AGRICULTURAL POTENTIALS OF SOILS DERIVED FROM SELECTED PARENT MATERIALS ON THE JOS PLATEAU, NIGERIA

By

Andrew Olabanji AKINWA
MATRIC. NUMBER: 15528
B. Sc. Agric. Soil Science (UI), M.Sc. Soil Science (ABU)

A Thesis in the Department of Soil Resources Management Submitted to the Faculty of Agriculture in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

of

UNIVERSITY OF IBADAN

JULY, 2023

CERTIFICATION

I certify that this research was carried out by Andrew Olabanji AKINWA under my supervision in the Department of Soil Resources Management, University of Ibadan, Nigeria.

……………………………………………………………

Supervisor
G. E. Akinbola
B.Sc., M.Sc., Ph.D. (UI)
Professor of Soil Survey and Land Use Planning
Department of Soil Resources Management,
Faculty of Agriculture,
University of Ibadan, Nigeria

DEDICATION

To the Most High God, who saw me through a most trying time in my quest to obtain a Ph.D. degree, at a relatively old age.

ACKNOWLEDGEMENTS

My foremost gratitude goes to the Almighty God, who saw me through a most harrowing experience in my life! He did not allow me to be put to shame. He did not allow enemies to gloat over me. To Him be glory, majesty, power and dominion and honour forever and ever.

I thank my supervisor, Professor G. E. Akinbola, for his patience, understanding, support and goodwill. My gratitude also goes to Professors G. O. Obigbesan, A. O. Ogunkunle, J. A. I. Omueti, M. O. Akoroda, H. Tijani-Eniola, E. A. Aiyelari, G. O. Adeoye, E. A. Akinrinde and V. O. Adetimirin, for their love and support. I equally wish to thank Professor J. A. Fagbayide, O. Fagbola, G. A. Oluwatosin, S. O. Oshunsanya and the Head, Department of Soil Resources Management of the University of Ibadan, Professor K. O. Oluwasemire, for their love and encouragement.

I wish to thank Drs. J. R. Orimoloye, O. O. AdeOluwa, O. W. Olaniyi, B. Olasanmi, A. Abe; Dr. (Mrs.) L. O. Babatola, Dr. (Mrs.) E. Y. Thomas, Dr. (Mrs.) O. A. Fashae, Mrs. F. I. Borokinni and Mr. S. A. Omosuli, all for their love and goodwill. I equally wish to thank my fellow postgraduate students for their love, especially Messrs A. B. Osumah, H. U. Nkwocha, O. Aliku, O. A. Ogah and O. T. Ayodeji.

My sincere appreciation goes to my dear wife, Mrs. M. M. Akinwa, for her support and encouragement. Same goes to our dear children, Mrs. O. O. Oloke, Mr. B. T. Akinwa, Mr. S. I. Akinwa, Miss M. T. Akinwa, Miss M. K. Akinwa and Mr. E. O. Akinwa. I appreciate your love, prayers and encouragement.

I wish to thank the following colleagues and friends in the former Federal Department of Agricultural Land Resources, for their love and goodwill: Messrs M. M. Mshelia, J. U. Adamu, O. R. Yekeen, C. A. Bikom, A. Y. Cheshi, D. Manhan, O. O. Ojuola, A. Y. Akubo, Drs M. O. Adenekan, B. A. Adebusuyi, O. Y. Momoh, S. O. Sanni and O. A Ogunsola. Same goes to Mrs. D. Bothar, Mrs. E. Shammar, Former Miss S. Yohanna and former Miss R. Ocholi (Late). I also thank Mr. A. R. Sanni and his wife Mrs. M. Sanni, same goes to Mr. B. Adesiyan.

My appreciation also goes to the following members of Evangelical Church Winning All (ECWA), for their prayers, love and encouragement: Rev. A. O. Farinto (Former ECWA President), Rev. (Dr.) E. Ogundiya, Rev. T. Ajibola, Rev. S. O. Oshoaro; Mrs. G. A. Oguntolu, Rev. S. O. Babayomi, Rev. L. O. Afolayan, Elder O. Aina and Mrs. E. Aina.

I also wish to thank my late parents Mr. C. A. Adegunleye and Mrs. J. O. Akinwa, they both contributed their quotas towards my success in life. Finally, I wish to thank all the individuals whose names I have not mentioned, but who have contributed in one way or the other, to my success story; God Bless You All.

ABSTRACT

The agricultural potentials of soils depend on their properties which are usually influenced by the Parent Materials (PMs). An understanding of the properties of soils from different PMs is required for effective management and utilisation. Despite the high agricultural prospects of the semi temperate climate of the Jos Plateau, limited information is available on the effects of the PMs on the agricultural potentials of the soils. This study was, therefore, conducted to characterise, classify and assess the agricultural potentials of soils resulting from three major PMs (Basalt, Granite and Unconsolidated deposits [UD]) on the Plateau.

A reconnaissance survey of the Jos Plateau was conducted to identify soils from the three PMs. One profile pit each was sunk and described at the crest, upper slope, middle slope, lower slope and valley bottom positions on two toposequences of soils formed on each PM, using standard methods. Randomised complete block design was used with three PMs as treatments replicated twice. Parent materials and soil samples were collected, assessed for morphological characteristics and analysed for physical and chemical properties, following standard procedures. These properties were used to classify the soils using USDA and FAO/World Reference Base systems while their agricultural potentials were assessed using Land Capability (LC) and Fertility Capability (FC) evaluation systems. Land capability was rated classes I (soils with few limitations), II (some limitations), III (severe limitations), IV (very severe limitations), V (limitations other than erosion hazards), VI (extreme limitations), VII (use restricted to grazing) and VIII (unsuitable). Fertility Capability was rated on specific constraints to soil fertility; the less the constraints, the better the soil. Data were analysed using descriptive statistics and ANOVA at $\alpha_{0.05}$.

Basalt was fine grained, Granite and rock remnants of UD were coarse grained and their soils differed significantly in properties. Soils were red, strong brown and yellowish brown in colour on Basalt, Granite and UD PMs, respectively. The soils were well drained in the upper and middle slope positions and imperfectly or poorly drained in the lower slope and valley bottom positions. Total nitrogen was 1.32±0.75 g/kg, 1.47±0.82 g/kg and 1.08±0.62 g/kg for soils derived from Basalt, Granite and UD, respectively. Exchangeable potassium was significantly higher (0.63±0.38 cmol/kg) for the soils from Granite than those from Basalt (0.41±0.38 cmol/kg) and UD (0.37±0.34 cmol/kg). Effective cation exchange capacity was 10.78±6.2 cmol/kg, 15.24±3.6 cmol/kg and 15.48±2.88 cmol/kg for the soils from Basalt, Granite and UD, respectively. The soils from Basalt and Granite were classified as Inceptisols (Cambisols) and Alfisols (Lixisols); those from UD were Alfisols (Lixisols). In LC classification, class II land was 50%, 40% and 30% on Basalt, UD and Granite, respectively. Soils from UD had the least constraints to fertility (three), Basalt (four) and Granite (six), in FC classification.

The soils of the Jos Plateau investigated were mainly Inceptisols (Cambisols) and Alfisols (Lixisols). Basalt and Unconsolidated deposits derived soils with minimal constraints had higher agricultural potentials than those from Granite and could support sustainable agricultural production with good management.

Keywords: Parent materials, Soil properties, Land evaluation, Soil classification, Jos Plateau
Word count: 493

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

CHAPTER 1

INTRODUCTION

1.1 Background of the study

The agricultural potential of a soil, refers to the inherent capacity or ability for agricultural production. It depends on both the physical and chemical properties of the soil. Lawal *et al*., (2014) observed that the productivity of a soil is a function of its physical and chemical properties. Soil properties are indicators of the assets or liabilities of a soil, depending on the magnitude or levels of the respective soil properties; with respect to agricultural production. Major constraints to increased soil productivity are linked to the state of soil properties. Ololade *et al*., (2010), have identified poor knowledge of soil, as a hindrance to agricultural development in most part of Africa. A good knowledge of the properties of a soil is therefore crucial and critical for a meaningful evaluation or assessment of the agricultural potential of the soil. The overall properties of a soil are largely dictated by its parent material. Parent material is one of the factors of soil formation, the others are climate, organism, topography and time. Parent material provides the building blocks in soil development and functions as the fulcrum around which the other factors of soil formation revolve. Gray and Murphy (1999), stressing the importance of the parent rock, cited an earlier worker who described soil as a type of disintegrated condition of the original rock.

