in Opi-Agu soils owing to poor structural development in the sub-surface horizons. The coefficient of variation was less than 30% for macroporosity, microporosity and total porosity.

The saturated hydraulic conductivity ranged from 2 to 14 cm h^{-1} with the mean value of 6.43 cm h^{-1} in Agu-Ibagwa soils, 13 to 17 cm h^{-1} with the mean value of 13.41 cm h^{-1} in Opi-Agu soils and 34 to 88 cm h^{-1} with the mean value of 60.99 cm h^{-1} in Nkpologwu soils. Also, for Agu-Ibagwa and Nkpologwu soils, the coefficient of variation was greater than 35% indicating high variability whereas Opi-Agu has CV less than 35%. The variation in saturated hydraulic conductivity across different locations might be attributed as differences in the particle size distribution.

4.1.3 Chemical properties

Table 9 shows the chemical characteristics of soil profiles of the study area. The soils had pH (H_2O) values ranging from 5.0 to 6.8 with the mean value of 5.94, 5.5 to 7.3 with the mean value of 6.43 and 5.8 to 6.3 with the mean value of 6.1 for Agu-Ibagwa, Opi-Agu and Nkpologwu soils respectively with CV (< 30%) indicating that the soils were very strongly acidic to neutral (Table 9). The soils were likely to be high in exchangeable hydrogen and aluminum ions and deficient in some basic cations especially calcium and magnesium (Chude *et al.* 2004). These conditions occurs due to excessive leaching of exchangeable bases and their replacement with exchange acidity especially under the high rainfall conditions of the study

Table 7: Morphological properties of soils of the study area

Pedon	Depth (cm)	HD	Colour (moist)	TC	Structure	Consistency moist	wet	Drainage	Roots	Hb	others
Agu Ibagwa	0-26	Ap	2.5YR 4/3 (dRB)	LS	f m sab	fr	np	perfect	present	CS	-
	26-61	Bt_1	2.5YR 6/6 (O)	SCL	mod m sab	fr	sp	perfect	present	GS	-
	61-127	Bt_2	2.5YR 5/8 (bB)	SCL	mod m sab	fr	sp	perfect	absent	GS	-
	127-176	Bt_3	2.5YR 5/8 (bB)	SCL	mod m sab	fi	sp	imperfect	absent	GW	-
	176-200	C	2.5YR 6/8 (O)	SCL	mod m sab	fi	sp	imperfect	absent	-	Many Stones
Opi-Agu	0-29	Ap	7.5 YR 4/4 (B)	S	mod co sab	fr	msp	perfect	present	CS	-
	29-55	A_1	2.5YR 5/4 (dRB)	SL	mod co sab	fr	msp	perfect	present	AS	-
	55-121	Bt	5 YR 5/8 (bRB)	SCL	s co g	fr	sp	perfecr	present	GD	-
	121-200	C	10 R 4/8 (R)	SL	mod co g	v	sp	perfect	present	-	-
Nkpologwu	0-20	Ap	2.5YR 2/3 (VDRB)	S	vf w cr	fr	np	perfect	present	GS	-
	20-62	AB	2.5YR 3/6 (DRB)	S	vf w cr	fr	np	perfect	present	CS	-
	62-98	B_1	10R 4/6 (R)	S	f m mag	fr	np	perfect	absent	CS	-
	98-161	B_2	2.5YR 4/8 (RB)	S	f m mag	fr	np	perfect	absent	CS	-
	161-200	BC	10YR 4/6 (B)	S	f m mag	fr	np	perfect	absent	-	-

HD: horizon designation; RB: reddish brown; R: red; VDRB: very dark reddish brown; DRB: dark reddish brown: bB: bright brown; bRB: bright reddish brown; dRB: dull reddish brown; Textural Class (TC) S: sand; LS: loam sand; SL: Sandy Loam; SCL: sandy clay loam: f: fine; s: strong; w: weak; co: coarse: cr: crumb; mag: massive granular; vf: very fine; m: medium; mod: moderate, sab: sub angular blocky; fr: friable; vfr: very friable; fr: firm; v: very firm; np: not plastic; ss: slightly plastic; msp: moderately sticky; Hb: horizon boundary; CS: clear smooth; GS: gradual smooth; GW: gradual wavy; DS: diffuse smooth; AS: abrupt smooth; GD: gradually diffuse

Ap
0 - 26 cm

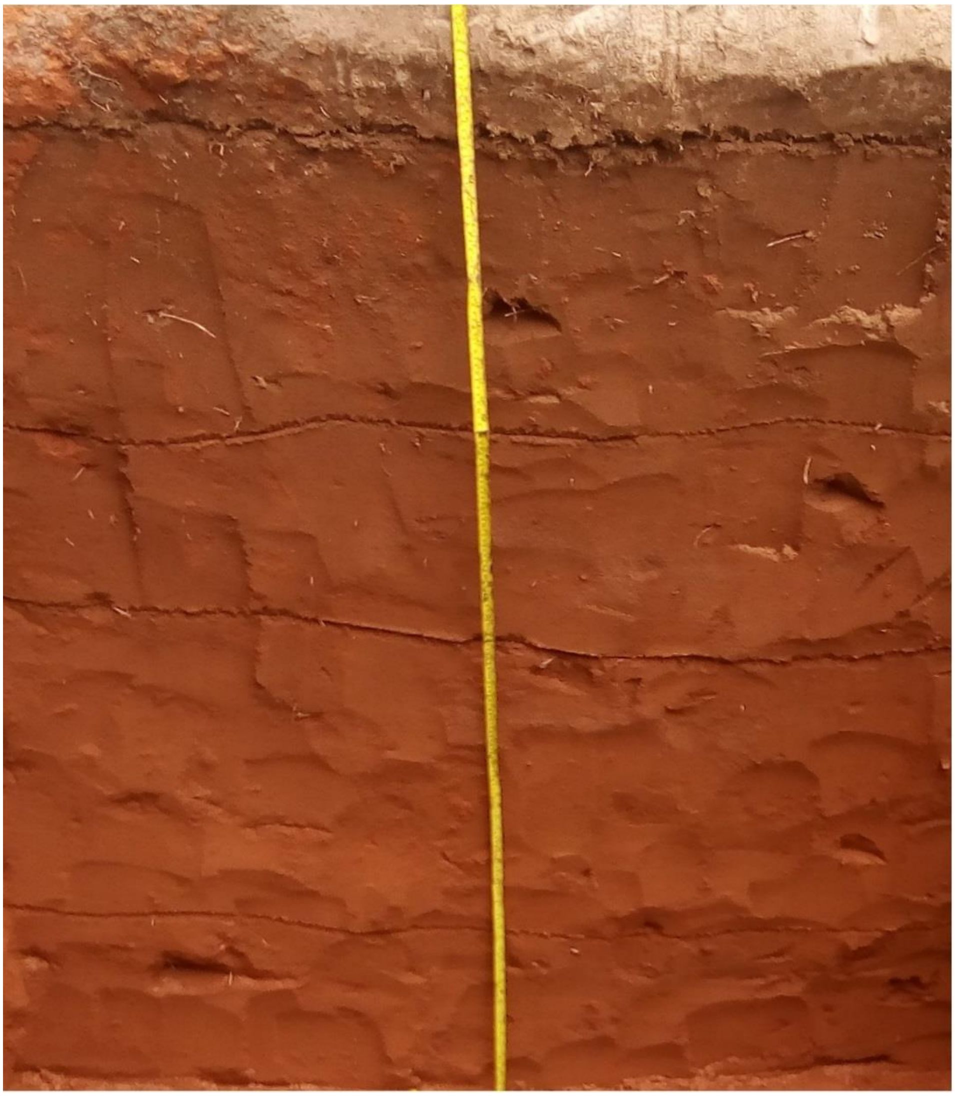
Bt1
26 - 61 cm

Bt2
61 - 127 cm

Bt3
127 - 176 cm

C
176 - 200 cm

Plate 1: A typical soil profile of the upper coal measure parent material at Agu-Ibagwa



Ap
0 - 20 cm

AB
20 - 62 cm

B1
62 - 98 cm

B2
98 - 161 cm

BC
161 - 200 cm

Plate 2: A typical soil profile of the false-bedded sandstone parent material at Nkpologwu

Ap
0 - 29 cm

A1
29 - 55 cm

Bt
55 - 121 cm

C
121 - 200 cm

Plate 3: A typical soil profile of the Nkporo shale parent material at Opi-Agu

Table 8: The physical characteristics of soil profiles of the study area

Horizon	Depth (cm)	Clay	Silt	Fine Sand	Coarse Sand	Texture	Bulk Density (g cm^{-3})	Macro Porosity (%)	Micro Porosity (%)	Total Porosity (%)	K_{Sat} (cm h^{-1})
		g kg^{-1}									
Agu-Ibagwa											
Ap	0 – 26	110	70	430	390	LS	1.50	12.08	39.27	51.35	13.89
Bt1	26 – 61	270	90	550	90	SCL	1.42	11.15	41.09	52.24	3.27
Bt2	61 – 127	250	50	600	100	SCL	1.51	12.35	44.71	57.06	1.73
Bt3	127 – 156	250	70	580	100	SCL	1.81	14.58	35.75	50.33	4.36
C	176 – 200	250	70	490	190	SCL	1.76	13.12	37.39	50.51	8.89
Mean		226	70	530	174		1.6	12.66	39.64	52.30	6.43
CV (%)		25.89	18.07	11.75	65.49		9.69	9.09	7.83	4.73	68.90
Opi-Agu											
Ap	0 – 21	50	30	820	100	S	1.41	18.01	33.90	51.91	16.81
A_1	21 – 55	190	170	590	50	SL	1.75	20.07	28.19	48.26	11.62
Bt	55 – 121	230	130	590	50	SCL	1.58	15.40	25.35	40.75	12.61
C	121 – 200	190	110	570	130	SL	1.70	16.13	24.22	40.35	12.61
Mean		165.00	110.00	642.50	82.50		1.61	17.40	27.92	45.32	13.41
CV (%)		41.44	46.35	16.00	41.44		8.13	10.40	13.42	10.90	14.93
Nkpologwu											
Ap	0 – 20	50	30	310	610	S	1.71	11.28	34.43	45.71	87.68
AB	20 – 62	50	30	320	600	S	1.67	13.99	29.54	43.33	77.78
B1	62 – 98	70	30	340	560	S	1.76	14.61	32.08	46.69	66.67
B2	98 – 161	70	30	260	640	S	1.83	11.63	31.40	43.03	33.94
B3	161 – 200	70	30	360	540	S	1.80	13.93	28.98	42.91	38.89
Mean		62	30	318	590		1.75	13.09	31.29	44.33	60.99
CV (%)		15.80	0	10.60	6.06		3.32	10.38	6.21	3.52	34.75

LS – loamy sand; SCL – sandy clay loam; S – sand; SL – Sandy Loam; K_{Sat} - Saturated Hydraulic conductivity areas (Nwokocha *et al.,* 2003; Igwe *et al.,* 2010; Ezeaku and Iwuanyanwu, 2013 and Okenmuo, 2015).

The mean values of soil organic matter (SOM) were Agu-Ibagwa (9.40 g kg^{-1}), Opi-Agu (13.80 g kg^{-1}) and Nkpologwu (8.10 g kg^{-1}) (Table 9). The SOM were rated very low to moderate based on the rating of Enwezor *et al.* (1989). The moderate contents of SOM at the Ap horizon might be attributed to high vegetation density in the area and crop residue return to the soil (Igwe and Nkemakosi, 2007; Atofarati *et al*., 2012). Moderate coefficient of variation (15 – 35%) was observed in the soils of Agu-Ibagwa while soils of Opi-Agu and Nkpologwu showed high variation (cv > 35%) among the horizons. The low organic matter content in the area is an indication of high rate of organic matter degradation made possible by the relatively high temperature and equally good soil aeration of the area (Asadu *et al.,* 2001).

The total N (TN) content ranged from 0.30 to 2.00 g kg^{-1} with the mean value of 0.60 g kg^{-1}, 0.30 to 1.40 g kg^{-1} with the mean value of 0.80 g kg^{-1} and 0.30 to 0.70 g kg^{-1} with the mean value of 0.40 g kg^{-1} for Agu-Ibagwa, Opi-Agu and Nkpologwu soils respectively (Table 9). The total N showed high variations (cv ≥ 35%) among the soil horizons. Since SOM accounts for 90 – 98% of total N; it has similar trend with SOM. Based on ratings by Shehu *et al.* (2015), TN ranges from low to moderate with higher values occurring at the Ap horizons. The low values of nitrogen content could be attributed to the low SOM content. Also, the low N contents of the soils may be as a result of the high N losses through leaching, as well as the rapid mineralization of organic matter resulting from the exposure of soils to high temperatures (Senjobi and Ogunkunle, 2011; Mustafa *et al*., 2011; Uzoho *et al*., 2014)

The Na^+, K^+, Ca^{2+} and Mg^{2+} ranged from 0.01 to 0.05 cmol kg^{-1}, 0.03 to 0.08 cmol kg^{-1} and 2.60 to 5.00 cmol kg^{-1} and 0.20 to 1.60 cmol kg^{-1} respectively with higher values of Na^+, K^+ and Ca^{2+} recorded in the Ap horizon of all soil profiles (Table 9). The exchangeable Mg^{2+} value varied irregularly with increase in depth in Agu-Ibagwa and Nkpologwu soils. Calcium and magnesium dominated the exchangeable cations in all the profiles and this is similar to the soils of Southeastern Nigeria (Okenmuo, 2015). The values of total exchangeable bases (TEB) in all the profiles ranged from 3.0 cmol kg^{-1} in AB horizon of Nkpologwu to 6.0 cmol kg^{-1} in Ap horizon of Opi-Agu soils and the values varied irregularly with depth.

The exchangeable Al^{3+} and H^+ values ranged from 0.40 to 2.00 cmol kg^{-1} and 0.20 to 0.80 cmol kg^{-1} respectively whereas the total exchangeable acidity (TEA) ranged from 0.60 to 2.20 cmol kg^{-1} (Table 9). The exchangeable Al^{3+} and H^+ showed high variation (cv > 35%) among horizons. The values of total exchangeable acidity based on the rating by (Enwezor *et al.,* 1989) were low to moderate. The low levels of TEA in the surface horizon of the three locations was probably due to the mineralization of vegetative materials into SOM. Generally, the exchangeable acidity was very low and suggesting that the soils have no acidity problem. The H^+ rather than Al^{3+} dominated the exchangeable acidity and is consistent with the findings of Amalu (1998) that H^+ rather than Al^{3+} dominates in majority of soils with pH less than 5.

The cation exchange capacity (CEC) ranged from 5 to 12 cmol kg^{-1} with the mean value of 7.76 cmol kg^{-1} for Agu-Ibagwa soils, 7 to 10 cmol kg^{-1} with the mean value of 8.90 cmol kg^{-1} for Opi-Agu soils and 9 to 12 cmol kg^{-1} with the mean value of 10.36 cmol kg^{-1} for Nkpologwu soils (Table 9). The coefficient of variation for Opi-Agu and Nkpologwu soils was < 15 % while that of Agu-Ibagwa soils was > 35 % among horizons. Down the profile, the values varied irregularly with depth. Based on the rating by Enwezor *et al*. (1989), CEC ranged from very low to moderate and this is consistent with the findings of Ogban and Ekerette (2001) that soils of Southeastern Nigeria are made up of low cation exchange capacity and basic cations.

The percentage base saturation (PBS) varied irregularly with depth with the CV > 35% for Agu-Ibagwa and < 35% for Opi-Agu and Nkpologwu soils. The PBS had the highest mean value (61.49%) in Agu-Ibagwa and lowest mean value (32.94%) in Nkpologwu; and generally in the order of Agu-Ibagwa > Opi-Agu > Nkpologwu (Table 9). FAO (1999) reported that soils with base saturation of > 50% are regarded as fertile soils while soils with less than 50% were regarded as not fertile soils. Based on this therefore, the soils of Agu-Ibagwa and Opi-Agu were fertile while that of Nkpologwu was generally not fertile.