The physical and morphological characteristics and chemical composition of a parent material play important roles in determining soil properties, especially during the early stages of soil development (Ritter, 2006). Soils developed on parent materials that are coarse grained and composed of materials resistant to weathering are likely to exhibit coarse grained texture. Fine grained soil develops where the parent material is composed of unstable minerals that readily weather (Smyth and Montgomery, 1962). Parent material composition has a direct impact on soil chemical and nutrient capacity. Limestone and lava from basalt have high level of soluble bases and produce fertile soils in humid climates. If parent materials are low in soluble ions, water percolating through the soil removes the bases and replaces them with hydrogen ions and the soil becomes acidic. Soils formed on sandstone have low soluble bases.

Orimoloye *et al.* (2018), reported that soil pH, exchangeable calcium, magnesium, potassium, sodium, available phosphorus, iron and zinc contents of the soils they investigated in Ibadan, South Western Nigeria, were all significantly influenced by the parent materials on which the soils were formed. Mirabella *et al.* (2002), noted that varying parent material lithology led to different clay mineral assemblage in the soil. Woodridge (1964), in the study he conducted, reported that several of the measured soil properties (water-stable aggregates, bulk density, organic matter, pH, total porosity and percentage clay, silt and sand), were related to parent material and horizon depth.

Arbestian *et al*. (1999), reported that soils developed from z-mica granite (with biotite and muscovite, the later prevailing in most cases) and from grandiorite (biotite dominant) were coarse textrured, while those developed from gneiss were loamy-textured. Soils developed from base rich parent material (amphibolite and biotitic schist) had, in general developed from more acidic parent material (phyllite and granite), translating into a higher SO_4^{2-} sorption in soils developed from basic materials than in the ones developed from more acidic ones. The basic ions in the basic materials attract the sulphate ions carrying negative charges.

Parent materials may be considered as predominantly comprising either primary in-situ bed-rock or secondary transported materials such as alluvium, aeolian or glacial deposits. Weathering forces such as heat, rain, ice, snow, wind, sunshine and other environmental forces, breakdown parent materials and affect how fast or slow soil formation processes go. Olowolafe (2002), observed that the resulting weathering products that form the soil, and their unique nature and properties are important for soil scientists to establish the proper management and utilization of soils.

1.2 Statement of the problem

The ability of a soil to support good crop yields depends significantly on its physical and chemical properties. Olowolafe (2002), observed that major constraints to increased soil productivity have their links to the state of soil properties. A soil in good physical condition with sufficient reservoir of nutrient elements in readily available forms should support good crop production under normal conditions. Great diversity occurs between and within soil types due to pedogenic and anthropogenic factors (Akinbola *et al*., 2002; 2007; Bolte, 2010); obtaining comprehensive soil information upon which reliable and efficient soil management practices for agricultural production can be based is therefore costly and time consuming. Most farmers in Nigeria practice 'blanket' fertilizer application because they cannot afford the high costs of soil information services. The high prospects of the Jos Plateau for agricultural production, including the cultivation of special crops such as Irish potato, apple, cabbage, cucumber, carrot and wheat amongst others, cannot be fully realized without reliable soil information.

Available comprehensive soil data on the Jos Plateau presently is scanty as compared to what obtains for soils of the other parts of Nigeria.

Only few of the soil studies of the Jos Plateau have attempted to establish any link between the soils and the parent materials and such information has been inadequate. Such studies include those of Tijjani and David (2017), Tijjani and Hassan (2017), and Danlami and Onimisi (2016). It was only the study by Olowolafe (2002), that had attempted to establish the relationship between parent materials and soil properties on the Jos Plateau. There is therefore the need for more efforts at establishing the relationship between parent materials and resultant soils on the Jos Plateau. Such will enhance insight into their agricultural potentials, and facilitate their better management for agricultural production. It will also enhance transfer of knowledge gained to other places with similar environments. Much still remains to be done in updating and employing soil information of the Jos Plateau, to evolve comprehensive soil management packages for enhanced crop production.

1.3 Aim and objectives of the study

The broad objectives of the study include the generation of more reliable and comprehensive soil data of the Jos Plateau; examine the levels of association between soils and the parent materials; evaluate the potentials of the soils for agricultural production and assess land degradation and its mitigation strategy through good land use and management. The aim of the study is to use the soils investigated for agricultural production, based on their potentials, thereby ensuring optimal yields as well as minimizing land degradation and wastage of resources.

Specific Objectives

The specific objectives of the study are to:

1. Identify, characterise and classify soils derived from three major parent materials on the Jos Plateau;
2. Investigate major pedogenic processes responsible for the weathering of the parent materials and soil formation in the area;
3. Evaluate the relationships between the properties of the major parent materials and those of the soils formed from them, and their variability;
4. Classify the soils according to internationally recognized classification systems;
5. Evaluate the potentials and limitations of the soils for the production of some major crops.

1.4 Significance of the study

The study will provide detailed and reliable soil information of the Jos Plateau for sustainable agricultural land use planning; it will also provide land utilization and management options on the plateau thereby improving farmer’s income and food security. Furthermore, the study will provide conservation strategies to reduce land degradation.

1.5 Scope of the study

The study entailed the digging of thirty (30) soil profile pits across soils derived from three major parent materials on the Jos Plateau viz: Basalt, Granite and Unconsolidated deposits. Soils and rock samples collected from the profile pits were analysed following standard procedures. The soils were classified according to the USDA (2014) and WRB (2014) classification systems and their agricultural potentials evaluated in accordance with some popular, internationally recorgnized systems. Possible soil management practices for sustainable agricultural production were suggested. Constituents of analysed rock parent materials were carefully studied and identified, to gain insight into the properties of soils formed from them and and facilitate their management for agricultural production.

CHAPTER 2

LITERATURE REVIEW

2.1 Soil formation

Soil formation refers to how the soil is made up or how the soil is formed. Soil formation starts with the breaking down of rocks and minerals. Weathering can lead to modification or destruction of the original structural composition of the parent minerals. Soil formation involves the interplay of climate, organism, relief, parent material and time through various processes. Parent materials and climate are important factors that affect pedogenesis. Topography, living organisms and time contribute significantly to pedoturbation, biogeochemical cycling and organic matter accumulation while topography significantly affects depth and thickness of soil (Okafor, 2016).

The specific processes of soil formation are (a) modification of minerals and organic materials in the soil through the breakdown of organic material or weathering of minerals; (b) translocation (movement of inorganic or organic material from one horizon to another by the action of water or micro/macro organisms); (c) addition (supply of materials to a soil profile from other sources such as dust from the atmosphere or organic matter from decomposing plant or animal material) and (d) losses; through removal of materials from the soil profile (Brady and Weil, 1999).

2.2 Factors affecting soil development

Five distinct, related factors affect soil profiles according to research, they are: climate, organism, parent material, topography and time. The factors are referred to as factors of soil formation, by soil researchers and they give profiles their unique properties. These are briefly discussed below.

2.2.1 Parent Material

The material a soil is formed from, is its parent material; it could be rock that has decayed in situ or a material deposited by water, ice or wind. The nature of the parent material plays an important role in determining the soil properties, especially during the early stages of development (Ritter, 2006).

The soil surveyor uses parent material to develop a model used for soil mapping. Soil Scientists and specialists in other disciplines use parent material to help interpret soil boundaries and project performance of the material below the soil. Many soil properties relate to parent material. Among these properties are proportions of sand, silt and clay; chemical content; bulk density; structure and the kinds and amounts of rock fragments. These properties affect interpretations and may be criteria used to separate soil series. Soil properties and landscape information may imply the kind of parent material (CT ECO, 2010).