The available phosphorus ranged from Opi-Agu (0.93 to 5.00 mg kg^{-1}) with the mean value of 2.80 mg kg^{-1}, Nkpologwu (0.93 to 4.0 mg kg^{-1}) with the mean value of 2.24 mg kg^{-1} and very low in Agu-Ibagwa (Table 9). These low available phosphorus values could have probably resulted from the nature of the parent material and partly to the fixation of this nutrient element by iron and aluminum oxides under well drained acidic condition (Nuga *et al.,* 2006; Orimoloye *et al.,* 2018). The low value recorded in the soils of Agu-Ibagwa were consistent with the findings of Amhakhian and Osewota (2012a) that tropical soils are generally low in available P due to low apatite content of the soil forming materials. However, the coefficient of variation for available phosphorus was > 35% indicating high variation according to Wilding and Dress (1983) among soil horizons.

Table 9: The chemical characteristics of soil profiles of the study area

Horizon	Depth (cm)	pH		SOM	Total N	Exchangeable Cations				TEB	Exch. Acidity		TEA	CEC	BS (%)	Av.P mg kg^{-1}
		H_2O	KCl			Na^+	K^+	Ca^{2+}	Mg^{2+}		Al^{3+}	H^+				
				g kg^{-1}		cmol kg^{-1}										
Agu-Ibagwa																
Ap	0 – 26	5.0	4.8	12.00	1.50	0.04	0.07	3.40	0.80	4.31	0.40	0.20	0.60	6.00	71.83	-
Bt1	26 – 61	5.0	4.8	12.40	0.30	0.03	0.05	3.20	0.40	3.68	0.80	0.60	1.40	12.40	29.68	-
Bt2	61 – 127	6.3	4.8	9.60	0.30	0.03	0.05	3.20	0.60	3.88	2.00	0.20	2.20	9.60	40.42	-
Bt3	127 – 156	6.8	4.9	6.90	0.60	0.02	0.05	3.00	1.60	4.67	0.60	0.20	0.80	5.60	83.39	-
C	176 – 200	6.6	5.0	6.20	0.40	0.02	0.05	3.00	1.20	4.27	0.60	0.20	0.80	5.20	82.12	-
	Mean	5.94	4.86	9.40	0.60	0.03	0.05	3.16	0.92	4.16	0.88	0.28	1.16	7.76	61.49	0
	CV (%)	13.20	1.64	26.98	73.13	26.72	14.81	4.74	46.83	8.35	65.24	57.14	50.44	36.10	36.13	0
Opi-Agu																
Ap	0 – 21	7.3	6.5	21.20	0.60	0.05	0.08	5.00	0.80	5.93	-	0.60	0.60	10.00	59.30	4.66
A2	21 – 55	6.0	4.8	14.50	1.40	0.04	0.07	3.60	0.60	4.31	0.40	0.60	1.00	9.60	44.90	0.93
B	55 – 121	5.5	4.8	11.00	0.30	0.03	0.05	3.60	0.40	4.08	1.20	0.20	1.40	8.80	46.36	-
C	121 – 200	6.9	4.9	8.30	0.70	0.03	0.05	3.80	0.40	4.28	0.80	0.40	1.20	7.20	59.44	-
	Mean	6.43	5.25	13.80	0.80	0.04	0.06	4.00	0.55	4.65	0.80	0.45	1.05	8.90	52.50	2.80
	CV (%)	11.08	13.77	35.13	53.75	22.11	20.78	14.58	30.15	16.01	40.82	36.85	28.17	12.05	13.12	66.73
Nkpologwu																
Ap	0 – 20	6.0	5.1	11.00	0.70	0.04	0.07	2.60	0.40	3.11	-	0.80	0.80	10.00	31.10	3.73
AB	20 – 62	6.1	5.1	11.00	0.30	0.03	0.05	2.60	0.40	3.08	0.60	0.20	0.80	10.00	30.80	2.80
B1	62 – 98	6.3	5.0	11.00	0.40	0.03	0.05	2.40	1.00	3.48	-	0.60	0.60	9.00	37.83	0.93
B2	98 – 161	5.8	5.0	1.40	0.30	0.01	0.03	2.80	0.40	3.24	0.60	0.20	0.80	12.40	26.13	0.93
B3	161 – 200	6.3	5.1	6.20	0.40	0.01	0.03	3.80	0.20	4.04	-	0.60	0.60	10.40	38.85	2.80
	Mean	6.1	5.06	8.10	0.40	0.02	0.05	2.84	0.48	3.23	0.60	0.48	0.72	10.36	32.94	2.24
	CV (%)	3.11	0.97	47.29	35.00	50.00	32.54	17.48	56.52	4.89	0.00	50.00	13.61	10.81	14.44	50.07

4.2 Soil Classification

The soils of Agu-Ibagwa has an argillic horizon and base saturation of > 35% in all the horizon within 150 cm hence classified as order Alfisols. An ustic moisture regime was established because the soils are dry in some or all the parts for 90 or more consecutive days in normal years, and this qualified them as sub-order Ustalfs. They were further classified as great group Haplustalfs and sub-group Typic Haplustalfs (Soil Survey Staff, 2014). According to World Reference Base (WRB), the soils were classified into the Reference group Lixisols due to presence of an argillic horizon, CEC of < 24 cmol kg^{-1} and base saturation of > 50% (FAO, 2014). Owing to the loamic textural class at the depth of ≥ 30 % from the mineral surface, the soils was further classified as Loamic Lixisols (FAO, 2014).

Opi-Agu soils met the characteristic requirement of oxisols as they have oxic horizon and low CEC values. They are moist, however in some part either for more than 180 cumulative days per year or for 90 or more consecutive days. This particular features placed the pedon at the Ustox sub-order. They were classified as great group Eutrustox due to the presence of base saturation (by NH_4OAc) of > 35 % in all the horizon within 125 cm of the mineral surface. At the subgroup level, they were further classified as Typic Eutrustox (Soil Survey Staff, 2014). At the WRB, the soils were correlated to Lixisols and Loamic Lixisols because of higher clay content in the subsoil than in the topsoil and a textural class of sandy loam and sandy clay loam in a layer ≥ 30 cm thick.

Nkpologwu soils were classified as order Ultisols owing to the presence of Kandic horizon and base saturation of < 35 % in all the horizon within 150 cm of the mineral soil surface. They were further classified as sub-order Ustults, great group Kanhaplustults and subgroup Arenic Kanhaplustults. They were classified as Arenic Kanhaplustults as they possessed sandy textural class throughout the layer extending from the mineral soil surface to the top of the kandic horizon. This correlated with Reference group Acrisols due to its presence of agric horizon; CEC of < 24 cmol kg^{-1} and base saturation of < 50 % in all the horizon (FAO, 2014). It was further classified as Arenic Acrisols owing to the presence of sandy textural class at depth of ≥ 30 cm within the 100 cm of the mineral surface.

Table 10: Classification of soils of the study area

Location	Order	Suborder	Great group	Sub group	FAO/UNESCO WRB
Agu-Ibagwa	Alfisols	Ustalfs	Haplustalfs	Typic Haplustalfs	Loamic Lixisols
Opi-Agu	Oxisol	Ustox	Eutrustox	Typic Eutrustox	Loamic Lixisols
Nkpologwu	Ultisols	Ustults	Kanhaplustults	Arenic Kanhaplustults	Arenic Acrisols

4.3 Effect of Geological Materials (Location) on the Particle Size Distribution of the Soils

The clay, silt, fine sand and coarse sand were significantly affected by the geological materials (Table 11). The highest values of clay (260 g kg^{-1}) and silt (100 g kg^{-1}) were obtained from Agu-Ibagwa whereas the lowest values of clay (68 g kg^{-1}) and silt (32 g kg^{-1}) were obtained from Nkpologwu. Subsequently, the highest value of fine sand (360 g kg^{-1}) was obtained from Opi-Agu while the highest value of coarse sand (614 g kg^{-1}) was obtained from Nkpologwu. The textural class for the three locations were Sandy Clay Loam, Sand and Sandy Loam for Agu-Ibagwa, Nkpologwu and Opi-Agu Soils respectively. The high coarse sand fraction observed in the soils of Nkpologwu could be due to the sandy nature of the parent material (Onweremadu *et al*. 2007a). The higher clay fraction obtained in the soils of Agu-Ibagwa could be attributed to the clayey nature of the parent material (Anenyeonwu, 2016). The low values of silt sized particles in the soil were attributed to the characteristics of the parent materials of the soils (Akamigbo and Asadu, 1983).

Table 12 shows the interaction effects of geological materials and soil depth. The clay content was significantly ($p < 0.05$) affected by the interaction of geological materials and soil depth with the highest (310 g kg^{-1}) and lowest (67 g kg^{-1}) values of clay obtained at the subsurface (20 to 40cm) layers of Agu-Ibagwa and Nkpologwu respectively. On the other hand, silt, fine and coarse sand were not significantly affected by the interaction of geological materials and soil depth. However, the highest (120 g kg^{-1}) and lowest (33 g kg^{-1}) values of silt content were recorded from the surface (0 – 20 cm) soils of Agu-Ibagwa and subsurface (20 – 40cm) soils of Nkpologwu; the highest (353 g kg^{-1}) and lowest (155 g kg^{-1}) values of fine sand were recorded from the subsurface soils of Opi-Agu and Agu-Ibagwa and highest (623 g kg^{-1}) and lowest (397 g kg^{-1}) values of coarse sand content were recorded from the surface soils of Agu-Ibagwa and Opi-Agu.

Generally, the values of the particle size distribution across each geological material varied irregularly with soil depth. These variations might be as a result of nature of the parent materials. Studies in Nigeria (Akamigbo and Asadu, 1983; Asadu *et al*., 2001; Ezeaku and Iwuanyanwu, 2013; Abam and Orji, 2019) on spatial variability of soil properties have shown similar changes.

Table 11: Main Effect of geological materials (location) on the particle size distribution

Location	**No**	**Clay**	**Silt**	**Fine Sand**	**Coarse Sand**	**Total Sand**	**Texture**
				g kg^{-1}			
Agu-Ibagwa	12	260	100	198	442	640	Sandy Clay Loam
Nkpologwu	12	68	32	286	614	900	Sand
Opi-Agu	12	143	88	360	409	769	Sandy Loam
F-LSD $_{(0.05)}$		19.37	38.20	52.4	27.60	64.64	

Table 12: Interaction of geological materials and soil depth on the particle size distribution

Location	Soil Depth (cm)	Clay	Silt	Fine Sand	Coarse Sand	Total Sand	Texture
		g kg^{-1}					
Agu-Ibagwa	0 – 20	210	120	230	440	670	Sandy Clay Loam
	20 – 40	310	80	155	455	610	Sandy Clay Loam
Nkpologwu	0 – 20	70	30	277	623	900	Sand
	20 – 40	67	33	295	605	900	Sand
Opi-Agu	0 – 20	150	100	353	397	750	Sandy Loam
	20 – 40	135	75	367	423	790	Sandy Loam
F-LSD$_{(0.05)}$		27.39	NS	NS	NS	NS	

4.4 Effect of Geological Materials (Location) and Soil Depth on Soil Chemical Properties

Soil pH

The Soil pH was significantly ($p \leq 0.05$) affected by the geological materials (Table 13). The highest pH value (6.08) was obtained from Opi-Agu soils while the lowest pH value (5.02) was obtained from Nkpologwu soils. Generally, the soils have very strongly to slightly acidic pH which may be due to high intensity rainfall in the area that leaches the basic cations (Igwe *et al.,* 1999) in addition to the acidic nature of the parent material. On the other hand, soil pH was not significantly ($p \geq 0.05$) affected by soil depth.

Also, the soil pH was not significantly ($p \geq 0.05$) influenced by the interaction of geological materials by soil depth. However, the highest value of soil pH (6.10) was obtained from the subsurface soil of Opi-Agu while the lowest value (5.00) was obtained from the subsurface soil of Agu-Ibagwa.

Soil organic matter

The Soil Organic Matter (SOM) was significantly ($p \leq 0.05$) affected by the parent materials or location and soil depth (Table 13). The soils of Agu-Ibagwa significantly ($p \leq 0.05$) recorded the highest mean value (18.80 g kg^{-1}) of SOM while the lowest mean value (13.30 g kg^{-1}) was recorded from Nkpologwu soils. The highest value of SOM recorded in Agu-Ibagwa soils might be attributed to high clay and silt proportion or colloidal nature of the soil (Ojomah and Joseph, 2017). The lowest value of SOM recorded in Nkpologwu soils is as a result of leaching problem because of the high proportion of sand content (Saggar *et al*., 1994; Saggar *et al*., 1996). But, as regards the two soil depths, higher SOM was observed in the surface (16.50 g kg^{-1}) than subsurface (12.10 g kg^{-1}) layers (Table 13). Similarly, in all the locations SOM decreased with increasing soil depth. The higher proportions of organic matter at the surface layer could be due to the fact that most of the organic residues are incorporated or deposited on the soil surface (Dick and Greorich, 2004).

Considering the interaction effect of location and soil depth, SOM was not significantly ($p \leq 0.05$) affected (Table 14). Nevertheless, the highest value of soil organic matter (20.60 g kg^{-1}) was recorded from the surface (0 – 20 cm) layer of Agu-Ibagwa while the lowest value (9.00 g kg^{-1}) was recorded from the subsurface soil (20 – 40 cm) of Opi-Agu.

Total nitrogen

The total nitrogen (TN) was significantly ($p \leq 0.05$) influenced by the location. The total nitrogen content (1.70 g kg^{-1}) obtained was highest in Agu-Ibagwa soils while the lowest (0.40 g kg^{-1}) was recorded from the Nkpologwu soils (Table 13). Following the rating of total N by Shehu *et al.* (2015), the topsoils of Agu-Ibagwa were very high in total N. The highest values of TN obtained in Agu-Ibagwa soils could be due to nutrient recycling from litter on the soil surface (Ezeaku and Iwuanyanwu, 2013 and Uzoho *et al.*, 2014).

With regard to soil depth interaction with location, total N was not significantly ($p \geq 0.05$) affected. However, the highest value of total N (2.10 g kg^{-1}) was obtained at the surface layer of Agu-Ibagwa while the lowest (0.30 g kg^{-1}) value was obtained from the subsurface layer of Nkpologwu.

Available phosphorus

The available phosphorus was significantly ($p \leq 0.05$) affected by the interaction of location with soil depth (Table 14). The content of available phosphorus was highest (3.57 mg kg^{-1}) in the subsurface (20 – 40 cm) soil of Opi-Agu while the lowest (1.40 mg kg^{-1}) was obtained in the subsurface (20 – 40 cm) layer of Agu-Ibagwa. Generally, variations in available phosphorus contents in the location could be related to the intensity of soil weathering or soil disturbance and the degree of P- fixation with Fe and C as indicated by Paulos (1996). The low values of available phosphorus could have stemmed from the low SOM content and possible lack of abundant native phosphate – bearing rocks in the geological materials of the area. (Asadu *et al.*, 2001).

The available phosphorus was not significantly ($p \geq 0.05$) affected by the main effects of location and soil depth (Table 13). But, the highest value (2.94 mg kg^{-1}) and lowest value (2.10 mg kg^{-1}) were obtained from Opi-Agu and Agu-Ibagwa soils respectively. Considering the soil depth, the highest value (2.64 mg kg^{-1}) was obtained from the topsoil while the lowest value (2.33 mg kg^{-1}) was obtained from the subsoil.

Table 13: Effect of location and soil depth on pH, organic matter, total nitrogen and available phosphorus

Location	No	pH		OM	TN	Av. P
		H_2O	KCl	g kg^{-1}	g kg^{-1}	(mg kg^{-1})
Agu-Ibagwa	12	5.02	4.10	18.80	1.70	2.10
Nkpologwu	12	5.17	4.35	10.80	0.40	2.42
Opi-Agu	12	6.08	5.18	13.30	0.60	2.94
F-LSD $_{(0.05)}$		0.20	0.24	0.38	0.06	NS
Soil Depth						
0 – 20	12	5.41	4.53	16.50	1.10	2.64
20 – 40	12	5.44	4.56	12.10	0.70	2.33
F-LSD $_{(0.05)}$		NS	NS	0.31	NS	NS

Table 14: Interaction effect of location and soil depth on pH, organic matter, total nitrogen and available phosphorus

Location	Depth (cm)	pH		OM	TN	Av. P
		H_2O	KCl	g kg^{-1}	g kg^{-1}	(mg kg^{-1})
Agu-Ibagwa	0 – 20	5.05	4.10	20.60	2.10	2.80
	20 – 40	5.00	4.10	17.00	1.30	1.40
Nkpologwu	0 – 20	5.12	4.30	11.30	0.40	2.80
	20 – 40	5.22	4.40	10.30	0.30	2.03
Opi-Agu	0 – 20	6.07	5.18	17.60	0.70	2.32
	20 – 40	6.10	5.18	9.00	0.60	3.57
F-LSD $_{(0.05)}$		NS	NS	NS	NS	1.47

Exchangeable cations

Table 15 shows the main effect of location on the exchangeable cations. The highest (1.05 cmol kg^{-1}) and lowest (0.68 cmol kg^{-1}) values of exchangeable Ca was obtained from Agu-Ibagwa and Opi-Agu soils respectively. The mean exchangeable Na (0.05 cmol kg^{-1}), K (0.09 cmol kg^{-1}) and Mg (1.40 cmol kg^{-1}) were highest in Agu-Ibagwa soils whereas the lowest mean exchangeable Na (0.04 cmol kg^{-1}), K (0.08 cmol kg^{-1}) and Mg (1.22 cmol kg^{-1}) were obtained from the Nkpologwu soils.

Considering the soil depth, the higher values of exchangeable sodium (Na) and magnesium (Mg) was significantly ($p \leq 0.05$) obtained from the subsurface (20 – 40 cm) layer while the lower values was obtained at the surface (0 – 20cm) layer. The higher values of exchangeable potassium (K) and calcium (Ca) was obtained from the surface layer whereas the lower value was obtained from the subsurface layer. However, they are statistically the same ($p \geq 0.05$). On the other hand, the content of exchangeable cations were not significantly ($p \geq 0.05$) affected by the interaction of location with soil depth.

Generally, the low pH of the soils and the high amounts of rainfall in the study area could be associated in leaching out of the basic cations that the soils had undergone and the nature of the parent material (Ca^{2+}, K^{+}, Na^{+} and Mg^{2+}) (Okoli *et al.*, 2019). Also, Amberger (2006) opined that in the acid soils of the humid tropics, base cations tend to be deficient while Igwe and Okebalama (2006) reported that very low contents of exchangeable cations in southeastern Nigeria could be attributed to high mineralization rate of the soil organic matter.

Total exchangeable bases

The total exchangeable bases (TEB) was significantly ($p \leq 0.05$) affected by location (Table 16), with the highest (2.65 cmol kg^{-1}) and lowest (2.04 cmol kg^{-1}) values obtained from Agu-Ibagwa and Opi-Agu soils respectively. The values of TEB ranged from relatively low to moderate with the moderate values obtained in Agu-Ibagwa. The general low TEB prevalent in Nkpologwu soils was largely due to the effect of parent material; the porous nature of the soils; the corresponding low SOM content and the dominance of low activity clays as earlier reported in similar soils around Nsukka area (Akamigbo and Asadu, 1983; Asadu, 1990; Asadu and Bosah, 2002).

The TEB was not significantly ($p \geq 0.05$) affected by the interaction between soil depth and location. Though the highest (2.67 cmol kg^{-1}) and lowest (1.95 cmol kg^{-1}) values of TEB were obtained in the surface (0 – 20cm) soils of Agu-Ibagwa and Nkpologwu respectively (Table 16).

Exchangeable acidity

The total exchangeable acidity (TEA) was significantly ($p \leq 0.05$) affected by location, soil depth and their interaction, with the highest (5.35 cmol kg^{-1}) and lowest (2.22 cmol kg^{-1}) values of exchangeable acidity obtained from Agu-Ibagwa and Opi-Agu soils respectively (Table 15). Enwezor *et al.* (1989) reported that soils with TEA of ≥ 5 cmol kg^{-1} are rated high. The high TEA could be as a result of high leaching rate that favours the development of acidity which inversely leading to high exchangeable aluminum and hydrogen when compared with the exchangeable base forming cations. The values of TEA obtained were comparable to those earlier reported by Akamigbo and Asadu (1983) for the soils derived from similar parent materials in the area. Also, the mean value of TEA decreased with increase in soil depth.

Considering the interaction of location and soil depth (Table 16), the highest value of TEA (6.50 cmol kg^{-1}) was obtained from the subsurface soil of Agu-Ibagwa whereas the lowest value of TEA (2.23 cmol kg^{-1}) was obtained from the surface soil of Nkpologwu.

Cation exchange capacity

The cation exchange capacity (CEC) of the soil was significantly ($p \leq 0.05$) affected by location and its interaction with soil depth. The highest (12.00 cmol kg^{-1}) and lowest (7.90 cmol kg^{-1}) values of CEC were obtained from Opi-Agu and Nkpologwu soils respectively (Table 15). Also, with regard to the interaction of location and soil depth, the highest (13.23 cmol kg^{-1}) and lowest (7.53 cmol kg^{-1}) CEC values were obtained from the surface (0 – 20 cm) layer of Opi-Agu and Nkpologwu soils respectively (Table 16). The lowest CEC value obtained in the Nkpologwu soil can be attributed to the low contents of colloidal materials such as clay and organic matter, which are essential for cation exchange and adsorption in soils (Uzu *et al.* 2003). On the other hand, CEC was not significantly ($p \geq 0.05$) affected by soil depth. However, CEC was higher in surface (0 – 20 cm) than in the subsurface (20 – 40 cm) soils.

Percentage base saturation

The percentage base saturation (PBS) was significantly ($p > 0.05$) influenced by the location (Table 15). The highest (29.10%) and lowest (18.30%) values of PBS were recorded in Agu-Ibagwa and Opi-Agu soils respectively. According to Enwezor *et al.* (1989), the soils having a

PBS of 16.62 – 30.30% ranged from very low to low. In general, processes that affect the extent of basic cations such as high mineralization rate of the soil organic matter also affect percent base saturation.

The PBS was not significantly ($p \geq 0.05$) affected by soil depth and the interaction of location and soil depth. However, the highest (30.30%) and lowest (16.62%) contents of PBS were obtained from the subsurface (20 – 40 cm) layer of Agu-Ibagwa and surface (0 – 20 cm) layer of Opi-Agu soils as regards the interaction of geological materials and soil depth.

Table 15: Main effect of geological materials and soil depth on some soil chemical properties

Location	No	Exchangeable Cations				TEB	Exch. Acidity		TEA	CEC	BS
		Na^+	K^+	Ca^{2+}	Mg^{2+}		Al^{3+}	H^+			(%)
		cmol kg^{-1}									
Agu-Ibagwa	12	0.05	0.09	1.05	1.40	2.65	2.30	3.00	5.35	8.90	29.10
Nkpologwu	12	0.04	0.08	0.70	1.22	2.04	0.58	1.63	2.22	7.90	25.83
Opi-Agu	12	0.04	0.09	0.68	1.28	2.34	0.20	2.90	3.10	12.00	18.30
F-LSD (0.05)		NS	NS	0.16	NS	0.33	0.35	0.37	0.49	1.42	3.03
Soil Depth											
0 – 20	12	0.04	0.09	0.87	1.23	2.28	0.80	2.42	3.22	10.12	23.53
20 – 40	12	0.05	0.08	0.76	1.37	2.40	1.26	2.60	3.89	9.08	25.29
F-LSD (0.05)		0.01	NS	NS	0.13	NS	0.29	NS	0.40	NS	NS

Table 16: Interaction effect of geological materials and soil depth on soil chemical properties

Location	Soil Depth (cm)	Exchangeable Cations				TEB	Exch. Acidity		TEA	CEC	BS (%)
		Na^+	K^+	Ca^{2+}	Mg^{2+}		Al^{3+}	H^+			
		cmol kg^{-1}									
Agu-Ibagwa	0 – 20	0.05	0.09	1.10	1.30	2.67	2.20	2.00	4.20	9.10	27.90
	20 – 40	0.05	0.09	1.00	1.50	2.62	2.40	4.00	6.50	8.70	30.30
Nkpologwu	0 – 20	0.04	0.08	0.67	1.17	1.95	0.10	2.13	2.23	7.53	26.07
	20 – 40	0.04	0.08	0.73	1.27	2.12	1.07	1.13	2.20	8.27	25.60
Opi-Agu	0 – 20	0.05	0.10	0.83	1.23	2.22	0.10	3.13	3.23	13.73	16.62
	20 – 40	0.03	0.07	0.53	1.33	2.46	0.30	2.67	2.97	10.27	19.98
F-LSD $_{(0.05)}$		NS	NS	NS	NS	NS	NS	0.52	0.70	2.01	NS

4.5 Suitability Evaluation of the Soils of Nsukka Area

The three locations (Agu-Ibagwa, Nkpologwu and Opi-Agu) were evaluated for its suitability for pepper, turmeric, ginger and tomato cultivation using the limitation and parametric method of land evaluation.

4.5.1 Suitability of the soils of Nsukka area for pepper production

The suitability ratings of the soils of Nsukka area for the production of pepper is presented in Table (2). From the results of the aggregate suitability, one location (Agu-Ibagwa) out of three was currently placed at S2 (moderately suitable) for pepper production. The major land characteristics limiting the cultivation of pepper in Agu-Ibagwa were total rainfall and organic carbon. Nkpologwu soils was not suitable (N) due to limitations posed by its sand nature whereas Opi-Agu soils was marginally suitable (S3) for pepper production due to limitations posed by organic carbon.

Under the parametric method of land suitability evaluation, the soils of the study area were highly suitable at S1 for pepper production.

4.5.2 Suitability of the soils of Nsukka Area for turmeric production

The suitability class scores of soils of various locations in Nsukka area for the cultivation of turmeric is summarized in Table 20. The result of the aggregate suitability showed that Agu-Ibagwa and Opi-Agu were moderately suitable (S2) for Turmeric production due to limitations such as the total rainfall and the acidic nature of the soil. The soils of Nkpologwu was marginally suitable (S3) for turmeric production due to its sand texture.

Using the current productivity index of the parametric system of land evaluation (Ezeaku, 2011a), the soils of Agu-Ibagwa, Opi-Agu and Nkpologwu were highly suitable (S1) for turmeric production.

Table 17: Land Suitability Evaluation of Pepper by Limitation Method

Land qualities	Unit	Agu-Ibagwa	Nkpologwu	Opi-Agu
Climatic regime				
Mean temperature in growing season	^{o}C	S1	S1	S1
Total Rainfall	mm	S2	S2	S2
Topography				
Elevation	m	S1	S1	S1
Wetness				
Soil drainage	class	S1	S1	S1
Soil physical properties				
Texture	class	S1	N	S2
Effective soil depth	cm	S1	S1	S1
Soil chemical properties				
OC	%	S2	S3	S3

Table 18: Land Suitability Evaluation of Pepper by Parametric Method

Land qualities	Unit	Agu-Ibagwa	Nkpologwu	Opi-Agu
Climatic regime				
Mean temperature in growing season	^{o}C	S1 (100)	S1 (100)	S1 (100)
Total Rainfall	mm	S2 (75)	S2 (75)	S2 (75)
Topography				
Elevation	m	S1 (100)	S1 (100)	S1 (100)
Wetness				
Soil drainage	class	S1 (100)	S1 (100)	S1 (100)
Soil physical properties				
Texture	class	S1 (100)	N (25)	S2 (75)
Effective soil depth	cm	S1 (100)	S1 (100)	S1 (100)
Soil chemical properties				
OC	%	S2 (75)	S3 (50)	S3 (50)
Aggregate Suitability		S1 (92.9)	S1 (78.6)	S1 (85.7)

Table 19: Land Suitability Evaluation of Turmeric by Limitation Method

Land qualities	Unit	Agu-Ibagwa	Nkpologwu	Opi-Agu
Climatic regime				
Mean temperature in growing season	^{o}c	S1	S1	S1
Total Rainfall	mm	S2	S2	S2
Topography				
Elevation	m	S1	S1	S1
Slope	%	S1	S1	S1
Wetness				
Soil drainage	class	S1	S1	S1
Soil physical properties				
Texture	class	S1	S3	S1
Effective soil depth	cm	S1	S1	S1
Soil chemical properties				
pH (H_2O)		S2	S2	S1

Table 20: Land Suitability Evaluation of Turmeric by Parametric Method

Land qualities	Unit	Agu-Ibagwa	Nkpologwu	Opi-Agu
Climatic regime				
Mean temperature in growing season	^{o}C	S1 (100)	S1 (100)	S1 (100)
Total Rainfall	mm	S2 (75)	S2 (75)	S2 (75)
Topography				
Elevation	m	S1 (100)	S1 (100)	S1 (100)
Slope	%	S2 (75)	S2 (75)	S2 (75)
Wetness				
Soil drainage	class	S1 (100)	S1 (100)	S1 (100)
Soil physical properties				
Texture	class	S1 (100)	S3 (50)	S1 (100)
Effective soil depth	cm	S1 (100)	S1 (100)	S1 (100)
Soil chemical properties				
pH (H_2O)		S2 (75)	S2 (75)	S1 (100)
Aggregate Suitability		S1 (90.6)	S1 (84.4)	S1 (93.8)

4.5.3 Suitability of the soils of Nsukka Area for Ginger Production

Tables 21 and 22 show suitability ratings of Nsukka area for ginger production. The results of the qualitative evaluation show that inspite of the favourable climatic conditions, fertility limitations currently placed the three locations at N (Not Suitable) for ginger production. The Agu-Ibagwa and Nkpologwu soils were placed at N (Not Suitable) class due to its acidic nature of the soil and not having enough rainfall all throughout its growing season while for Opi-Agu, total rainfall is the only limiting factor.

The current productivity index of the parametric system of evaluation revealed that Agu-Ibagwa and Opi-Agu soils were highly suitable (S1) whereas Nkpologwu soils were moderately suitable (S2**)** for ginger production.

4.5.4 Suitability of the soils of Nsukka Area for Tomato Production

The results of the suitability ratings and classes of soils of different locations in Nsukka Area are presented in Tables 23 and 24. The results of the aggregate suitability showed that Agu-Ibagwa and Opi-Agu were marginally suitable (S3) while Nkpologwu was not suitable (N) for tomato production. The land characteristics limiting tomato production in the three locations are total rainfall, coarse fragments and CEC for Agu-Ibagwa; texture for Nkpologwu, and total rainfall and coarse fragments for Opi-Agu.

Using the parametric method of land evaluation, the aggregate suitability of Agu-Ibagwa and Opi-Agu were highly suitable (S1) whereas Nkpologwu were moderately suitable (S2) for tomato production.