The parent material from which soil develops is a key factor that in many cases determines the kind and contents of secondary minerals of soils. Formation of non crystalline constituents and Al- and Fe- humus complexes take place preferentially in soils derived from volcanic ejecta, giving these soils a typical andic character (variable surface charge, high water holding capacity, high anion retention, low bulk density) (Shoji *et al*., 1993). Soils developed from 2-mica granite (with biotite and muscovite, the latter prevailing in most cases) and from granodiorite (biotite dominant) are coarse-textured, while those developed from gneiss are loamy-textured.

2.2.1.1 Types of parent materials

(a) Residual or Sedentary Parent material

This type of parent material developed in place (in situ) from the underlying rock. Typically, it experienced long and intense weathering. Residual parent materials can be found overlying any rock type, provided that the landscape has been stable for a sufficient period of time for weathering to occur

(b) Transported Parent material

These parent materials consist of loose sediments or surficial materials (i.e weathering products of rocks that are not cemented or consolidated) that have been transported and deposited by gravity, water, ice, or wind.

(c) Cumulose Parent material

The parent material consists of deposited organic materials that have developed in situ from plant residues and preserved by a high-water table (or some other factor slowing down decaying) e.g., peat, muck.

2.2.2 Climate

There seems to be a strong geographical relationship between climate and soil especially at the global scale. Sunshine and rainfall strongly affect physical and chemical reactions of parent material. Climate also dictates vegetal cover which in turn influences soil development. Rainfall also affects factors involved in horizon development like the translocation of dissolved ions through the soil. As time progresses, climate tends to be a prime influence on soil properties and the influence of parent material becomes less (Ritter, 2006).

2.2.2.1 Influence of climate on vegetation and weathering

Climate influences vegetal growth and the activity of organisms. There is only limited organic material available for the soil in hot, dry desert areas with scanty vegetation. The lack of precipitation retards chemical weathering resulting in coarse textured soil in dry regions. The cold temperatures in the tundra limit bacterial activity causing organic matter build up. Leaf litter is well decomposed where bacterial activity is fast. Under the lush tropical forest vegetation, available nutrients are quickly taken back up by the trees. Some organic materials are washed from the soil by the high annual rainfall. All the factors result in soil lacking much organic matter in their upper horizons.

Soil Chemistry is affected by the interaction between climate and vegetation. Cool, humid climates are often dominated by pine forests. A weak acid is created by decomposing pine needles in the presence of water and the soil is stripped of soluble bases, resulting in an acid stste. tend to dominate.

Again, few soil nutrients are taken back up by pine trees which have low nutrient demands. The nutrients are recycled later by decaying needle litter. Broad leaf deciduous trees such as Maple and Oak with higher nutrient demand, recycle soil nutrients continually and keep soils high in soluble bases.

2.2.3 Topography

Topography has a significant influence on soil formation as it determines runoff of water, and its orientation affects micro climate which in turn affects vegetation. For soil to form, the parent material needs to lie relatively undisturbed so horizon processes can proceed. Water moving across the surface strips parent material away impeding soil development. Water erosion is more effective on steeper, unvegetated slopes (Ritter, 2006). Lawal et al., (2014), noted that topography could hasten or delay the work of climatic factors.

2.2.3.1 Effect of topography on soil erosion

Slope angle and length affects runoff generated when rain falls to the surface. The amount of water on a particular hill slope segment is dependent on waterfalls from precipitation and water runs into it from an upslope hill slope segment. As water runs down slope, the water that has accumulated in a preceeding upper segment of the slope runs into the lower segment that follows, adding to the water received by that lower segment of the slope, by precipitation. The amount of water increases in the down slope direction as water is contributed from upslope segments of the slope. The velocity of the water increases as well as it moves towards the base of the slope. As a result, the amount and velocity of water, and hence rate of erosion increases as one approaches the base of the slope. Rather than infiltrating into the soil to promote weathering and soil development, water runs off. Erosion causes stripping of the soil thus preventing parent material to stay in place to develop into a soil. So, we should expect to find weakly developed soil at the mid and near the bottom of the slope.

2.2.3.2 Effect of topography on deposition and soil texture

Water velocity not only determines the rate of erosion but the deposition of soil material in suspension too. As water empties from a mountain stream, its velocity start to decrease. The largest size particles, like sand, are the first to drop out of suspension. Fine, clay size particles can be carried further away from the base of the slope before they are deposited. As a result, coarse textured soils tend to be found near the base of the mountain and fine textured soils are located further away.

2.2.3.3 Microclimatic effects of topography

The microclimate of a place is influenced by hill slope orientation. Sun angle in the locality increases to an extent according to the increase of the surface slope. Heating intensity increases with an increase in the local sun angle, resulting in warmer surface temperature and possibly, increased evaporation. Hill slope orientation is also important. More heat is received by slopes facing the sun than those backing it. Flatter surfaces facing the sun are not as warm or dry as tilting surfaces, again, vegetation type is influenced by the microclimate.

2.2.4 Organisms

In soil evolution and composition, plants and animals carryout a significant function. They fast track decomposition, weathering, nutrient cycling and add organic matter. The abundance and variety of organisms and plants growing within the soil are linked with climate. When the climate is favourable, plants and animals flourish and increase greatly in number; when they die, they decay and add organic matter is rich in nutrient elemens and improves soil fertility.

2.2.4.1 Nutrient cycling

Nutrients from the soil are needed by living things in the environment, to survive. Nutrients taken up form the soil by organisms are returned to the soil when the organisms die and are taken up by other organisms. The nutrient status of soils is refreshed and maintained by the cycling, it prevents the leaching of nutrients from the soil and the soil is able to support life steadily.

The requirments of the organisms in a place, determine the level of cycling of nutrients. High nutrient demand is required for example, by oak and maple and a surface litter rich in nutrients, is created when the leaves die. In contrast, pine have low nutrient requirements and the decaying leaves are low in nutrients, resulting in little cycling of soluble nutrients which are leached, creating an acidic soil environment.

2.2.4.2 Organisms and weathering

Weathering is also influenced by soil organisms. A weak acid emerges from the decaying pine needles, which can remove soluble ions from the soil. Channels are created in the soil by burrowing animals, earthworms and termites, to help aerate and allow water to infiltrate into it. The animals move materials down the soil and enrich the soils with nutrients at lower depths.

2.2.5 Time

As time progresses, weathering breaks down parent materials. Layers are being differentiated in the soil profile by their physical and chemical properties through horizon development processes, giving rise to older more mature soils with well developed sequence of horizons, though some may have experienced intense weathering making it difficult to observe visually distinct layers.

2.3 Modern concepts of soil and land

The precious, varied, delicate natural resources at the surface of the earth, providing life support is the soil. It is an active porous biological medium known as pedosphere. Most of the interactions between the land, surface and ground waters and the atmosphere involves the soil (Orimoloye, 2011). Survey Staff (2003) defined soil as the natural discernable layers. According to World Reference Base for Soil Resources (FAO, 1998), it as a continuous natural body with three spatial and a temporal dimension, developed from mineral and organic materials having solid, liquid and gaseous phases; arranged in specific structures for pedological medium and is in constant development, with a time dimension. Air or shallow water marks its upper limit. Its margins are marked by deep water, barren areas of rock or ice. Soils include the layers near the surface differing from the underlying rock material and resulting from interactions, between time, climate, living organisms, parent materials, and relief. The lower limit of soil is usually the lower limit of biologic activity, which coincides with the common rooting depth of local perennial plants (Soil Survey Staff, 1975; Orimoloye, 2011). Soil carries physical structures, used as it is used in construction and sustains biomass productivity, reactor of organic/mineral weathering, living filter for water supplies, remediators of wastes and serves as the medium determining the continuity of the ecosystem. It constitutes the long-term asset which nations build their resources on (Orimoloye, 2011).

At a point in time, land was commonly equated with soil. According to FAO (1976), land was considered the basic requirement for agriculture and other rural activities involving the use of land and embracing too, climate, nature of slope, vegetation as well as other God-given assets. Accordingly, land was described as a portion on the surface of the earth which attributes entails every resoanably stable cyclic, characteristics of the biosphere both above and below, involving atmosphere, soil, underlying rocks, living things, outcomes of anthropogenic activities, both before and present, based on any notable impact of the attributes on current and future uses of the land by humans.