Table 21: Land Suitability Evaluation of Ginger by Limitation Method

Land qualities	Unit	Agu-Ibagwa	Nkpologwu	Opi-Agu
Climatic regime				
Mean temperature in growing season	^{o}c	S1	S1	S1
Total Rainfall	mm	N	N	N
Topography				
Elevation	m	S1	S1	S1
Slope	%	S1	S2	S1
Wetness				
Soil drainage	class	S1	S1	S1
Soil physical properties				
Texture	class	S1	S2	S1
Effective soil depth	cm	S1	S1	S1
Soil chemical properties				
pH (H_2O)		N	N	S2
OC	%	S2	S3	S3

Table 22: Land Suitability Evaluation of Ginger by Parametric Method

Land qualities	Unit	Agu-Ibagwa	Nkpologwu	Opi-Agu
Climatic regime				
Mean temperature in growing season	^{o}c	S1 (100)	S1 (100)	S1 (100)
Total Rainfall	mm	N (25)	N (25)	N (25)
Topography				
Elevation	m	S1 (100)	S1 (100)	S1 (100)
Slope	%	S1 (100)	S2 (75)	S1 (100)
Wetness				
Soil drainage	class	S1 (100)	S1 (100)	S1 (100)
Soil physical properties				
Texture	class	S1 (100)	S2 (75)	S1 (100)
Effective soil depth	cm	S1 (100)	S1 (100)	S1 (100)
Soil chemical properties				
pH (H_2O)		N (25)	N (25)	S2 (75)
OC	%	S2 (75)	S3 (50)	S3 (50)
Aggregate Suitability		S1 (80.6)	S2 (72.2)	S1 (83.3)

Table 23: Land Suitability Evaluation of Tomato by Limitation Method

Land qualities	Unit	Agu-Ibagwa	Nkpologwu	Opi-Agu
Climatic regime				
Mean temperature in growing season	^{o} c	S1	S1	S1
Total Rainfall	mm	S3	S3	S3
Topography				
Slope	%	S1	S2	S1
Wetness				
Soil drainage	class	S1	S1	S1
Soil physical properties				
Texture	class	S1	N	S1
Coarse fragments	Vol %	S3	S3	S3
Effective soil depth	cm	S1	S1	S1
Soil chemical properties				
pH (H_2O)		S2	S2	S1
CEC	cmol kg^{-1}	S3	S3	S2

Table 24: Land Suitability Evaluation of Tomato by Parametric Method

Land qualities	Unit	Agu-Ibagwa	Nkpologwu	Opi-Agu
Climatic regime				
Mean temperature in growing season	^{o} c	S1 (100)	S1 (100)	S1 (100)
Total Rainfall	mm	S3 (50)	S3 (50)	S3 (50)
Topography				
Slope	%	S1 (100)	S2 (75)	S1 (100)
Wetness				
Soil drainage	class	S1 (100)	S1 (100)	S1 (100)
Soil physical properties				
Texture	class	S1 (100)	N (25)	S1 (100)
Coarse fragments	Vol %	S3 (50)	S3 (50)	S3 (50)
Effective soil depth	cm	S1 (100)	S1 (100)	S1 (100)
Soil chemical properties				
pH (H_2O)		S2 (75)	S2 (75)	S1 (100)
CEC	cmol kg^{-1}	S3 (50)	S3 (50)	S2 (75)
Aggregate Suitability		S1 (80.6)	S2 (69.4)	S1 (86.1)

4.6 Land/crop Suitability map of the study area

4.6.1 Land/crop suitability map for common horticultural crops production

The suitability of the study areas for the production of horticultural crops (pepper, turmeric, ginger and tomato) were presented in Figure 11, 12 and 13 using the procedure of GIS-based Multiple-Criteria Decision Analysis (MCDA) presented in Figure 7.

Approximately ≈ 60 % and ≈ 40 % of the area at Agu-Ibagwa were highly and moderately suitable respectively for pepper production; ≈ 89 % and ≈ 11 % were highly and moderately suitable for turmeric production and 100 % of the land area was moderately suitable for ginger and tomato production (Figure 11). The suitability analysis indicated that ≈ 2 % and ≈ 98 % of the Opi-Agu study area was highly and moderately suitable for pepper production; ≈ 90 % and ≈ 10 % were highly and moderately suitable for turmeric production; ≈ 99 % and ≈ 1 % were moderately and marginally suitable for ginger production and ≈ 7 % and ≈ 93 % were highly and moderately suitable for tomato production (Figure 12). Nkpologwu was moderately suitable for pepper, turmeric and tomato production while ≈ 3 % and ≈ 97 % of the study area was marginally and moderately suitable for ginger production (Figure 13).

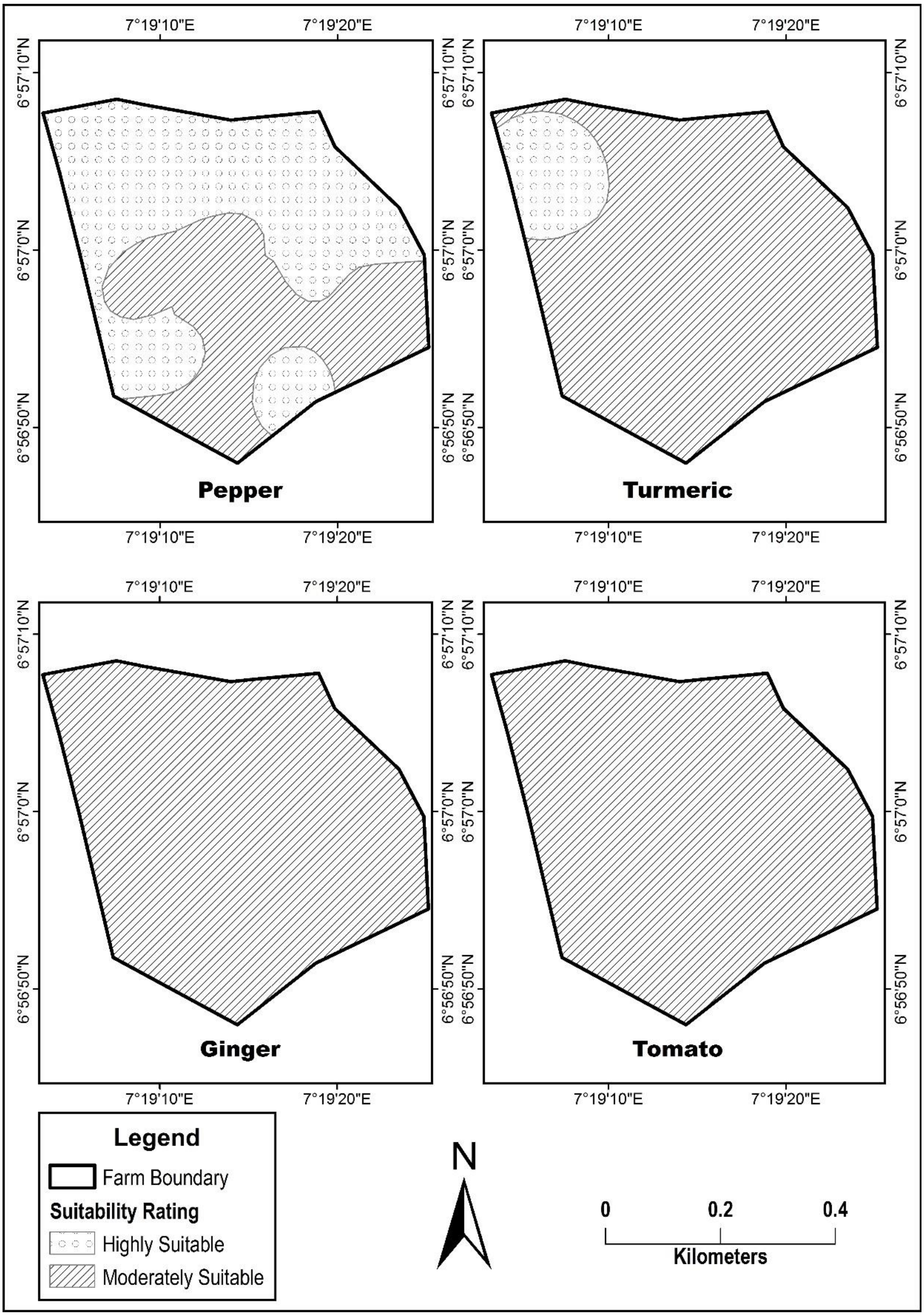


Figure 8: Land/Crop suitability map of Agu-Ibagwa study area.

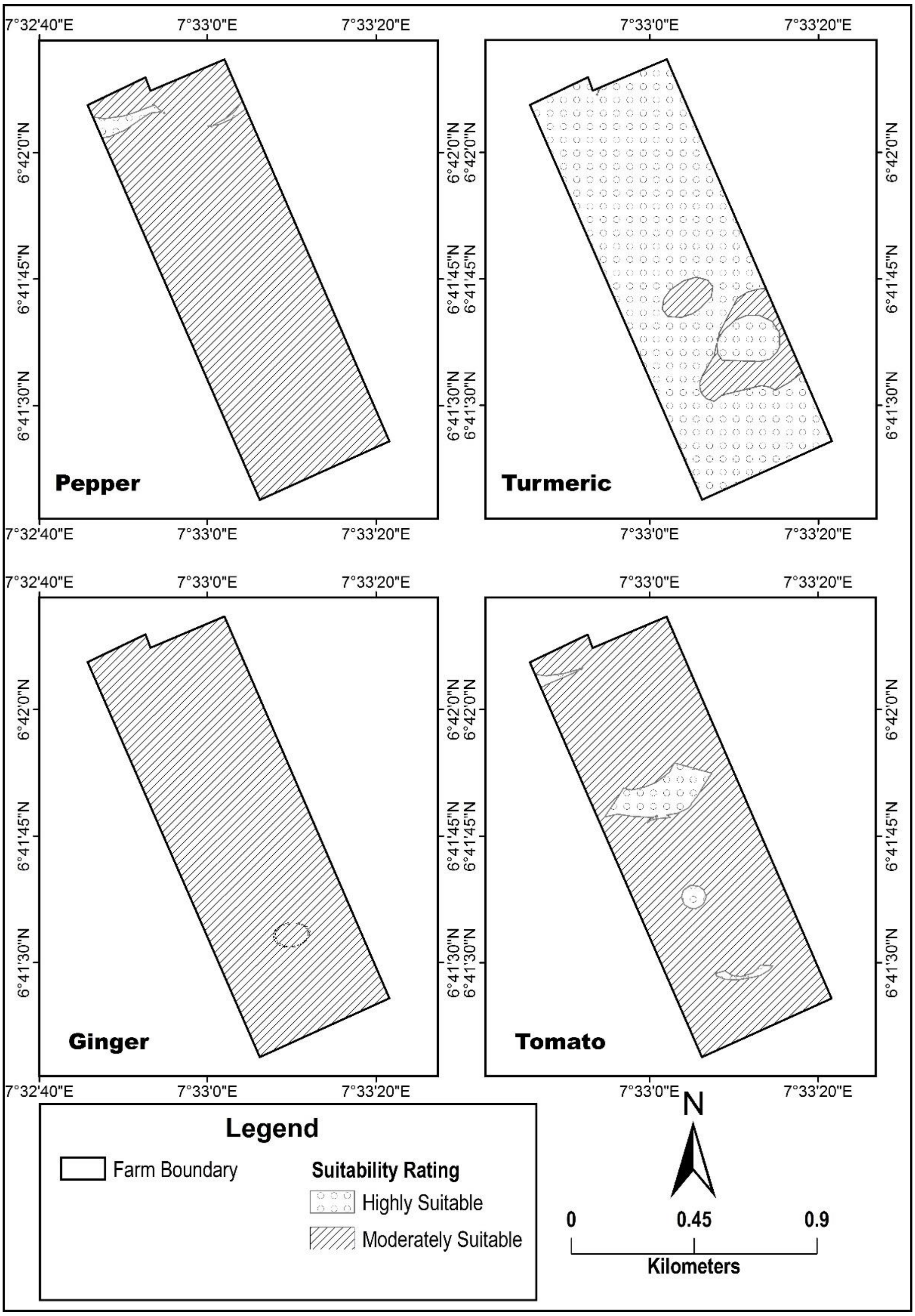


Figure 9: Land/Crop suitability map of Opi-Agu study area.

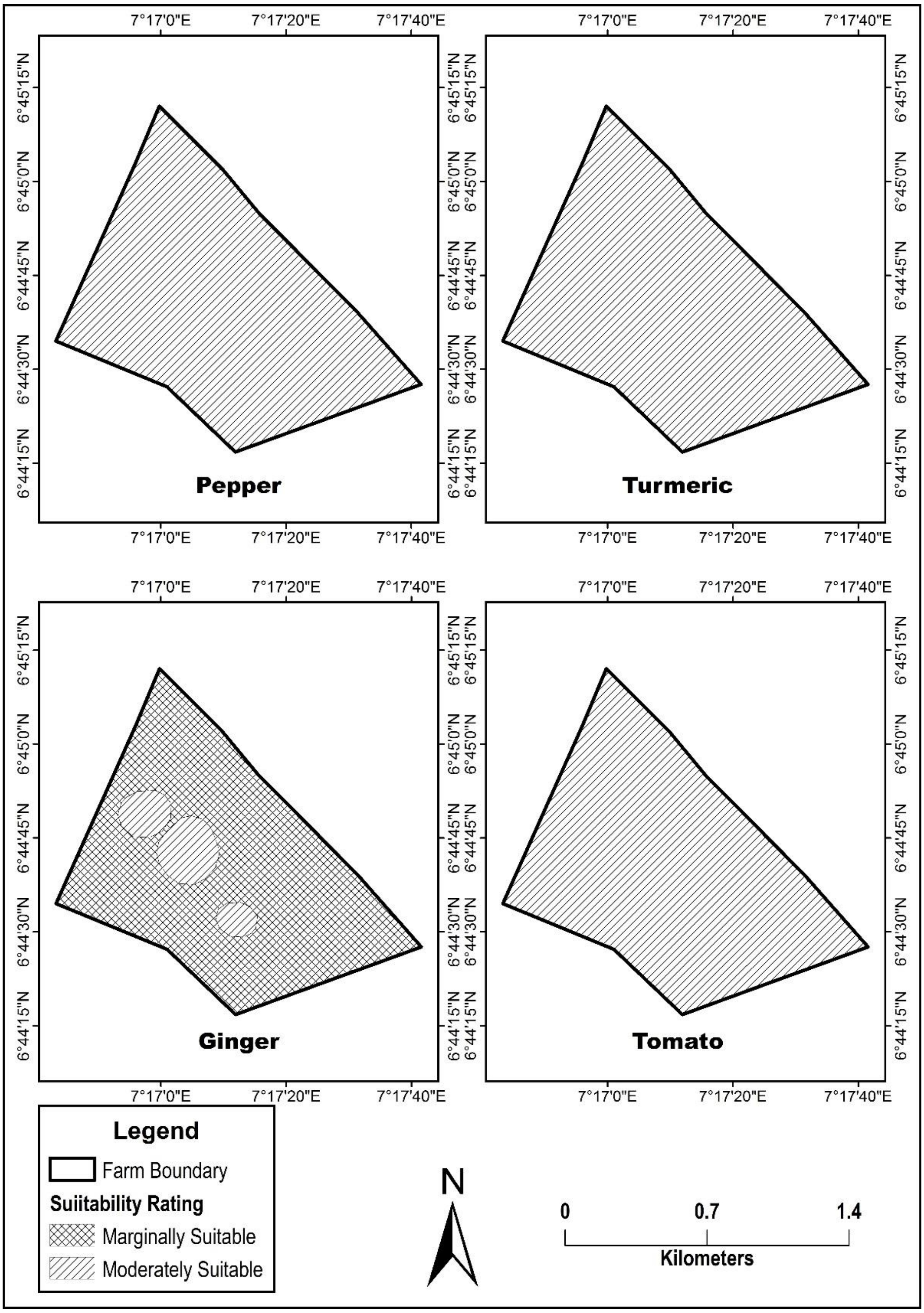


Figure 10: Land/Crop suitability map of Nkpologwu study area.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

Soils of three geological materials were characterized, classified and assessed for their suitability for the production of pepper, turmeric, ginger and tomato in Nsukka Area of Enugu State. The effects of the geological materials and soil depth on the soil properties were also determined. Three profile pits were dug and described in each of the geological materials after preliminary information was obtained from several auger points in the study areas which was located in Upper Coal Measure formation (Agu-Ibagwa), Nkporo Shale formation (Opi-Agu) and False Bedded Sandstones formation (Nkpologwu). A total of 36 samples (i.e. 12 samples in each of the geological materials) were collected at two depths (0-20 and 20-40).

The soils were very deep (> 150 cm) in all the locations. The soil colours for Ap horizons were dark reddish brown, brown and very dark reddish brown for Agu-Ibagwa, Opi-Agu and Nkpologwu soils respectively but, mottles were absent. The soils varied in structure from very fine weakly developed structure to fine medium massive granular in Nkpologwu soils; granular to sub-angular blocky structure in Opi-Agu soils and sub-angular blocky structure in Agu-Ibagwa soils. The texture of Agu-Ibagwa soils were Loamy Sand in Ap horizon and Sandy Clay Loam at the subsurface horizons, Opi-Agu soils were Sand at Ap horizon, Sandy Loam at A_1 and C horizon and Sandy Clay Loam at Bt horizon while Nkpologwu soils were predominantly Sand. The topsoils of Agu-Ibagwa and Opi-Agu soils had bulk density values below the critical limit of 1.6 g cm^{-3} whereas Nkpologwu soils had bulk density value greater than 1.6 g cm^{-3}. Also, the total porosity values were within the range of 45 – 50% and over 50% of volume which are good for agricultural soils. Soil reaction ranged from very strongly acidic (4.8) to neutral (7.3) in all the horizons. The soil organic matter ranged from low (0.6%) to high (2.1%) in all horizons with the higher values at the topsoils. The contents of total N, available P, CEC, exchangeable Na^+, and K^+ and exchangeable acidity were generally low, exchangeable Mg and Ca and PBS varied from moderate to high.

Using the United States Department of Agriculture (USDA) Soil Taxonomy, Agu-Ibagwa, Opi-Agu and Nkpologwu soils were classified as Alfisols, Oxisols, and Ultisols respectively and correlated to Loamic Lixisols for Agu-Ibagwa and Opi-Agu soils and Arenic Acrisols for Nkpologwu soils according to FAO / WRB system.

Statistically, analysis showed significant (*p* $\leq$ 0.05) influence of geological materials on particle size distribution and some soil chemical properties (such as soil reaction, OM, TN, exchangeable Ca, TEB, TEA, CEC, and BS). Soil depth significantly (*p* $\geq$ 0.05) influenced OM, exchangeable Na and Mg, and TEA. Silt and sand contents, soil reaction, OM, TN, exchangeable cations, TEB and BS were not significantly (p $\leq$ 0.05) influenced by the interaction of geological materials (location) and soil depth.

Generally, using the parametric method of land evaluation, soils of the three locations were highly suitable for the production of the four test crops except Nkpologwu that was moderately suitable for ginger and tomato production. Also, with regard to the Multiple-Criteria Decision Analysis (MCDA), the three locations Agu-Ibagwa and Opi-Agu soils were highly and moderately suitable whereas Nkpologwu soils were moderately and marginally suitable for the four test crops.

5.2 Conclusions

From this study, soils developed from false-bedded sandstones, upper coal measure, and Nkporo shale parent materials were characteristically deep, with darker topsoils than subsoils with sandy textures dominating on the surface horizon. The soils were acidic in nature, with low values of organic matter, total nitrogen, available P, exchangeable Na and K and exchangeable acidity whereas exchangeable Ca and Mg, and BS were generally rated moderate to high. According to USDA of Soil Taxonomy at the suborder level, the pedons of Agu-Ibagwa, Opi-Agu and Nkpologwu were classified as Ustalfs, Ustox and Ustults respectively and correlated to Loamic Lixisols for Agu-Ibagwa and Opi-Agu soils and Arenic Acrisols for Nkpologwu at the FAO/WRB system.

Quantitatively, the soils were highly suitable for the production of pepper, turmeric, ginger and tomato with the exception of Nkpologwu soils which were moderately suitable for ginger and tomato production.

5.3 Recommendations

The common constraints to agricultural productivity in the study areas were low values of organic matter, total N and available phosphorus. Also, Nkpologwu soils were dominated by coarse sand particles and manual ploughing is not recommended. However, for optimum agricultural productivity, the use of organic materials and recommended rates of N and P will ensure sustainable soil productivity. The application of organic residues would generally raise the nutrient status of the soils and lower the bulk density. Generally, this study recommends improvement of the physicochemical fertility of the soils of the study area in order to increase the productivity of the soils for horticultural crops production.

REFERENCES

Abam, P.O. and Orji, O.A. (2019). Morphological and Physico-Chemical Properties of Soils Formed from Diverse Parent Materials in Cross River State, Nigeria. *IOSR Journal of Applied Geology and Geophysics* (IOSR-JAGG) 7 (1): 1 – 7

Abay, A., Sheleme, B. and Fran, W. (2015). Characterization and classification of soils of selected areas in Southern Ethiopia. *Journal of Environment and Earth Science* 5 (11): 116-137

Aberra, Y. and Belachew, T. (2011). Effects of land use on soil organic carbon and nitrogen in soils of Bale, southeastern, Ethiopia. *Tropical and Subtropical Agroecosystems*, 14: 22 –235

Abua, M.A., Offiong, R.A., Iwara, A.I., and Ibor, U.W. (2010). Impact of newly constructed roads on adjoining soil properties in Tinapa resort, southeastern Nigeria. *Annals of Humanities and Development Studies*, 1 (1): 176-184

Adornado, H.A. and Yoshida, M. (2008). Crop suitability and soil fertility mapping using Geographic Information System (GIS). *Agricultural Information Research* 17 (2): 60 – 68

Adugna, A. and Abegaz, A. (2015). Effects of soil depth on the dynamics of selected soil properties among the highlands resources of Northeast Wollega, Ethiopia: are these sign of degradation?. *Solid Earth Discuss*., 7, 2011–2035

Agbede, O.O. (2009). Phosphorus Nutrition in Plant. In: *Understanding soil and plant nutrition* (pp. 147-167). Keffi: Salman Press and Co. Nig. Ltd

Agriculture and Soils Division (ASD) (1995). Cropping System analysis using temporal IRS-LISS II data - A case study of Madnur Watershed, Nizamabad district, AP. PG Diploma Training project report of Agriculture and Soils Division, IIRS, Dehradun

Agronomy Fact Sheet Series (AFSS) (2015). Cation Exchange Capacity (CEC). Cornell University Cooperative Extension. *Fact Sheet*, 22

Ahukaemere, C.M. Ndukwu, B.N. and Agim, L.C. (2012). Soil Quality and Soil Degradation as Influenced by Agricultural Land Use Types in the Humid Environment. *International Journal of Soil, Forest and Erosion*, 2 (4): 175-179

Ahukaemere, C.M., Ekpe, I.I. and Unachukwu, I.C. (2015). Suitability Evaluation of Soils Derived from Dissimilar Lithological Materials for Maize and Groundnut Production in Owerri Agricultural Zone, Southeastern Nigeria. *Malaysian Journal of Soil Science*, 19: 73-82

Ahukaemere, C.M., Onweremadu, E.U. Ndukwu, B.N and Nkwopara, U.N. (2016a). Properties of Soils of Contrasting Lithosequences in South-Eastern Nigeria. *FUTO Journal Series (FUTOJNLS)*, 2 (1): 48-56

Ahukaemere, C.M., Onweremadu, E.U., Akamigbo, F.O.R. and Ndukwu, B.N. (2016b). Suitability Evaluation of Soils of the coastal plain sands for rain-fed maize production in acid sands of Southeastern, Nigeria. *Nigerian Journal of Soil Science*, 26:138-144

Akamigbo, F.O.R (1984). The accuracy of field texture in humid tropical environment. *Soil Survey and Land Evaluation* 4 (3): 63-70

Akamigbo, F.O.R. (1999). Influence of land use on soil properties of the humid tropical agro-ecology of Southeastern Nigeria. *Niger Agricultural Journal*. 30:59-70

Akamigbo, F.O.R. (2001). Soil survey, classification and land use of wetland soils in Nigeria. Limited Paper Presented at the 27th Annual Conference of Soil Science Society of Nigeria at the University of Calabar, 5-9 November

Akamigbo, F.O.R. (2010). *Fundamental Methods of Soil Resource Survey, Classification, Interpretation and Application*. University of Nigeri, Press Ltd, UNN, pp 81

Akamigbo, F.O.R. and Asadu, C.L.A. (1983). Influence of parent material on the soils of Southeastern Nigeria. *East Africa Agriculture and Forest Journal* 48: 81-91

Akpan-Idiok, A.U. (2002). *Characterization and Classification of the Mangrove Swamp Soils in the Cross-River State Estuary, South-East Nigeria.* Ph.D Thesis, University of Calabar, Calabar, Cross River State (Unpublished) pp 107

Akpan-Idiok, A.U., Esu, J.E. and Ibanga, I.J. (2006). Characteristics and classification of wet soils of Abini in Southeast, Nigeria. *Proceedings of the 30th Annual Conference of the Soil Science Society of Nigeria, 5th – 9th December, 2006 at University of Agriculture, Makurdi,* pp 65 – 69

Akpan-Idiok, A.U., Ukabiala, M.E. and Amhakhian, S.O. (2013). Characterization and classification of River Benue floodplain in Bassa Local Government Area of Kogi State, Nigeria. *International Journal of Soil Science,* 8(2): 32 – 46

Alem, H., Kibebew, K. and Heluf, G. (2015). Characterization and classification of soils of Kabe Subwatershed in South Wollo Zone, Northeastern Ethiopia. *African Journal of Soil Science* 3 (7): 134-146

Allison, F.E. (1982). Organic matter. In: Black C.A. (ed). *Methods of Soil Analysis part 2. American Society of Agronomy*, 9:1367-1378

Amalu U.C. (1998) Evaluation of Properties of Selected Soils of Cross River Area and Their Management for Increased Cassava Yields. *Global Journal of Pure and Applied Sciences*, 4 (3): 243-249

Amalu, U.C. (2016) Properties and Fertility status of Soils supporting Pineapple (*Ananascomosus* L. [Merr.] in select – Communities of Cross River State, South – East Nigeria. *Nigeria Journal of Crop Science*. 3 (1): 78 – 91

Amberger, A. (2006). *Soil fertility and plant nutrition in the tropics* IFA/IPL. Pp 96

Amhakhian, S.O. and Achimugu, S. (2011). Characterization of Soil on Toposequence in Egume, Dekina Local Government Area of Kogi State. *PAT December*, 7 (2): 29-36

Amhakhian, S.O. and Osemwota, I.O. (2012). Characterization of Phosphorus Status in Soils of the Guinea Savanna Zone of Nigeria. *Nigerian Journal of Soil Science,* 22 (1): 37 – 44

Amhakhian, S.O. and Osemwota, I.O. (2012a). Physical and chemical properties of soils in Kogi State Guinea Savannah Zone of Nigeria. *Nigerian Journal of Soil Science,* 22 (1): 44-52

Amhkhian, S.O. and Achimugu, S. (2011). Characterization of Soil on toposequence in Egume, Dekina Local Government Area of Kogi State. *Journal of Production Agriculture and Technology,* 7 (2): 29-36

Amusan, A.A., Shitu, A.K. Makinde, W.D. and Orewole, O. (2002). Assessment of changes in selected soil properties under different land use in Obafemi Awolowo University Community, Ile-Ife. Nigeria. *Agriculture Food Chemistry* 6

Ande, O.T. (2011). Soil Suitability Evaluation and Management for Cassava Production in the Derived Savanna Area of Southwestern Nigeria. *International Journal of Soil Science*, 6: 142-149

Ande, O.T., Adediran, J.A., Ayoola, O.T. and Akinlosotu, T.A. (2008). Effects of Land Quality, Management and Cropping Systems on Cassava Production in Southern Western Nigeria. *African Journal of Biotechnology,* 7(14): 2368 – 2374

Anenyeonwu A.U. (2016). *Geotechnical Properties and Classification of Some Soils Formed on Two Lithologic Materials in Imo State, Nigeria*. An MSc Thesis, Postgraduate School, Federal University of Technology, Owerri Nigeria. 102 pp

Asadu, C. L. A. (2000). Fluctuations in the Characteristics of an Important Short Tropical Season August Break in Eastern Nigeria. *Discovery and Innovations,* 14: 92-100

Asadu, C.L.A. (1990). Comparative characterization of two-foot slope soils in Nsukka area of Eastern Nigeria. *Soil Science* 150:527-533

Asadu, C.L.A., Nnaji, G.U. and Ezeaku, P.I. (2012). Conceptual Issues in Pedology. University of Nigeria, Press Limited Bookshop/Bank Building Complex, Nsukka Enugu State/

Asadu, C.L.A. and Bosah, C.S. (2002). A comparative study of soils of upper coal measure residua under cropped-grassed-forestland continuum in eastern Nigeria. *Eastern African Agriculture and Forest Journal,* Pp 63

Asadu, C.L.A. and Eze, A.O. (2003). Comparative study of soils under pockets of virgin forests and adjacent grasslands on slopes in Nsukka area of eastern Nigeria. *Proceedings of the 28th Annual Conference of the Soil Science of Nigeria,* pp 212-219

Asadu, C.L.A., Ekwo, A.U. and Udigwe, T.K. (2001). Soil Characteristics around lake Opi in Eastern Nigeria and Land Use Recommendations. *Journal of Tropical Agriculture, Food, Environment and Extension*, 2 (1): 76-89

Asadu, C.L.A., Obasi, S.C., and Dixon, A.G.O. (2010). Variations in Soil Physical Properties in a Cleared Forestland Continuously Cultivated for Seven Years in Eastern Nsukka, Nigeria. *Communications in Soil Science and Plant Analysis,* 41(2): 123-132

Ashenafi, A., Abayneh, E., Sheleme, B. (2010). Characterizing soils of Delbo Wegene watershed, Wolaita Zone, Southern Ethiopia for planning appropriate land management. *Journal of Soil Science and Environmental Management,* 1: 184-199

Atofarati, S.O., Ewulo, B.S. and Ojeniyi, S.O. (2012). Characterization and classification of soils on two toposequence at Ile-Oluji, Ondo State, Nigeria. *International Journal of Agricultural Science* 2 (7): 642-650

Azuka C.V. and Obi M.E. (2012). Structural stability and hydraulic conductivity of Nkpologu Sandy Loam soil under different land covers in Southeastern Nigeria. *Journal of Tropical Agriculture, Food, Environment and Extension,* 11 (1): 1-9

Babalola, T.S., Fasina, A.S. and Tunku, P. (2007). Relationship between soil properties and slope position in a humid forest of Southwestern Nigeria. *Agricultural Journal,* 2 (3): 370-374

Balasubramanian, A. (2017). *Chemical properties of soils*. Mysore: Centre for Advanced Studies in Earth Science, University of Mysore

Baniya, N. (2008). *Land suitability evaluation using GIS for vegetable crops in Kathmandu valley, Nepal*. Ph.D. thesis submitted to Humboldt University of Berlin

Belachew, T. and Abera, Y. (2010). Assessment of Soil Fertility Status with Depth in Wheat Growing Highlands of Southeast Ethiopia. *World Journal of Agricultural Sciences*, 6 (5): 525-531

Blanco-conqui, H. and Lal, R. (2009). Crop residue removal: Impact on soil productivity and environmental quality. *Critical Reviews in Plant Sciences* 28 (3): 139-163

Boonyanuphap, J., Wattanachaiyingcharoen, D. and Sakurai, K. (2004). GIS-based land suitability assessment for Musa (ABB group) plantation. *Journal of Applied Horticulture,* 6 (1): 3-10

Boul S.W, Southard R.J, Graham R.C and McDaniel P.A. (2003). *Soil Genesis and classification*. 5th edition Iowa state press, a blackwell publishing company. 3 - 34pp

Brady N.C and Weil R.R. (2006). *Elements of the nature and properties of soils*. Prentice Hall Inc. New York, USA pp95

Brady, N.C. and Weil, R.R. (1999). The Nature and Properties of Soils. 12th Edn., Prentice Hall, Upper Saddle River, New Jersey

Brady, N.C. and Weil, R.R. (2002). *The Nature and Properties of Soils.* Pearson Education, Inc. new Jessy, USA

Brady, N.C. and Weil, R.R. (2008) *The nature and properties of soil*, 14 ed. Prentice-Hall, Upper Saddle River, New Jersey

Bremner, J. M. and Mullvaney, C. S. (1982). Total Nitrogen. In: Page, A.L. (Ed.). *Methods of Soil Analysis, Part 2: Chemical Methods: Agronomy Monograph No.9*, American Society of Agronomy, Madison Wisconsin. Pp. 595-624

Brewer, R. (1954) Soil parent material: the role of parent material in controlling the distribution of the zones of great soil groups in South Eastern Australia. And a proposed scheme for its classification. The *Australian Journal of Science*, 134-138

Bruland, G.L and Richardon, C.J. (2005). Spatial variability of soil properties in created, restored and paired natural wetlands. *Soil Science Society of America Journal*, 69:273-284

Buol, S.W., Southard, R.J., Graham, R.C. and McDaniel, P.A. (2011). *Soil Genesis and Classification*. 6th edition. John Wiley and Sons, Inc

Buol, S.W., Hole, F.D. and McCracken, R.J. (1973). *Soil Genesis and Classification.* The Iowa State University Press, USA, pp 65