Land is a measurable segment of the land surface of the earth and embracing properties of the biosphere above or below the area, near-surface climate, soil and terrain forms, surface water types (shallow lakes, rivers, marshes and swamps), near-surface sedimentary layers and accompanying groundwater reserve, living things, human settlement pattern, physical outcome of previous and present human activity (terracing, water storage, etc) according to the United Nations (Orimoloye, 2011). The UN definition harps more on the aspect of the environment.

NCR (2001) introduced the idea of the critical zone which is the segment of the earth's surface including the biosphere, atmosphere, lithosphere and pedosphere interactions. It is largely the delicate conglomerate of rock, soil, air, water, vegetation, lakes, rivers, shallow seas, saturated and unsaturated ground water regions, referred to as the epiderm of the earth. This has a wilder outlook than those of Wilding (1994) and spsrks (2000).

2.4 Soil formation and pedogenesis

Soil formation starts with the disintegration of rocks and minerals. Weathering can result in modification or destruction of the original structure of the parent materials. Soils are products of various processes. Soil formation involves the interplay of five (5) soil factors. These factors include climate, parent materials, vegetation, relief and biological activities as conditioned by relief over time (Okafor, 2016). Parent material and climate are important factors that affect pedogenesis. Topography, living organisms and time contribute significantly to pedoturbation, biogeochemical cycling and organic matter accumulation while topography significantly affects depth and thickness of soils.

Pedogenic processes may be general or specific (Okafor, 2016). The general processes are (a) horizonation (differentiation in initial materials into soil profiles with many horizons); (b) haploidazation (inhibition or deceleration by which horizons are mixed or disturbed). The specific processes of soil formation are (a) transformation of minerals and organic substances within the soil through the breakdown of organic material or weathering of minerals. (b) translocation (movement of inorganic or organic materials from one horizon to another by the action of water and micro/macro-organisms). (c) addition (supply of materials to a soil profile from other sources such as dust from the atmosphere or organic material) and (d) losses; through removal of materials from the soil profile (Okafor, 2016). Transformation and translocation lead to accumulation of materials within a soil horizon while losses are due to removal of materials and this can be caused by leaching and erosion. Soil horizonation involves eluviations /illuviation, leaching, alkalization, pedoturbation, decalcification, salinization, podzolization and leucinization, etc. The interactions between factors and processes of soil formation contribute significantly to variability of soil properties. On the Jos Plateau, the soil type is highly influenced by the tropical pedogenic processes involving intensive weathering and leaching. Andisols are not expected to be formed in Nigeria climatic environment (Paffit, 1990). Olowolafe (2008) in his study of soil genesis in volcanic areas of the Jos Plateau, Nigeria, noted as follows: the youngest soils occur around the cones, that is, the crest and side-slopes where soils are shallow as a result of constant erosion. Entisols are the soils found around the cones. Soil formation in the volcanic area commences with the formation of amorphous clay minerals, which gradually undergo further pedogenic processes that lead to kaolinite formation. Kaolinite has been found in volcanic parent materials in similar climatic environments. The important pedogenic processes occurring around the crest are organic matter addition and bioturbation. In the upper foot-slope areas, Inceptisols are found and are rich in clay content with better aggregate structure particularly in the surface soils and a slight decrease in ECEC. The pedogenic processes at work include clay enrichment as a result of continued hydrolytic weathering, structure formation and loss of basic cations.

Olowolafe (2002), observed that Inceptisols are relatively young and that they show the initiation of many pedogenic processes. In the middle foot-slope areas, Alfisols dominate and the predominant pedogenic processes at work include clay formation from hydrolytic weathering, structure formation, clay migration (eluviation and illuviation), acidification and loss of basic cations through leaching. In the lower foot-slope areas, most of the properties observed for the soils in the middle foot-slope areas are also observed. However, in addition, soils in the lower foot-slopes contain mottles throughout the profiles, lateritic concretions and high values of CBD extracted Al. The dominant soils are Ultisols and pedogenic processes involved are gleying, plinthization and allitization, in addition to the pedogenic processes occurring in the middle foot-slope areas. Formation of 2:1 clay mineral is said to be probably precluded in the area because of high temperatures, absence of mica, loss of basic cations and dessilication as a result of heavy rains. Such clay lattice may not persist under acid conditions and rapid leaching characteristics of the tropical environment.

2.5 Soil variability

Soil variability refers to variations in soil physical, chemical, biological and morphological properties (Gupta *et al*., 2010). The status of these properties of the soil is often used in assessing soil quality (Okafor, 2016). Soils are in dynamic equilibrium and are always changing due to pedogenic (inherent) causes such as nature of parent materials and climate or anthropogenic processes (introduced) such as land use types (Manchanda *et al*., 2002; Okafor, 2016). Variations in soils can be across toposequence (Akinbola *et al*., 2006; Akinbola and Ojimadu, 2008; Okafor, 2016), within a chronosequence (Obi *et al*., 2010). The scale of variability may be small, medium or large with climate and vegetation being responsible for large scale variability in soils (Brady and Weil, 1999). The high variability of tropical soils requires thorough studies and good management in order to attain sufficiency in food production (Okafor, 2016).

Variation in soil properties over space results in unevenness in crop performance and makes modeling for soil management difficult (Lobel, 2004; Okafor, 2016). However, identification and mapping of soils aid management of soil variability. Information on soil variability is used to ascertain the adequate number of samples and the spacing for collecting soil samples for studies on fertilizer recommendations (Ogunkunle, 1986). Changes in soil system can be seen in colour, composition or behavoiur of the soil (Doi and

Ranamukhaarachchi, 2007). Most changes are caused by humans and various land use types (Manchanda et al., 2002; Phil-Eze, 2010).

Human activities which influence soil properties on a small scale include tillage, fertilizer application and erosion (Aiboni, 1989). Understanding soil variability offers a leyway to sustainable soil management as soil's response to treatment and use varies significantly with soil type (Stavi and Lal, 2011; Lobb, 2011). Using Ibadan soil series as a taxonomic unit, (Ogunkunle *et al*., 1989) observed that there could be variation even within taxonomic unit. Babalola and Lal (1977), reported that gravel content of surface soils had significant effect on the yield of maize of two Ibadan series with the difference in the gravel content of the A horizon affecting yield widely.

2.6 Soil characterisation and classification

Soil characterization is the identification and description of soil properties and qualities (Okafor, 2016). During characterization of soils, individual properties of soils at each observation point are recorded (Rossiter, 2001). Information generated from soil characterization is used for classification of soils. Soil features assessed during soil characterization include soil depth, soil colour, presence and size of mottles, stoniness, and soil structure (shape of peds, size of peds, pores), consistence, presence of cutans (Brady and Weil, 1999). Characteristics of the soil profile can be altered by land form, stone removal, drainage, presence of restrictive layers, subsidence, or by increased erosion due to land use.

Soil classification is the systematic arrangement of soils into groups or categories on the basis of their morphological, physical, chemical and biological characteristics (Bzali *et al*., 2011). Soils are grouped or organized on the basis of their common properties (Rossiter, 2001). Soil classification helps to deal with the complexity in soils as it aids soil grouping through examination, description and appraisal of soil properties (Ontkean and Serafinchon, 2000). There are two major approaches used in soil classification and these are (a) natural and (b) technical.

Natural soil classification deals with naturally occurring assemblages of soil properties i.e known genetic relationship. Natural soil classification groups soils based on pedogenesis e.g USDA, while technical processes classify based on properties that relate directly to proposed use or group of uses such as hydrologic response, fertility capability classification, suitability classification, urban and land use capability classification (Rossiter, 2001). Some soil classification systems are developed for national use for example Australian, French, Canadian, Russian or German land classification systems such as World Reference Base (WRB)/ International Union of Soil Science (IUSS, 2008), USDA Soil Taxonomy (2014) are developed for international application.

There are 12 soil orders in the USDA soil classification system namely alfisol, ultisol, inceptisol, aridisol, entisol, histosol, spodosol, gelisol, vertisol, andisol and mollisol. Alfisol and Ultisol are soils with argillic, kandic or natric horizons (NRCS, 2013). However, a distinguishing feature between them is that base saturation of ultisol is < 35% while alfisol is > 35%. Furthermore, the base saturation of ultisol decreases with depth while base saturation of alfisol increases with depth (NCSU, 2013).

2.7 Soil inventory

Soil inventory has to do with the determination of the spatial distribution of the soils of an area. The determination of the spatial distribution of the soils of an area can be done through soil survey. Soil survey, which is the inventory of different soils, their distribution, kinds, nature and composition thereby providing knowledge of the potentials and constraints of various land use types. Other information generated through soil survey includes land use/land cover types, drainage and forms of lithology (Loro, 2005). An inventory of Nigeria's soils has been done although till date Nigeria lacks a national classification system (Fagbami and Ogunkunle, 2000). Pioneer efforts at inventory of Nigeria's soils include the works of Moss (1957) and Jungerius (1964), on the sedimentary soils of Nigeria; Smyth and Mongomery (1962), on the assorted underlying rocks of South-Western Nigeria; Klinginberg and Higgins (1968), on the soils of Nothern Nigeria; Murdoch *et al*., (1976), on the soils of Nigeria located on the savanna vegetation of South-Western Nigeria. Others are Juo and Moormann (1980); Fagbami (1980); Ojanuga and Awujola (1981); Lekwa (1985); Ogunkunle (1986); Esu and Ojanuga (1986); Okusami (1988); Sutton and Loganathan (1989); Ogunsola and Omueti (1989); Akinwa (1989); FDALR (1990); Igwe *et al*., (1995); Akinbola and Kutu (1999); Aruleba and Fashina (2003); Akinbola (2003);

Olowolafe (2002); Ibanga *et al*., (2005); Osodeke and Ojeniyi (2005); Idoga and Azagaku (2005); Chukwu (2007); Babalola *et al*., (2011); Ogbodo and Chukwu (2012), Onyekanne *et al*., (2012) and Okafor (2016).

2.8 Previous soil studies on the Jos Plateau

Different workers or organizations have undertaken studies of soils of some parts of the Jos Plateau. Grove (1952), investigated the use of land and soil conservation on the Plateau. The Land Resources Division of the Overseas Development Agency, United Kingdom, conducted a reconnaissance survey of soils of the Plateau, (Hill, 1978). Morgan (1979) undertook a survey of Environmental and Land Use of the Jos Plateau. Ojanuga and Awujoola (1981), studied some soils of the Plateau and classified them as Typic Haplustalf (Orthic Luvisol), Udic Rhodustalf (Chromic Luvisol) and Typic Eutropept (Chromic Cambisol).

Ugwu (1983), undertook a study of the properties, classification and geomorphic relationships of some soils of the Jos Plateau. Some of the soils involved in the study were classified as Ultic Haplustalf (Eutric Nitosol), Acquic Ustifluvent (Dystric Fluvisol), Typic Paleustult (Ferric Acrisol) and Andic Ustic Humistropept (Dystric Cambisol).

Onyike (1983), investigated the application of semi-detailed soil survey to rural land use planning, using a part of Riyom Local Government Area, of Plateau State as a case study. Adepetu (1985), investigated some farmer's plots on four Fadamas in the jos Plateau. The Federal Department of Agricultural Land Resources carried out a reconnaissance survey of Plateau State (Okoye, 1985), the main seat of the Jos Plateau. The result of the survey classified some of the soils as Oxic Haplustalf (Ferric Luvisol), Andic Eutropept (Ferralic Acrisol and Arenic Haplustalf (Orthic Luvisol).

Akinwa (1989), undertook a characterization and classification of the Irish Potato growing soils of the Jos Plateau. The soils were classified as Typic Rhodustult (Orthic Acrisol) Plinthic Paleustalf (Plinthic Lixisol) and Plinthic Udic Paleustalf (Plinthic Lixisol). Dabi (1990), investigated farming possibilities on soils of the heavily mined terrain of the Rayfield area of Jos Plateau.

Olowolafe (1997), investigated the distribution, characteristics and land use predication of soils developed on the volcanic parent materials on the Jos Plateau, Nigeria. Olowolafe (1998), also undertook the study of limitations to sustainable production of crop in soils of the biotite-granite areas of Plateau and soil management for sustainable agriculture and environmental harmony. Olowolafe and Nyagba (1999), investigated soil constraints to sustainable agricultural production in the volcanic area of the Jos Plateau, Nigeria.

Olowolafe and Dung (2000), studied soils derived from biotite granite on the Jos Plateau, Nigeria and their nutrient status and management for sustainable agriculture. Olowolafe (2002), undertook a study of soil parent materials and soil properties in two separate catchment areas on the Jos Plateau, Nigeria. Adepetu *et al*. (2003) investigated the effects of the use of different amounts of nitrogen and phosphorus fertilizers on upland rice yields on the Jos Plateau, Nigeria.

Yusuf *et al*. (2004), investigated the properties and fertility of mine wastes of the Plateau. Olowolafe (2008), studied the impacts of using municipal waste as fertilizer on soil charcteristics in the Jos area, Nigeria. Hassan *et al*. (2015), investigated the basaltic soils of Plateau State, Nigeria: properties, classification and management practices. Sohotden *et al*. (2015), undertook An Evaluation of Landscape Sections Suitable for Agriculture in Keran Volcanic Area of Jos Plateau, Nigeria. Danlami and Onimisi (2016), undertook An Assesment of properties of Kerang Volcanic Landscape Catena, Jos Plateau. Tijjani *et al*. (2017), investigated Forms and Distribution of Potassium in a Toposequence on Basaltic Soils of Vom, Jos, Plateau. Mahmud *et al*. (2017), investigated Variability of some soil characteristics in a toposequence of a basaltic parent material of Vom, on the Plateau.

The predominant parent materials of the soils of the Jos Plateau are loose deposits from disintegrated granites, varied basement complex rocks and older basalts (Hill, 1978). Slight laterization has modified the materials resulting in natable mottles. Gravels from the erosion of iron pan, have been spread over the loose deposits in some places. In other places, the soils form on granite, newer basalt and iron pan.

The surface horizons of the soils are influenced by aeolian, fine loamy materials (Macleod *et al*., 1971). Any of the different categories of soils could be influenced by poor drainage. The water table fluctuates because of the pronounced seasonal rainfall (Hill, 1978).

The soil moisture regime is ustic and the temperature regime is interfered as isohyperthermic. Most of the soils are poor in nutrients. The Effective cation exchange capacity of most of the soils is reported to be less than 80 cmol/kg of soil except for those on basalt (Hill, 1978). Soil pH is less than 6.0 and often less than 5. The low pH limits the growth of common arable crops like maize, sorghum, yam, millet and groundnut. Fixation of phosphorus is likely at the low pH, sandy nature and red colour of many of the soils and this could be one reason for the observed limitation to the growth of the listed arable crops.

2.9 Geology and geomorphology of the Jos Plateau

Figure 2.1 is the geological map of the Jos Plateau. It has been described by Macleod *et al*., (1971) and Hill (1978). It consists of gneisses, migmatites and granites, generally known as Pre-Cambrian Basement assorted rocks. Medium to coarse grained granites (Younger granites), were ejected into the Basement assorted rocks, forming many round assorted rocks of Jurassic age (Jacobson *et al*., 1958).

Volcanic activities have influenced the Plateau from early to recent times. According to Macleod *et al*., (1971), there were laterized older basalts, unlaterized older basalts and newer basalts.

Secondary iron pan and loose deposits on valley side slopes have been formed from the erosion of the lateratized older basalts. During the Pleistocene, many cycles of erosion and deposition seemed to have occurred, giving rise to Rayfield, Bokkos and Bisichi deposits (Hill and Rackham, 1974). A fine, yellowish loam material, has in more recent times been deposited over much of the Plateau and has been suggested as Aeolian in origin Macleod *et al*., (1971).