Buol, S.W., Hole, F.D. and McCracken, R.J. (1973). *Soil Genesis and Classification.* The Iowa State University Press, USA, pp 65

Burrough, P.A., and McDonnell, R.A., (1998). *Principle of geographic information systems*. Oxford University Press, Oxford, UK

Cambardella, C.A., and Karlen, D.L., (1999). Spatial analysis of soil fertility parameters. *Precision Agriculture*, 1 (1): 5-14

Carver, S.J., 1991. Integrating multi-criteria evaluation with geographical information systems. *International Journal of Geographical Information System*, 5: 321-339

Chandra, P. and Singh, V. (1985). Forms of potassium in alluvial soils of Western utta Pradesh. *Journal of Indian Society of soil Science*, 33:911-914

Chapman, H.D. (1982). Total Exchangeable Bases. In: C. A. Black (ed.), *Method of Soil Analysis, Part 2*. ASA, 9: 902-904, Madison, Wisconsin

Chude, V.O., Malgwi, W.B., Amapu, I.Y. and Ano, O.A. (2004) *Manual on Soil Fertility assessment*. Federal Fertilizer Department and National Special Programme for Food Security, Abuja, Nigeria. pp 48

Chude, V.O., Malgwi, W.B., Ampu, I.Y. and Ano, A.O. (2011). *Manual on Soil Fertility Assessment*. Abuja, Nigeria: Federal Fertilizer Department in collaboration with National Programme for Food Security. Pp 102

Coleman, N.T. and Thomas, G.W. (1967). The basic chemistry of soil acidity. *Agronomy Monograph*, 12:1-41

Cooperative Resources International (CRI) (2015). Base Saturation fact sheet. Publication of AgSource Laboratories

Cornell University Cooperative Extension (CUCE) (2007). Cation Exchange Capacity (CEC). Agronomy Fact Sheet Series # 22. Department of Crop and Soil Sciences, College of Agriculture and Life Sciences, Cornell University

Culman, S., Mann, M. and Brown, C. (2019). Calculating Cation Exchange Capacity, Base Saturation, and Calcium Saturation fact sheet. Publication of Agriculture and Natural Resources

D'Hoore. J.L. (1964). Soil Map of Africa, Scale I : 5.000.000. Joint Project No. I I. Commission for Technical Cooperation in Africa. Ceuterick, Louvain. Pp 205

Dent, D. and Young, A. (1981). *Soil Survey and Land Evaluation*. George Allens and Unwin. London

Dibabe, A. (2000). Effect of fertilizer on the yield and nodulation pattern of Faba bean on a Nitosol of Adet North Western Ethiopia. *Ethiopian Journal of Natural Resources*, 2: 237-244

Dick W.A. and Greorich E.G. (2004). Development and maintaining soil organic matter levels. In: *Managing soil quality challenges in modern Agriculture* (eds. Pschjonning, S. Elmholt & B.T Christen Gen), PP. 103-120 (ABI publishing, Wallingford)

Dobos, E., Micheli, E., Baumgardner, M. F., Biehl, L. and Helt, T. (2000). Use of combined digital elevation model and satellite radiometric data for regional soil mapping. *Geoderma* 97:367–391

Donahue, R.L. and Herren, R.V. (1991). *The Agriculture Dictionary,* Deliner Publishers Inc. New York, pp 326

Duff, D. (1993). *Holmes' Principles of Physical Geology*, Chapman and Hall, London, New York and Melbourne

Dwivedi, R.S. (2001). Soil resource mapping: a remote sensing perspective. *Remote Sensing Reviews*, 20: 89–122

Eden, M.J., Furley, McGregor, P.A., Milliken, D.F.M. and Ratter, J.A. (1991). Effect of forest clearance and burning on soil properties in Northern Roraima. Brazil, *Ecology Management.*, 38:283-290

Edeth, A.E., Oden, M.I. and Efretuei, O.E. (1994). Correlation between cone penetration resistance and standard penetration in parts of the Coastal plain sand, Southeastern Nigeria. *Bulletin of the International Association of Engineering Geology*, 49:41 – 49

Effiong, G.S. and Akpan, G.U. (2013). Characterization and management of some inland depression soils for sustainable crop production in Southeastern Nigeria. *research Journal of Science and IT Management*, 2(11): 1 – 15

Elango, L. (2011). *Hydraulic Conductivity: Issues, Determination and Applications*

Ellers, E.G. and Blatt, H. (1982). *Petrology - Igneous, Sedimentary and Metamorphic*, W.H. Freeman, San Francisco

Environmental Systems Research Institute (ESRI) (2020). ArcGIS 10.8.

Enwezor, W.O., Ohiri, A.C., Opuwaribo, E.E., and Udo, E.J. (1990). Literature review on soil fertility investigations in Nigeria. *Federal Ministry of Agriculture and Natural Resources, Lagos*

Enwezor, W.O., Udo, E.J., Usoro, N.J., Ayotade, K.A., Adepetu, J.A., Chude, V.O. and Udegbe, C.I. (1989). Fertilizer use and management practices for crops in Nigeria. *Series 2. Federal Procurement and Distribution Division. Federal Ministry of Agriculture. Water Resources and Rural Development*, Lagos. Pp 163

Esu, I.E. (1987). Fertility status and management of some upland basement complex soils in Nigeria. Tropical Savanna region. *Nigerian Journal of Soil Science*, 7:155-183

Esu, I.E. (2005). Characterization, classification and management problems of major soil orders in Nigeria. The 26th Inaugural Lecture of the University of Calabar, Nigeria, pp:66

Esu, I.E. (2010). Soil characterization, classification and survey. HEBN Publishers Plc. Nigeria. 232pp

Esu. I.E. (1988). *Detail soil survey of the Isiga Scheme, Jare River Basin Irrigation Project* (Final Report). A Study commission by Enplen Group consulting Engineers and Planners for the Katsina State Group. 82 pp

Ezeaku, P.I. (2011a). Soil quality as influenced by land use and management in the southern guinea savannah of Nigeria. *Nigerian Journal of Soil and Environmental Resources*, 9:1-11

Ezeaku, P.I. (2011b). *Methodologies for Agricultural Land-Use Planning – Sustainable Soil Management and Productivity*. Great AP Express Publishers Ltd, Nsukka, Nigeria pp 69

Ezeaku, P.I. (2013). Determining minimum dataset from soil properties associated with three forms of Land Use and Management in south-eastern Nigeria. *International Science and Investigation Journal*, 2 (5): 71 – 90

Ezeaku, P.I. and Anikwe, M.A.N. (2003). A Model for Description of Water and Solute Movement in Soil-Water Restrictive Horizon Across Two Landscapes In Southeast Nigeria. *Journal of Soil Science*, 17 (6): 492-500

Ezeaku, P.I. and Iwuanyanwu, F.C. (2013). Degradation rates of soil chemical fertility as influenced by topography in southeastern, Nigeria. *Journal of Environmental Science, Toxicology and Food Technology* 6 (6): 39-49

Ezeaku, P.I. and Tyav, C. (2013). Fuzzy and parametric methods for land evaluation along Katsina-ala flood pains in central region of Nigeria: Application to rice production. *Elixir International Journal*, 61:17033-17039

Ezeaku, P.I., Eze, F.U. and Oku, E. (2015). Profile distribution and degradation of soil properties of an *Ultisols* in Nsukka semi-humid area of Nigeria. *African Journal of Agricultural Research*, 10 (11): 1306-11

Fageria, N.K., Baligar, C.V. and Wright, R.J. (1988), Aluminium toxicity in crop plants. *Journal of Nutrition*, 11 (3); 303-319

Fallik, E. (2004). Prestorage hot water treatments immersion, rinsing and brushing. *Postharvest Biology and Technology*, 32:125–134

Federal Department of Agricultural Land Resources (FDALR). 1990. The reconnaissance soil survey of Nigeria. *Soils Report*, 4:337

Fekadu, E., Kibret, K., Bedadi, B. and Melese, A. (2018). Characterization and classification of soils of Yikalo Subwatershed in Lay Gayint District, Northwestern Highlands of Ethiopia. *Eurasian Journal of Soil Science*, 7 (2): 151-166

Fetter, C.W. (1998). *Contaminant Hydrogeology*. 2nd Edn., Prentice Hall, New Delhi, India, ISBN-13: 9780130802293, Pages: 500

Fisher, G., Vethuizen, H.U., Shah, M. and Nachtergaele, F. (2002). *Global Agro-Ecological Assessment for Agriculture in the 21st Century*. Methodology and Results. International Institute for Applied Laxenburg, Australia. FAO of the United Nations Viale delle Termedi Caracalla Rome, Italy

Flores-Magdaleno, H., Mancilla-Villa, O.R., Mejia-Saenz, E., Olmedo-Bolantilde, M.D.C. and Bautista-Olivas, A.L., (2011). Heavy metals in agricultural soils and Irrigation wastewater of Mixquiahuala, Hidalgo, Mexico. *African Journal of Agriculture Research*, 6(24): 5505-5511

Food and Agriculture Organization (1985). Guidelines: Land Evaluation for Irrigated Agriculture. FAO Soils Bulletin No.55, Rome, Italy

Food and Agriculture Organization (1993). Guidelines for land-use planning. FAO Development Series 1, Food and Agricultural Organization of the United Nations, Rome, Italy

Food and Agriculture Organization (FAO) (1976). A frame work for land evaluation. *FAO Soils Bulletin* 32, Rome

Food and Agriculture Organization (FAO) (1999). *World Reference Base for Soil Resources*. World Soil Resources Rep. vol. 84. Food and Agricultural Organisation of the UN, Rome, Italy, 161p

Food and Agriculture Organization (FAO) (2014). *World Reference Base for Soil Resources.* 84 World Soil Resources Report, *International Society of Soil Science, Rome*

Food and Agriculture Organization of the United Nations (FAO) (2006). *Guidelines for soil description.* Pp 5

Foth, H.D. and Ellis, B.G. (1997). Soil fertility, 2nd Ed. Lewis CRC Press LLC., USA. 290p.

Gebherdt, H. and Coleman, N.J. (1974). Anion adsorption by allophanic tropical soils. *Soil Science Society of America, Proceeding,* 38: 259-262

Gee, G.W. and Or, D. (2002). Particle Size Analysis. In: Dane, J.H. and Topp, G.C. (eds.) *Methods of Soil Analysis*. Part 4, Physical Methods. Soil Sci. Soc. Am. 5:255-293

GENSTAT (2012). GENSTAT Discovery Edition 4. Release 12.2DE. Lawes Agricultural Trust Rothamsted Experimental Station, UK

Giesler, R; Anderson T; Lovgren, L and Persson, P. (2005). Phosphate sorption in aluminum and iron-rich humus. *Soil Sci. Soc. Am. J,* 69:77-86

Gray, J and Murphy, B. (2002). *Parent material and world soil distribution*. Department of Land and Water Conservation, NSW.17th WCSS, 14-21, August 2002, Australia. Symposium no. 21. 2215-1-2215-13

Gray, J.M. and Murphy, B.W. (1999). *A Guide to the Influence of Parent Material on Soil Distribution in Eastern Australia*. Technical report No 45 of NSW Department of Land and Water Conservation

Gray, J.M., Bishop, T.F.A. and Wilford J.R. (2016). Lithology and soil relationships for soil modelling and mapping. *Catena,* 147: 429–440

Grossman, R.B. and Reinsch, T.G. (2002). Bulk Density and Linear Extensibility. *In: Methods of Soil Analysis, Part 4:* Physical Methods, Dane, J.H. and G.C. Topp (Eds.). Chapter 2.1, Soil Science Society of America, Madison, WI., USA., ISBN-13:978-0891188414, pp:201-228

Guggenberger, G., Christensen, B.T., and Zech, W. (1994). Land use effects on the composition of organic matter in particle-size separates of soil: I. Lignin and carbohydrate signature. *European Journal of Soil Science*, 45: 449–458

Guggenberger, G., Zech, W. and Thomas, R.J. (1995). Lignin and carbohydrate alteration in particle-size separates of an Oxisol under tropical pastures following native savanna. *Soil Biology and Biochemistry,* 27: 1629–1638

Harold, M.F. (1975). Field experience on light soils. In: *Physical conditions and crop production*. MAFF: Technical Bulletin London. 29: 25–51

Hope, D. (2005). Spatial variation in soil inorganic nitrogen across an arid urban ecosystem. *Urban Ecosystems,* 8: 251–273
http://www.esri.com/software/arcgis

Huand, X., Skidmore, E.I. and Tibke, G. (2001). Spatial variability of soil properties along a transect of conservation reserve land and continues cropped land. *In*: Stott, D.E., Mohtar, R.H. and Stainhandt, G.C. (eds), *Sustaining the global farm*: 641-647.

Idoga, S., Abagyeh, S.O. and Agber, P.I. (2005). Characteristics, classification and crop production potentials of soils of Nigeria. *Nigerian Journal of Soil Science,* 15 (2): 101-110

Igwe, C.A. (2003). Erodibility of soils of the upper rainforest zone, Southeastern, Nigeria. *Land Degradation and Development,* 14 (13): 323-334

Igwe, C.A. and Nkemakosi, J.T. (2007). Nutrient element contents and cation exchange capacity in fine fractions of Southeastern Nigeria soils in relation to their stability. *Communications in Soil Science and Plant Analysis,* 38 (9-10): 1221-1242

Igwe, C.A. and Okebalama, C.B. (2006). Soil strength of some central eastern Nigeria soils and effect of potassium and sodium on their dispersion. *International Agrophysics,* 20: 107-112

Igwe, C.A., Zarei, M. and Karl, S. (2004). Chemical properties of Niger floodplain soils, eastern Nigeria, in relation to mineralogy. *Paddy Water Environment,* 2: 51-58

Igwe, C.A., Zarei, M. and Stahr, K. (2010). Fe and Al oxides distribution in some Ultisols and Inceptisols of Southeastern Nigeria in relation to soil total phosphorus. *Environmental Earth Sciences,* 60 (5): 1103-1111

Inyang, P.E.B. (1975). Climate Regions. In G.E.K. Ofomata (Ed). *Nigeria in maps Eastern state*. Ethiope publishing House, Benin, Nigeria, pp 27-28

Iqbal, J., Thomasson, J.A., Jenkins, J.N., Owens, P.R. and Whisler, F.D. (2005). Spatial Variability Analysis of Soil Physical Properties of Alluvial Soils. *Journal of Soil Science Society of America*; 69: 1339-1351

Irmak, S., Surucu, A.K. and Aydogdu, I.H. (2007). Effects of Different Parent Material on the Mineral Characteristics of soils in the Arid Region of Turkey. *Pakistan Journal of Biological Sciences,* 10 (4): 528-536

IUSS Working Group WRB (2006). World Reference Base for Soil Resources (2006). Food and Agriculture Organization, Rowe: (World Soil Resource Reports).