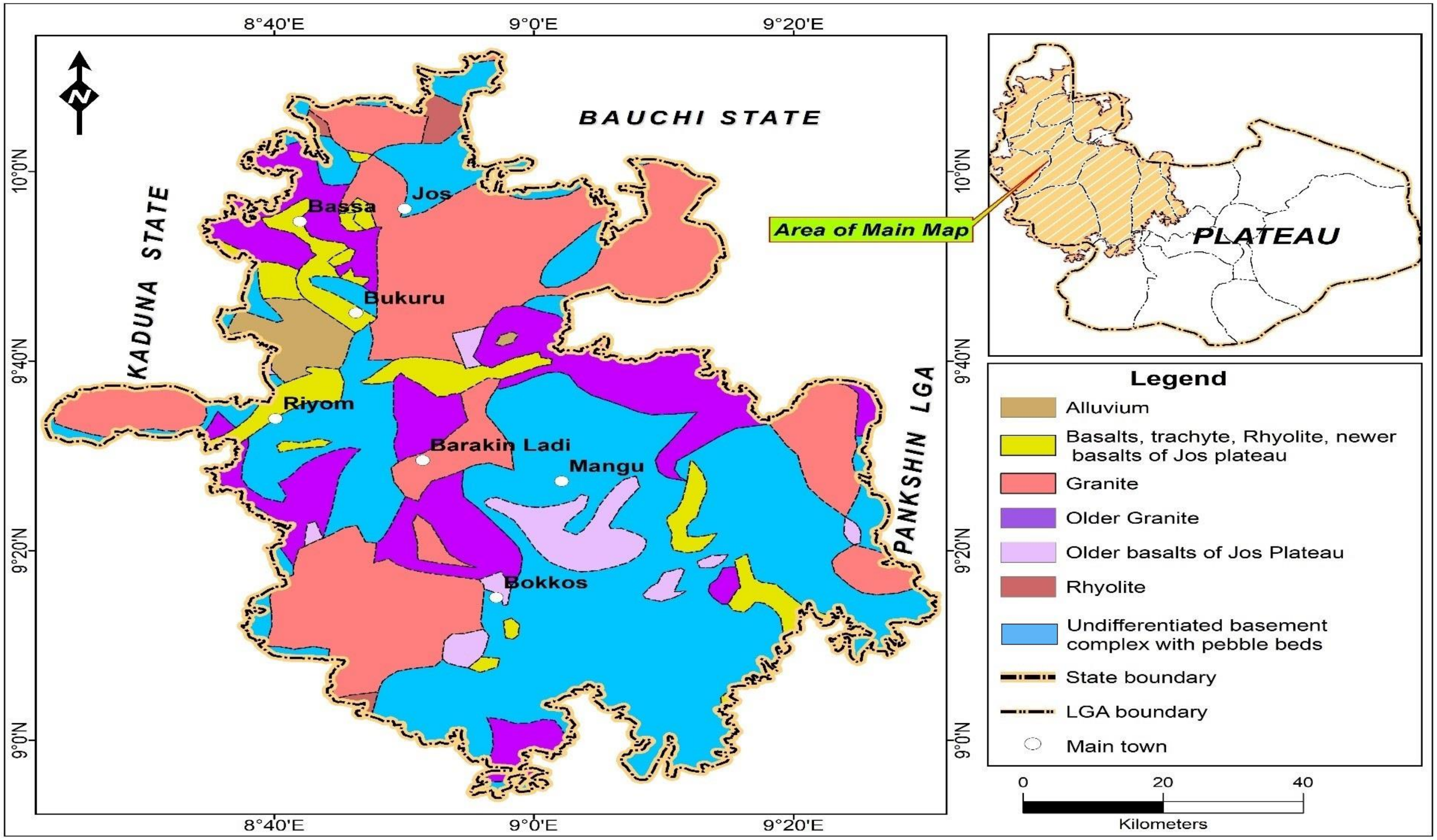

Figure 2.1: Geology of the Jos Plateau (Modified from Hill and Rackham, 1973)

Ugwu (1983) has given an in-depth discussion of the geomorphology of the Jos Plateau. The Plateau is an erosion relic which assumed its present form in Cretaceous times, when the sedimentary rocks of the Benue were deposited (Grove, 1952). The view is supported by the argument of Moss (1968), that in West Africa, the ubiquity of the late Cainozoic Post-African elements is seriously challenged only in the vicinity of the Jos Plateau where remnants of the Jurassic Gondwana and the Cretaceous Post-Gondwana elements exist in association with a subjacent development of African surface. Pugh and King (1952) have also referred to the remnant of the Gondwana Landscape which governs the aspect of Jos Plateau at about 1220 m or more mainly south and south-east from Jos where it has been preserved on the relatively younger Granites.

Furthermore, King (Hill and Rackham, 1973) implied that the earliest planation surface, the Gondwana surface, is represented only by the highest parts of the younger granites hills, as he referred to remnant at 1,769 meters. He therefore suggested a Post-Gondwana date for the main Plateau surface which Thorpe (1967) has assigned to a Planation surface developed on the Jos-Bukuru complex at 1,280 - 1,370 meters and which as observed by Hill and Rackham (1973), is now mainly represented by hill summits.

A chronological order for the development of the Jos Plateau during the Tertiary and Quaternary periods following the preservation of the Gondwana and Post-Gondwana surfaces, has been suggested by Hill and Rackham (1973). Many of the development are due to alternations between wet and dry climates. First, there was late tertiary erosion resulting in the accumulation of the pre-older Basalt Alluvium. The older Basalts were then extruded over this alluvium during the Pliocene. A period of lateratization associated with a climate of alternating wet and dry seasons then followed. This is suggested to have taken place during the early quaternary age and resulted in the production of Lateratized Older Basalts. Another period of intensive erosion ‘‘probably under arid conditions’’ then followed. This resulted in the dissection of the Lateratized Older Basalts with the formation of mesas and scarps. This erosion also produced great quantity of debris which formed thick unconsolidated deposits referred to as Ray field and Bokkos deposits.

The newer Basalts were then extruded and it has been suggested that another period of erosion followed which cut valleys into the Ray field and Bokkos deposits. The valleys are believed to have been filled by another group of deposits, the Bisichi deposits, in which true alluvial deposits alternate with materials believed to have originated from mass movement. In addition to the generally, gently undulating surface of the Jos Plateau, hills mountains and dissected terrains have been identified by Hill and Rackahm (1973), in addition to the undulating plains. The hills and mountains are predominantly formed of the resistant younger granites, the dissected terrain, mainly of granites and other basement complex rocks and undulating plains, of migmatites, granite and granite-gneiss, Lateratized Older Basalts and Newer Basalts.

2.10 Definition of land use

According to the FAO frame work (1976) land use shows the intended use to which a land is to be put. It includes land use for extensive or intensive agriculture and forestry.

2.10.1 Land use, soil productivity and land degradation

Attaining food security in Nigeria has remained a challenge due to poor soil management. In addition, Fasina *et al*. (2005), stated that one of the problems affecting self sufficiency in food production in Africa is unplanned use of land. Different forms of agricultural land use types such as sole or intercropping of arable and tree crops, multi-varietal sole cropping confer variation on soil properties (Raji *et al*., 2011). Soil management depends extensively on the knowledge of the properties as well as the nature of the soils (Amusan *et al*., 2006). Inappropriate use of land results in degradation, leading to a decrease in soil quality, removal of vegetation, land degradation and land use change (Long et al., 2006; Wu, 2008). Land degradation increase soil bulk density, reduces soil infiltration rate, leads to loss of organic matter and a reduction in crop yield (Mbagwu, 2008). Aruleba and Ogunkunle (2005), observed that in many parts of the world, land under cultivation is not properly maintained to sustain long term crop production.

2.11 Land evaluation

Land evaluation is the process of estimating the potentials of land for one or several alternative uses. The basic feature of land evaluation is the comparison of the potentials of the land with requirements of land use (Dent and Young, 1981). According to FAO (1976) framework on land evaluation, collection of data and interpretation of physical characteristics of land, economic feasibility, social consequences and environmental impacts of proposed use whether for agriculture or other uses should be determined while a multidisciplinary approach is required. Land evaluation is done to assess the effects of present and future use of land (Eriba, 2002). Land units are grouped into interpretive classes depending on their relative capability for sustainable crop production. This classification also identifies potential problems that may occur with land use and make recommendations for appropriate management under different land use types (Akinbola *et al.*, 2008). Evaluation of land give the blueprint for interpretation of soil characteristics, their potential or limitations for agronomic and other agricultural uses, through provision of information and recommendation required for planning the use of land (Attua and Fisher, 2010).

2.12 Land evaluation systems

Land capability classification (LCC), productivity indices, land suitability evaluation (LSE), irrigation capability classification (ICC) and fertility capability classification (FCC), obtained from suitability index of California University (Storie Index), are some of the widely accepted land evaluation systems currently put in place to group lands based on their potential for agriculture; and Agro-ecological zoning (AEZ) (Orimoloye, 2011).

2.12.1 Land Capability Classification (LCC)

The Land Capability Classification (LCC) of the USDA (Klingebiel and Montgomery, 1961) is the most popular system for land classification. It was put in place in the United States of America for the purpose of farm planning. It is now in use the world over at varying levels. Soils are grouped together with respect to their capability for arable cropping. Land resource survey provides the required information for the classification. The basic guidelines are:

i. Physical land characteristics obtained through the survey of soil, constitute the main considerations in evaluating units of land.

ii. Magnitude of a constraint is on the basis of the extent to which the growth of crop is hindered.

iii. Capacity of an area of land for the conservation of crop.

Soil mapping consists of classes (I-VIII) based on their capacity for general kinds of use devoid of deterioration or noticeable unpleasant effects. Classes (I-IV) are arable land, with constraints on use as well as the need for conservation efforts with painstaking maintenance increasing with the class number (Orimoloye, 2011). Classes (V-VIII) are non arable land but could be used for grazing, woodland, pasture, wildlife, recreation and other uses. Subclasses e, w, s and c which indicate distinct special hindrances namely excess wetness, erosion, rooting zone constraints and climatic limitations respectively, are attached to the general classes. Subclasses have units which are indicative of the degrees of limitations and management needs. Even though land capability classification is indicative of local use and management of soil, it takes account of only relatively permanent, static land properties and takes no account of economic or social considerations. The method has been used in the classification of many farms in Nigeria however, Oluwatosin and Ogunkunle (1991) observed that separation of subclasses into units is below usual maintenance of farms and therefore, may not give a true picture of things on the farmer's plot.

2.12.2 Land Suitability Evaluation (LSE)

Land suitability operates on the FAO 1976, guidelines for the evaluation of land. The application is more far reaching than what obtains from soil surveys. It also considers climatic, vegetal and other aspects of land as regards the needs of other possible forms of land use. The guideline operates on six rules and spells out ideas, methodology and processes for a step-by-step bio-physical and social cum economic evaluation of the prospects for specified land uses that may be key to the location. It gives details of what should be taken into account with respect to assessment for various options of land use and how the potentials should be evaluated. The guidelines are:

i. Suitability of land is evaluated and graded based on specific kinds of uses.

ii. Assessment involves a comparison of benefits derived vis-avis resources required, on diverse kinds of land.

iii. A multi-disciplinary method is needed in the assessment exercise.

iv. Evaluation should take cognizance of the economy, bio-physical and the socio-political setting of the place in focus.

v. Suitability implies engagement, on a sustainable term.

vi. Evaluation entails comparing a number of possible options of use.

Land suitability assessment results in suitability classes such as very suitable (S1), moderately suitable (S2), marginally suitable (S3) and non suitable (NS). The limitation that warrants putting a land into particular suitability class e.g., wetness (w), erosion hazards (e), is usually affixed to the class. There are also limitation units (1, 2, 3), affixed to the specific limitations, to indicate the severity of the limitations.

In the latest reviews of the guidelines (FAO, 2007), some social and economic aspects that were in the original guidelines but rarely used, were made elaborate to include legislations (such as legal guidelines, native laws, ownership rights, etc), land tenure guides, trades, job, transport, population, political and policy considerations and others.

2.12.3 Fertility capability classification (FCC)

Fertility Capability Classification of soils was done to explain soil taxonomy and more soil properties in ways linked to plant growth. Furthermore, it bridges the vacum between classification of soil and fertility (Sanchez *et al*., 2003; Okafor, 2016). A soil classified as Segkm is sandy, highly leached, prone to water logging, has low nutrient reserves and low organic matter. The FCC designation for a given soil can be interpreted in relation to various land uses. Fertility capability classification places more emphasis on subsoil characteristics because of their more permanent nature (Sanchez, 1986). It has some relevance to soil quality assessment as it can be used to interpret soil characteristics with direct effects on crop performance and seems a suitable framework for agronomic soil taxonomist with acceptability by both soil and crop scientists (Lin, 1989). Furthermore, FCC employs soil attributes across temporal and spatial scales especially in cases where fertilizer is the main nutrient requirement (Sanchez *et al*., 1982). Fertility capability classification is made up of distinct levels which are highlighted by Sanchez *et al*., (2003) as follows:

i. **Type**: **Top soil texture**: Top soils are categorized into:

a. Sandy (S): Loamy sands and sands (by USDA definition)

b. Loamy (L): Loamy top soils < 35% clay but not loamy sand or sand

c. Clayey (C): > 35% clay

d. Organic (O) > 35% organic matter to a depth ≥ 50cm.

ii. **Substrata type, subsoil texture**: This considers the texture of the subsoil and it is used for classification if there is significant change in texture from the surface if there is presence of root restricting layers such as hardpans, concretions or underlying rocks within 50cm. They are symbolized as follows:

a. S – Sandy subsoil

b. L – Loamy subsoil

c. C – Clayey subsoil

d. G – Gravel

e. R – Rock or other root restricting layer

iii. **Modifiers**: Modifiers are properties of the surface soil which limit soil fertility (Lin, 1989). They are represented in lower case letters as:

a = aluminum toxicity, b = basic reaction (pH > 7.3), e = low Effective Cation Exchange Capacity, k = low potassium reserve, f = low level of free iron oxides, g = gley (mottle ≤ 2 chroma within 70cm of soil surface and below), and s = salinity. Soil fertility constraints identified in tropical soils include seasonal soil moisture stress, aridity, high soil erosion risk, low nutrient reservoir, water logging, high P fixation, high leaching potential, cracking clays, aluminum toxicity, salinity, acidity and sodicity (Ahamed *et al*., 2006).

2.12.4 Irrigation capability classification (ICC)

The classification is of a special purpose set out to evaluate technical and economic possibility of a planned irrigation project serving to guide engineering and project plans. The United States Bureau of Reclamation land classification for irrigation (USBR, 1951), is the widely used ICC system. It employs no fixed method but applies general guidelines to adapt classification to the important conditions e.g., economic, social; existing in the project area. The quantitative classification places emphasis on economic assessment. It consists of six classes, four of which are appropriate for surface irrigation, one, potentially appropriate and one, inappropriate. The FAO guidelines was notably influenced by the USBR system, especially on the notion that economic aspect alone can correctly classify land for developmental purposes.

2.12.5 Productivity indices

They are mainly indices of multiplication linked to soil characteristics and engaged to relatively rank soils as regards yield. Soil characteristics that enhance suitable rooting depth and available water potential, constitute the main consideration. University of California's suitability index known as the Storie Index (Edwards, 1970), constitutes the crux of the system. Some indices of productivity depend on some crucial soil characteristics like pH and bulk density, to rank soils **(**Orimoloye, 2011).

The impact of adverse land properties on land production potential were expressed by Sys *et al*. (1991) with a soil value. Calculation of the value is done through multiplying numerical ratings due to each property after comparing the data collected or measured data with the requirement for the production of a particular crop (Laya *et al*., 1998). Classes indicating the quality of a soil for a specific purpose matched with other soils of a specific area, are known as soil potential ratings: (1) yield, (2) cost of employing latest technology to reduce the impact of soil constraints and (3) unfavourable effect of continuous constraints on economic, social or ecological assets.