Iwara, A.I., Ogundele, F.O., Ibor, U.W., Arrey, V.M., and Okongor, O.E. (2011). Effect of Vegetation Adjoining Tourism Facilities on Soil Properties in the Tourism Enclave of Cross River State. *Research Journal of Applied Sciences*, 6 (4): 276-281

Jenny, H. (1980). Soil Resource: Origin and Behaviour. Springer-verlag, New York

Jungerius, P.D (1964). The Soil of Eastern Nigeria Pub. Service Geologiue in Luxemburg vol. xiv. Pp. 185-196

Kader, A.A. (1992). Postharvest biology and technology: an overview. In: Kader AA (ed) *Postharvest technology of horticultural crops*. UC Publication No. 3311. University of California, Division of Agriculture and Natural Resources, Oakland, pp 15–20

Kanlaya, T., Songkot, D., Chalie, N. (2009). Integration of land evaluation and the analytical hierarchical process method for energy crops in Kanchanaburi, Thailand. *Science Asia*, 53: 170-177

Karale, R.L., Saini, K.M. and Narula, K.K. (1988). Mapping and monitoring ravines using Remotely Sensed data. *Journal of Soil and Water Conservation* 32 (1): 75

Khadka, D., Lamichhane, S., Shrestha, S.R. and Pant, B.B. (2017). Evaluation of soil fertility status of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal. *Eurasian Journal of Soil Science,* 6 (4): 295-306

Khan, M.S.N. and Khan, M.M. (2014). Land Suitability Analysis for sustainable agricultural land use planning in Bulandshahr district of Uttar Pradesh. *International Journal of Scientific and Research Publications,* 4(3): 1 – 11

Khoi, D.D. and Murayama, Y. (2010). Delineation of suitable cropland areas using a GIS based multi-criteria evaluation approach in the Tam Dao National Park Region, Vietnam. *Sustainability*, 2: 2024-2043

Koorevaar, P., Menelikm G. and Dirksen, C. (1999). *Elements of Soil Physics. Developments in Soil Science* 13. Elsevier Science, Netherlands

Kosmas, C., Danalatos, N., Moustakas, N., Tsatiris, B., Kallianou, Ch., and Yassoglou, N. (1993). The impacts of parent material and landscape position on drought and biomass production of wheat under semi-arid conditions. *Journal of Soil Technology*, 6: 337–349

Krumbein, W.C. and Sloss, L.L. (1963). *Stratigraphy and Sedimentation*, 2nd edn, W.H. Freeman and Co., San Francisco and London

Lal, R. (2000). Physical management of soils of the tropics: priorities of the 21st century. *Journal of Soil Science,* 165: 191-207

Lal, R., Mokma, D. and Lowery, B. (1998). Relation between soil quality and erosion In: R Lal (ed.) "*Soil Quality and Soil Erosion*" CRC Press, Boca Raton, FL: 237-257

Landon, J.R. [ed] (1991). *Booker Tropical Soil Manual*. A handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics. John Wiley and Sons Inc., 695, Third Avenue, New York, USA

Langley-Turnbaugh, S.J. and Keirstead, D.R. (2005). Soil properties and land use history: a case study in New Hampshire: *Northeastern Naturalist,* 2 (4): 391-402

Li, P. (2014). Book Review: "*Hydraulic Conductivity—Issues, Determination and Applications*", L. Elango (ed.), InTech, Croatia. Environmental Processes, 1 (4): 613–616

Lupia, F. (2012). Crop/Land Suitability Analysis by ArcGIS Tools. INEA Istituto Nazionale di Economia Agraria

Lupia, F. (2012). Crop/Land Suitability Analysis by ArcGIS Tools. Technical Report · March 2012

Malczewski, J. (1996). A GIS-based approach to multiple criteria group decision-making. *International Journal of Geographical Information Science*, 10: 955-971

Malczewski, J. (1999). *GIS and multicriteria decision analysis*. Wiley & Sons Inc., New York, USA

Malczewski, J. (2006). GIS-based multicriteria analysis: a survey of the literature. *International Journal of Geographical Information Science*, 20: 703–726

Maniyunda, L.M. (1999). *Pedogenesis on Loess and Basement Complex rocks in a subhumid environment of Nigeria and the suitability of the lands for rainfed cultivation*. Unpublished M.Sc. Thesis. Dept. of Soil Science, ABU, Zaria. Pp 49-75

Maribeng, L. (2007). *The influence of parent material (Granite and Schist) on physical and chemical properties of soils on Syferkuil Experimental Farm*. Unpublished mini-dissertation submitted to School of Agriculture and Environmental Sciences. University of Limpopo

McCarty, L.B., Rodriguez, I.R., Bunnell, B.T. and Waltz, F.O. (2003). *Fundamentals of Turf Grass and Agricultural Chemistry*. John Wiley and Sons Inc., Hoboken, New Jersey, 1198

McDonagh, J.F., Thomsen, T.B. and Magid, J. (2001). Soil organic matter decline and compositional change associated with cereal cropping in southern Tanzania. *Land Degradation and Development*, 12: 13-26

Mclean, E.O. (1982). Soil pH and Lime Requirements. In: Page, A.L. (Ed.). *Methods of Soil Analysis, Part 2. Chemical and Microbial Properties*, Second Edition Agronomy Series No. 9 Madison, Wi, Usa, Asa, Sssa

Mehlich, A. (2014). The Significance of percentage base saturation and pH in relation to soil differences. *Agronomy Journal Series*, No 156, pp 173

Mengel, K. and Kirkby, E.A. (1987). *Principles of plant nutrition*. Panima Publ. Corporation, New Delhi, Bangalore, India. 687p

Mesfin A. (1998). *Nature and management of Ethiopian soils*. Alemaya University of Agriculture, Ethiopia. 272p

Microsoft Corporation. (2016). Microsoft Excel. Retrieved from https://office.microsoft.com/excel

Middlemost, E.A.K. (1985). *Magmas and Magmatic Rocks: An Introduction to Igneous Petrology*, Longman, London

Miller, R.W. and Donahue, R.L. (1995). *Soils in our Environment.* Prentice-Hall International (UK) Limited, London

Munsell Soil Color Chart (2009). Standard soil color charts

Mustafa, A.A., Singh, M., Sahoo, R.N., Ahmed, N., Khanna, M., Sarangi, A. and Mishra, A.K. (2011). Land Suitability Analysis for Different Crops: A Multi Criteria Decision Making Approach using Remote Sensing and GIS. *Researcher,* 3 (12): 1–24

Nafiu, A.K., Abiodun, M.O., Okpara, I.M. and Chude, V.O. (2012) Soil fertility evaluation: a potential tool for predicting fertilizer requirement for crops in Nigeria. *African Journal of Agricultural Research,* 7 (47): 6204-6214

Nahusenay, A., Kibebew, K., Heluf, G. and Dababneh, E. (2014). Characterization and classification of soils along the toposequence at the Wadla Delanta Massif, north central highlands of Ethiopia. *Journal of Ecology and the Natural Environment* 6 (9): 304-320

Naidu, L.G.K., Ramamurthy, V., Challa, O., Hegde, R. and Krishnan, P. (2006). *Manual soil-site suitability criteria for major crops*. National Bureau of Soil Survey and Land Use Planning (NBSS and LUP)

Ndukwu, B.N., Chukwuma, M.C., Idigbor, C.M. and Obasi, S.N. (2012). Forms and Distribution of Potassium in soils underlain by Three Lithologies in Southeastern Nigeria. *International Journal of Agriculture and Rural Development*, 15 (2):1104–1108

Ndukwu, B.N., Onweremadu, E.U., Nkwopara, U.N. and Ahukaemere, C.M. (2015). Variability of Selected Soil Properties of a River Slope in Amaigbo, Southeastern Nigeria. *FUTO Journal Series (FUTOJNLS)*, 1 (2): 8-16

Nega, E. (2006). *Land use changes and their effects on physical and chemical properties in Senbat sub-watershed, western Ethiopia*. MSc Thesis Submitted to School of Graduate Studies, Alemaya University, Ethiopia. 72p

Nelson, D.W. and Summers, L.E. (1996). Total Carbon, Organic Carbon, and Organic Matter. In: Page, A. L. (Ed.), *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties*, Second Ed. Agronomy Series, No. 9, Madison, WI, USA, ASA, SSSA

Nigerian Geological Survey Agency (2006). Geological and Mineral Resources Map of Enugu State, Nigeria: 1:250000 scale

Nizeyimana, E., Petersen, G.W., Imhoff, M.L. and Lawrence, W.T. (1998). A GIS-based assessment of soil productivity loss due to urbanization in Pennsylvania. p.460-465. *Proceedings of the International Symposium on Resource and Environmental Monitoring. Local, regional and global scales*. International Society for Photogrammetry and Remote Sensing. ECO'98. Sept. 1-4, 1998. Budapest, Hungary

Njoloma, J.P., Sileshi, W.G., Sosola, B.G., Nalivata, P.C. and Nyoka, B.I. (2016). Soil fertility status under smallholder farmers' fields in Malawi. *African Journal of Agricultural Research*, 11(19): 1679-1687

Nkongolo, N.V. and Plassmeyer, C.J. (2010). Effect of vegetation type on soil physical properties at Lincoln University Living Laboratory. *Research Journal of Forestry* 4 (1): 1-13

Nuga B.O., Eluwa N.C., Abimbola G.E. and Wokocha C.C. (2006). Characterization and Classification of Soils along a Toposequence in Ikwano Local Government Area of Abia State, Nigeria. *Agricultural Journal* 1 (2): 192 -197

Núñez, P.A., Pimentel, A., Almonte, I., Sotomayor-Ramírez, D., Martínez, N., Pérez, A. and Céspedes, C.M. (2011). Soil fertility evaluation of coffee (*Coffea spp*.) Production Systems and Management Recommendations for the Barahona Province, Dominican Republic. *Journal of Soil Science and Plant Nutrition,* 11 (1): 127–140

Nwite, J.N., Okolo, C.C., Ezeaku, P.I. and Enyioko, C. (2014). Effect of integrated nutrient management on soil chemical properties and maize yield on a sandy clay loam in Abakaliki, Ebonyi State. *International Journal of Agriculture and BioSciences,* 3 (6): 278- 282

Nwokocha, C.C., Akamigbo, F.O.R. and Chukwu, G.O. (2003). Characterization and evaluation of soils of Umuahia North Local Government Area of Abia State, for agricultural production. *Proceedings of the 28th Annual Conference of the Soil Science Society of Nigeria*. pp 308-315

O'Connell, D.J. (1975). The Measurement of Apparent Specific Gravity of Soils and its Relationship to Mechanical Composition and Plant Root Growth. In: *Soil Physical*

Conditions and Crop Production, pp 298 – 313. Ministry of Agriculture, Fisheries and Food. Technical Bulletin 29. H.M.S.O., London

O'Hare G (1997). *Soil, vegetation and ecosystems: Conceptual Frameworks in Geography*. Addison Wesley Longman Publishers (Pte) Ltd., UK

Ofomata, G.E.K. (1975). Landforms. In: *Nigeria in maps. Eastern States*. Ethiope Pub. House, Benin City, Nigeria

Ogban, P.I. and Ekerette, I.O. (2001). Physical and chemical properties of the coastal plain sands soils of South-Eastern Nigeria. *Nigerian Journal of Soil and Environmental Research*, 2: 6–14

Ogeleka, D.F., Nmai, O.O., Okieimen, F.E. and Ekakitie, A. (2017). Consideration of the Levels Exchangeable Cations and Selected Anions in Soils of Ethiope River Plain. *International Journal of Scientific Research in Agricultural Sciences*, 4 (1): 1–8

Ogunkule, O. (2013). A comparative study of the physical and chemical properties of soils under different vegetation types. *Journal of Environment and Earth Science*, 3 (1): 24-28

Ojanuga, A.G. and Awujoola, A.I. (1981). Characteristics and classification of the soils of the Jos Plateau, Nigeria. *Nigerian Journal of Soil Science*, 2: 101-119

Ojanuga, A.G., Okusami, T.A. and Lekwa, G. (2003). Wetland Soils of Nigeria: Status of Knowledge and Potentials. *Journal of Wetlands in Nigeria*, 2: 1-22

Ojomah, F.O. and Joseph, P.O. (2017). Assessment of Soil Fertility Status in Some Areas of Kogi East Agroecological Zone of Kogi State. *Journal of Agriculture and Rural Research*, 1 (1): 44-50

Okenmuo, F.C. (2015). *Impact assessment of the 2012 flooding on soil properties and pedogenesis in the lower Niger floodplain at Ogbaru, Anambra State, Nigeria. M. Sc. Thesis, (Unpublished)* Department of Soil Science and Land Resources Management, University of Nigeria, Nsukka pp. 64

Okoli N.H., Uzoho B.U., Ihem E.E. and Okon M.A. (2019). Differential Speciation and availability of Copper in Soils derived from different parent materials in Imo State, Southeastern Nigeria. *Journal of Tropical Agriculture, Food, Environment and Extension*, 18 (1): 7-15

Okusami, T.A., Rust, R.H. and Juo, A.S.R. (1987). Properties and classification of five soils on alluvial landform in central Nigeria. *Canadian Journal of Soil Science,* 67:249-261

Olson, K.R., Mokma, D.L., Lal, R., Schumacher, T.E. and Lindstrom, M.J. (1998). Erosion Impacts on Crop Yield for Selected Soils of the North Central United States. In: R. Lal (ed) "*Soil Quality and Soil Erosion*," CRC Press, Boca Raton, FL: 259-283

Olson, S.R. and Sommers, L.E. (1982). Phosphorus. Pp 403 – 434. In Page *et al.* (1982) (eds). *Methods of Soil Analysis.* Part 2. *Agronomy Monograph* 9, ASA and Soil Science Society of America, Madison WI

Onweremadu E.U., Akamigbo F.O.R. and Igwe C.A. (2007b). Physical shrinkage relationship in soils of dissimilar lithologies in Central Southeastern Nigeria. *Journal of Applied Science*, 7: 2495–2499

Onweremadu E.U., Eshett E.T. and Osuji G. (2007a). Temporal variability of selected heavy metals in automobile soils. *International Journal of Environment, Science and Technology,* 4 (1): 35–41

Onweremadu, E.U. (2007). Availability of selected soil nutrients in relation to land use and landscape position. *International Journal of Soil Science,* 2: 128-134

Onweremadu, E.U., Akamigbo, F.O.R. and Igwe, C.A. (2007a). Lithosequential variability and relationship between erodibility and sodium concentration in soils of a rainforest. *Research Journal of Forestry,* 1 (2): 73-79

Onweremadu, E.U., Okuwa, J.A., Njoku, J.D. and Ufot, U.O. (2011). Soil nitrogen forms distribution in Isohyperthermic Kandiudiults of central southeastern, Nigeria. *Nigerian Journal of Agriculture, Food and Environment*, 7 (2): 52-56

Onwuka, M.I., Ozurumba, U.V. and Nkwocha, O.S. (2016) Changes in Soil pH and Exchangeable Acidity of Selected Parent Materials as Influenced by Amendments in South East of Nigeria. *Journal of Geoscience and Environment Protection*, 4: 80-88

Onyekanne, C.F., Akamigbo, F.O.R. and Nnaji, G.U. (2012). Characterization and Classification of Soils of Ideato North Local Government Area. *Nigerian Journal of Soil Science*, 22 (1): 11-17

Orimoloye, J.R., Gheghere, E.J., Aliku, O. and Nkwocha, H.U. (2018). The effect of parent material and physiography on selected soil chemical properties in Ibadan, southwestern Nigeria. *Proceedings of the 42nd Annual Conference of the Soil Science of Nigeria*. pp 138-150

Orobator, P.O. and Odjugo, P.A.O. (2015). Influence of Parent Materials and Land Use on Exchangeable Cations in a Tropical Environment. *Journal of Geography, Environment and Earth Science International*, 3(4): 1 – 12

Osujieke, D. (2017). Characterization and Classification of Soils of Two Toposequence formed over Different Parent Materials in Imo State, Nigeria. *International Journal of Agric and Rural Development*, 20 (1): 2872-2884

Panhalkar, S. (2011). Land capability classification for integrated watershed development by applying RS and GIS techniques. *Journal of Agricultural and Biological Sciences* 6 (4): 46-55

Patil, S.S., Patil, V.C. and Khalid, A.A. (2010). Wheat Acreage, Productivity and Production Estimation through Remote Sensing and GIS Techniques. *Australian Journal of Basic and Applied Sciences*, 4 (8): 3132-3138

Paulos, D, (1996). Availability of phosphorus in the coffee soils of southwest Ethiopia. pp. 119-129. In: Tekalign Mamo and Mitiku Haile (Eds.). *Soil: The Resource Base for Survival*. *Proceeding of the 2nd Conference of the Ethiopian Society of Soil Science*, (ESSS), 23-24 September 1993, Addis Ababa, Ethiopia.

Pereira, J.M.C. and Duckstein, L. (1993). A multiple criteria decision-making approach to GISbased land suitability evaluation. *International Journal of Geographical Information Science*, 7: 407–424

Perry, L. (2015). Soil pH for the Garden. www.pss.uvm.edu/ppp/pubs/oh34.htm

Pettijohn, F.J. (1975). *Sedimentary Rocks*, Harper and Row, New York

Raji, B.A. (2016). Land suitability evaluation of some Basement Complex soils in Kwara State for cassava production. *Nigeria Journal of Soil Science*, 26: 232–241

Rakesh, K., Rakesh, K.U.S., Brijesh, Y., (2012). Vertical distribution of physico-chemical properties under different topo-sequence in soils of Jharkhand. *Journal of Agricultural Physics* 12 (1): 63-69

Raymond, W.M. and Roy, L.D. (1995). *Soils In our Environment.* 7th Edition, Prentice Hall, Englewood Cliffs, NJ07632. Pp 127

Reddy, G.P.O., Maji, A.K. and Gajbhiye Kothiram, S. (2004). Drainage Morphometry and Its Influence on Landform Characteristics in Basaltic Terrain – A Remote Sensing and GIS Approach. *International Journal of Applied Earth Observation and Geoinformatics* 6: 1-16

Reynolds, W.D. (1993b). Saturated hydraulic conductivity: Field measurement. p. 599–613. In M.R. Carter (ed.) *Soil sampling and methods of analysis*. Canadian Society of Soil Science, Lewis Publ., Boca Raton, FL

Reynolds, W.D. and Elrick, D.E. (2002). Pressure Infiltrometer. In: *Methods of Soil Analysis: Part 4 Physical Methods* (Eds. J.H. Dane, G.C. Topp). *Soil Science Society of America,* 826–836

Rhoades, J.D. (1982). Cation Exchange Capacity. In: Page, A.L., Miller, R.H. and Keeney, D.R. (Eds.). *Methods of Soil Analysis Part 2: Chemical Methods*. Agronomy Monograph No.9, *American Society of Agronomy*, Madison Wisconsin. Pp. 149-157

Rieu, M. and Sposito, G. (1991). Fractal fragmentation, soil porosity and soil water properties: II. Applications. *Soil Science Society of America Journal*, 55: 1239-1244

Robenhorst, M.C., Foss, J.E. and Fanning, D.S. (1982). Genesis of Maryland Soils formed from Serpentine. *Soil Sci. Soc. Am. J*. 46: 607-616

Rosser, J., Swartz, G.L., Dawson, N.M. and Briggs, H.S. (1974). *A Land Capability Classification for Agricultural Purposes*. Div. Land Utilization. Tech. Rep. p. 14

Saggar, S., Parshotam, A. Sparling, G.P., Feltham, C.W. and Hart, P.B.S. (1996). 14C-labelled ryegrass turnover and residence times in soils varying in clay content and mineralogy. *Soil Biology and Biochemistry*. 28: 1677-1686

Saggar, S., Tate, K.R., Feltham, C.W., Childs, C.W. and Parshotam, A. (1994). Carbon turnover in a range of allophonic soils amended with 14C-labelled glucose. *Soil Biology and Biochemistry*. 26: 1263-1271

Sanaullah, A.F.M. and Shamsuddin, A.M. (2010). Distribution of Active Acidity, Reserve Acidity, Clay Content and Cation Exchange Capacity of Some Soils of Sathgaon Tea Estate, Bangladesh. *Journal of Applied Sciences Research*, 6: 1627

Sanchez, P.A. (1976). *Properties and management of soils in the tropics*. John Wiley and Sons, Inc., New York, USA. 618p

Senjobi, B.A. and Ogunkunle, A.O. (2011). Effect of different land use types and their implications on land degradation and production in Ogun State Nigeria. *Journal of Agric. Biotech. and Sustainable Development*, 3 (1): 7-18

Sharu, M.B., Yakubu, M., Noma, S.S. and Tsafe, A.I. (2013). Characterization and Classification of Soils on an Agricultural landscape in Dingyadi District, Sokoto State, Nigeria. *Nigerian Journal of Basic and Applied Science*, 21 (2): 137-147

Sheru, B.M., Jibrin, J.M. and Samndi, A.M. (2015). Fertilizer status of selected soils in the sudan savanna biome of Northern Nigeria. *International Journal of Soil Science*, 10 (2): 74 – 83

Sims, J.T. and McGrath, J. (2012). Soil Fertility Evaluation. In: Huang, P.M., Li, Y. and Summer, M.E. (Eds). *Handbook of Soil Sciences Resource Management and Environmental Impacts (Second Edition)*.

Singh, B. and Yadvinder-Singh, S. (2015). Soil fertility: Evaluation and management. In: *Soil Science: An Introduction to Soil Fertility* Edition: IstChapter: 22Publisher: Indian Society of Soil ScienceEditors: Rattan, R.K., Dwivedi, B.S., Sarkar, A.K., Bhattacharyya, T., Tarafdar, J.C. and Kukal, S.S

Soil Survey Staff (1999). *Soil Taxonomy:* A Basic System of Soil Classification for Making and Interpreting Soil Surveys. Second Edition. United States Department of Agriculture, Natural Resources Conservation Service, Agriculture Handbook, Number 436

Soil Survey Staff (2003). *Keys to Soil Taxonomy 9th ed*. United State Department of Agriculture

Soil Survey Staff (2006). Keys to soil taxonomy 10th Edn, USDA, NRCS, Department of Agriculture, Natural Resources Conservation Services, Washington D.C., USA

Soil Survey Staff (2014). *Keys to Soil Taxonomy* 2nd Edition, United States Department of Agriculture/Natural Resources Conservation Service, USA

Soil Survey Staff (2015). *Illustrated guide to soil taxonomy*, version 2. U.S. Department of Agriculture, Natural Resources Conservation Service, National Soil Survey Center, Lincoln, Nebraska

Sonon, L.S., Kissel, D.E. and Saha, U. (2017). Cation Exchange Capacity and Base Saturation. UGA Cooperative Extension Circular 1040

Srivastava, R. and Saxena, R.K. (2004). Techniques of large scale soil mapping in basaltic terrain using satellite remote sensing data. *International Journal of Remote Sensing* 25 (4): 679-688

Steel, R.C. and Torrie, J.H. (1981). *Principles and Procedures of Statistics.* Macmillan, New York, U.S.A

Strudley, M.W., Green, T.R. and Ascough, J.C. (2008). Tillage effects on soil hydraulic properties in space and time. *Soil Tillage Research,* 99:4-48

Tabor, N.J., Myers, T.S., and Michel, L.A. (2017). *Sedimentologist's Guide for Recognition, Description, and Classification of Paleosols*. Terrestrial Depositional Systems, 165–208

Talent, J.A. (1970). *Minerals, Rocks and Gems - A Handbook for Australia*, Jacaranda Press, Milton, Queensland

Udoh, B.T. and Ogunkunle, A.O. (2012). Land Suitability Evaluation for Maize (*Zea Mays*) cultivation in a Humid Tropical Area of Southeastern Nigeria. *Nigeria Journal of Soil Science,* 22 (1): 1-9

Udoh, B.T., Henry, H.B. and Akpa, U.S. (2011). Suitability evaluation of alluvial soils for rice (*Oryza Satuva*) and Cocoa (*Theobroma Cacao*) cultivation in an acid sands area of Southern Nigeria. *journal of Innovative Research in Engineering and Science,* 2(3): 148 – 161

Udotong, I.R., Ofonime, U.M.J. and Udotong, I.R.J. (2008). Microbial and physicochemical studies of wetland soils in Eket, Nigeria. *World Academy of Science, Engineering and Technology,* 44: 837-842

Ukabiala, M.E. (2019). *Characterization, Classification and Suitability Evaluation of Soils of Eastern Kogi State of Nigeria for Rice, Maize, Cassava and Oil Palm Production.* PhD Dissertation submitted to School of Post Graduate Studies, University of Nigeria, Nsukka

Ukaegbu, E.P. and Akamigbo, F.O.R. (2003). Detailed soil survey of University of Nigeria, Nsukka. *Proceedings of the 28th Annual Conference of the Soil Science Society of Nigeria,* pp 307–316

Umeugochukwu, O.P., Ezeaku, P.I., Chude, V.O. and Nnaji, G.U. (2012). Impact of Soil Erosion on Land Degradation in Uga Southeastern Nigeria. *Nigerian Journal of Soil Science,* 22 (1): 26–36

Unamba-Oparah, I. (1985). The potassium status of sandy soils of Northern Imo State, Nigeria. *Soil Sciences*, 139 (5): 437-445.

United States Department of Agriculture. (1973). *Soil Conservation Service, Land Capability Classification, Agriculture Handbook* No. 210

USDA-NRCS (2015). Soil Bulk Density/Moisture/Aeration. Soil Quality Kit-Guides for Educators, pp 1

Uzoho, B.U., Ekpe, I.I., Ahukaemere, C.M., Ndukwu, B.N., Okoli, N.H., Osisi, F.A. and Chris-Emenyonu, C.M. (2014). Nitrogen Status of Soils of Selected Land-uses of Two Cropping Systems in the Humid Tropical Rainforest, Southeastern Nigeria. *Advances in Life Science and Technology,* 25: 24-33

Uzu, F.O., Orimoloye, J.R. and Ugwu, I.K. (2003). Characteristics and agricultural potentials of soils of the floodplains of north western Nigeria. *Proceedings of the 28th Annual Conference of the Soil Science Society of Nigeria,* pp 325-336

Van den Akker, J.J.H., and Soane, B. (2005). Compaction. *Encyclopedia of Soils in the Environment*, 285–293

Velmurugan, A., & Carlos, G.G. (2009). Soil resource assessment and mapping using remote sensing and GIS. *Journal of the Indian Society of Remote Sensing*, 37(3), 511–525.

Veparaskas, M.J. (1988). *Identification and management of soils that form tillage pans*. Wageningen Agricultural University; Department of Soil Science and Geology; Netherlands

Vishal, D.J., Narahari, N.P., and Punit, R.R., (2009). Physico-chemical properties of four farm site soils in area surrounding Rajkot, Gujarat, India. *International Journal of Chemical Technical Research* 1 (3): 709-713

Warrick, A.W. (2002). *Soil Physics Companion.* Florida: CRC Press, pp 13

Westin, F.C. (1976). Soil geology and soil test results in South Dakota. *Soil Science Society of America Journal*

White, R.E. (1997). *Principles and Practices of Soils Science:* The soil is the natural resource. Wiley and Sons, Inc., New York, pp489

Wild, A (1993). *Soils and the Environment: An Introduction*. Cambridge University Press, Britain, 287 pp

Wilding, L.P and Drees, L.R. (1983). Spatial variability and pedology "In L.P. Wilding, N.B. Smeck and G.F.Hall Eds. *Pedogenesis and soil taxonomy 1: concepts and interactions*. Elsevier, Amsterdem Pp 83-116

Ya'U, S.L., Aliyu, J. and Shobayo, A.B. (2018). Impact of Irrigation on some soil chemical properties of flood plain soils in Kano State. *Proceedings of the 42nd Annual Conference of the Soil Science of Nigeria.* pp 70-77

Yusuf, A.A. and Yusuf, H.A. (2008). Evaluation of Strategies for Soil Fertility Improvement in Northern Nigerian and the Way Forward. *Journal of Agronomy*, 7 (1): 15-24

Appendix 1

General site information

Profile name	Agu-Ibagwa
Described by	Umeugokwe, Chigozie Pascal
Date	21/06/19
Location	06^0 56' 56.364" N; 07^0 19' 14.9" E
Elevation	296 m
Climate	MAR: 1520 mm; MAT: 27 ^{0}C
Parent material	Upper Coal Measure
Taxonomic classification	Typic Hapludalfs (USDA) Loamic Lixisols (FAO)
Topography	Undulating rolling
Micro-topography	Gentle slope
Topographic position	Mid slope
Slope type	Rectilinear
Vegetation/land use	Grasses with few scattered tress
Erosion	Inter-rill
Drainage	Well drained
Moisture status	Top 127 cm slightly moist, moist below
Depth to water table	> 200 cm
Depth to impenetrable layer	None encountered
Surface stoniness	None
Rock outcrop	None
Biological activities	None

Horizon description

Horizon	Depth (cm)	Thickness (cm)	Description
Ap	0-26	26	Dull reddish brown (2.5YR 4/3) loamy sand; fine moderately subangular structure; firm (moist) and moderately sticky (wet); many very fine and few fine roots; moderately drained and clear and smooth boundary.
Bt1	26 – 61	35	Orange (2.5YR 6/6) sandy loam; moderately medium sub-angular blocky structure; firm (moist) and moderately sticky (wet); very few fine roots; perfectly drained; gradual smooth boundary.
Bt2	61 – 127	63	Bright brown (2.5YR 5/6) sandy loam; moderately medium sub-angular blocky structure; friable (moist) and sticky (wet); perfectly drained; gradual smooth boundary.
Bt3	127-176	49	Bright brown (2.5YR 5/8) sandy loam; moderately blocky structure; friable (moist) and sticky (wet); poor drained; fibrous root; undulating boundary.

C	176-200	24	Orange (2.5YR 6/8) sandy loam; blocky structure; loose (moist) and sticky (wet); poor drainage.

General site information

Profile name	Opi-Agu
Described by	Umeugokwe, Chigozie Pascal
Date	28/06/19
Location	06^0 42' 6.632" N; 7^0 32' 58.283" E
Elevation	193 m
Climate	MAR: 1520 mm; MAT: 27 ^{0}C
Parent material	Nkporo Shale
Taxonomic classification	Eutric Acrudox (USDA) Loamic Lixisols (FAO)
Topography	Undulating rolling
Micro-topography	Gently Sloping
Topographic position	Depression
Slope type	Concave
Vegetation/land use	Small sized tress with few grasses
Erosion	None encountered
Drainage	Well drained
Moisture status	Moist
Depth to water table	> 150 cm
Depth to impenetrable layer	None encountered
Surface stoniness	None
Rock outcrop	None
Biological activities	None

Horizon description

Horizon	Depth (cm)	Thickness (cm)	Description
Ap	0 – 29	29	Brown (7.5 YR 4/4) sand; moderate coarse angular blocky structure; firm (moist) and moderately sticky (wet); many very fine roots; perfectly drained; clear smooth boundary.
A_2	29 – 55	26	Dull reddish brown (2.5 YR 5/4) sandy loam; moderate coarse angular blocky structure; firm (moist) and moderately sticky (wet); few woody roots and many fine roots; moderately drained; abrupt boundary.
B	55 – 121	66	Bright reddish brown (5 YR 5/8) sandy clay loam; strong very coarse granular structure; firm (moist) and sticky (wet); perfectly drained; very few fine roots; gradually diffuse boundary.
C	121 – 180	59	Red (10 R 4/8) sandy loam; moderate coarse granular structure; very firm (moist) and sticky (wet); perfectly drained; very few fine roots.

General site information

Profile name	Nkpologwu
Described by	Umeugokwe, Chigozie Pascal
Date	29/06/2019
Location	06^{0} 41' 38.105" N; 07^{0} 19' 14.188" E
Elevation	259 m
Climate	MAR: 1520 mm; MAT: 27 ^{0}C
Parent material	False-Bedded Sandstone
Taxonomic classification	Arenic Kanhapludults (USDA) Arenic Acrisols (FAO)
Topography	Undulating rolling
Micro-topography	Gently sloping
Topographic position	Mid slope
Slope type	Rectilinear
Vegetation/land use	Grasses with few scattered tress
Erosion	Sheet
Drainage	Well drained
Moisture status	Slightly moist throughout
Depth to water table	None encountered
Depth to impenetrable layer	None encountered
Surface stoniness	None
Rock outcrop	None
Biological activities	None

Horizon description

Horizon	Depth (cm)	Thickness (cm)	Description
Ap	0-20	20	Very dark reddish brown (2.5YR 2/3) sand; weak very fine crumb structure; friable (moist) and not plastic (wet); many very few and fine roots; perfectly drained; gradual smooth boundary.
AB	20-62	42	Dark reddish brown (2.5YR 3/6) sand; moderate very fine crumb structure; friable (moist) and not plastic (wet); very few and fine roots; perfectly drained; clear smooth boundary.
B1	62-98	36	Red (10R 4/6) sand; moderate granular structure; friable (moist) and slightly plastic (wet); few and fine roots; perfectly drained; clear smooth boundary.
B2	98-161	63	Reddish brown (2.5 YR 4/8) sand; moderate granular structure; friable (moist) and slightly plastic (wet); few roots; perfectly drained; clear smooth boundary.
B3	161-200	39	Red (10R 4/8) sand; moderate granular structure; friable (moist) and slightly plastic (wet); few roots; perfectly drained.