2.12.6 Agro-Ecological Zoning

The quantitative evaluation of the adaptability of a plant to a certain region is referred to as Agro-Ecological Zoning (AEZ). It is an elaborate methodology anchored on frame-work concepts. It involves the mapping unit of a land resources, described with respect to climatic, soil and land form considerations and land cover with a particular range of prospects and limitations for the use of land, according to the FAO, (1996). Efforts at continental scale were aimed at obtaining an initial estimate of the land production prospect of the world's land assets. Agro-Ecological Zoning maps and reports on a national scale, provide the physical data bank needed to plan agricultural and zoning for rural developmental ploicies. Kenya had the first ever national-scale study (Kassam *et al*., 1991) and Ojanuga (2006), came up with Nigeria’s agro-ecological zones. The duration of the growing period dictated by rainfall and temperature regimes, constitutes a key concept. Growing periods constitutes the criteria for a quantitative climate classification of every selected crop under rain-dependent farming.

Popular crops grown on the Jos Plateau are Irish potato, maize, carrot, cucumber, yams, acha (Digitaria exilis and Digitaria iburua), citrus and sweet potato. The system of farming on the Jos Plateau has been referred to as the acha farming system.

CHAPTER 3

MATERIALS AND METHODS

3.1 Location of the Jos Plateau

The Jos Plateau is in Plateau State of Nigeria, West Africa. It occupies about 8,600 km^2 in an area situated within longitudes 8° and 20′ and 9° 30′ E and latitudes 8° 30′ N and 10° 30′ N Akinwa and Akinbola (2018). It has an average altitude of 1,250 m above sea level and stands at a height of about 600 m above the adjoining plains. A steep descent to the adjoining plains marks its boundary for the most part, which is only more gentle in the East (Figure 3.1).

3.2 Relief and Drainage

Most of the Plateau surface lies between 1050 – 137 m elevation. Areas at lower elevations are often linked to migmatites, the newer flows of basalt result in flat to gentle rolling landscape (Hill, 1978). Loose material, cover the rock beneath, over much of remaining part of the Plateau.

The Plateau has a radial drainage. Three major river systems of Nigeria, have their watersheds originating from the Plateau. Gongola river flows north east wards and divert into river Benue. Delimi river flows off Chad; Mada, Ankwe, Shemankar and Wase rivers flow to the Benue while Kaduna river flow to Niger river (Hill, 1978).

3.3 Climate

Only Jos has detailed climatological information, produced by Nigerian Meteorological Service, less comprehensive records are maintained for other towns in the region.

3.3.1 Rainfall

The rainfall data for Jos is contained in Table 3.1. The southwest section of the Plateau receives the highest rainfall, having mean annual rainfall around 1,600 mm, the rainfall which decreases gradually north east and the mean rainfall in Jos is 1,400 mm, highest amount could occur near the Shere Hills.

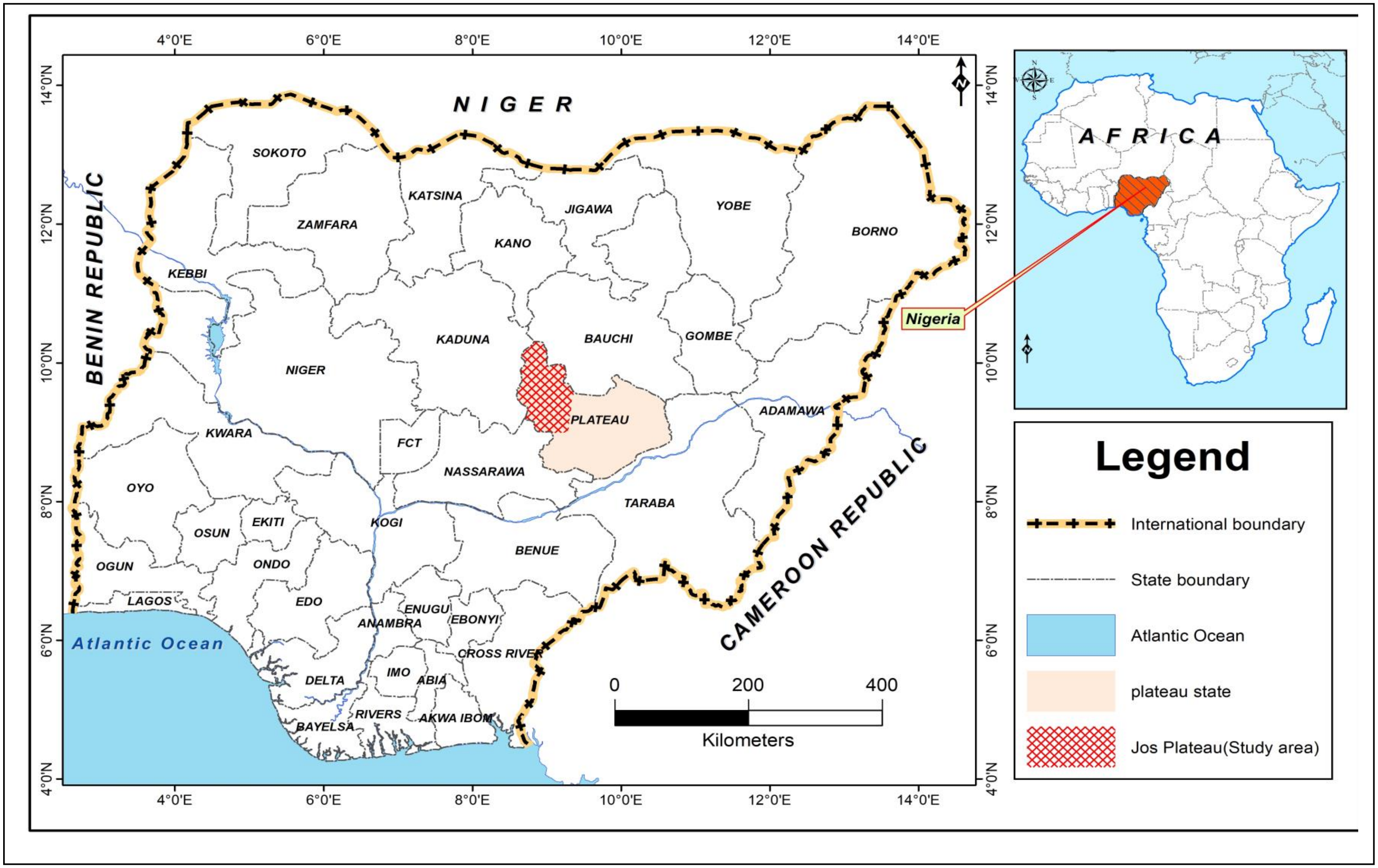

Figure 3.1: Location map of the Jos Plateau (Modified from Hill, 1978)

Table 3.1: Meteorological data for Jos

Observation	J.	F.	M.	A.	May	Jun	Ju	Au.	S.	O.	N.	D.	Total Annual or Monthly mean	Years of record
Rainfall (mm)	2.0	2.3	24.1	94.7	190.8	228.1	323.9	281.4	208.5	42.7	3.1	1.5	1403	50
Evapotranspiration (mm)	117	122	145	122	114	101.3	84.6	78.5	94.5	115.8	122	114	1331	34
Air Temp (°C)	20.5	22.5	24.5	24.5	24.6	23.5	21	21.5	22	22	21.5	19.5	22.3	10
Sunshine (hrs)	9.5	9.2	7.9	6.8	6.5	6.6	4.9	4.5	5.9	7.4	9.7	9.1	7.3	10
Relative Humidity (%)	17	17	23	47	67	73	80	80	71	53	22	18	47	10

J – January; F – February; M – March; A – April; May; Jun – June; Ju – July; Au – August; S – September; O – October; N – November; D - December

Source: Jos Airport Meteorological Station, Federal Ministry of Aviation.

Rains begin in April and end in October, only minimal rain is received for the remaining part of the year (Hill, 1978). The growing period is May to September.

Kowal and Knabe (1972), set out area with similar temperatures, precipitation and evapotranspiration cycles. The places are indicated as polygons built around synoptic climatic stations in northern Nigeria. Length of the rainy period for the polygons (Jos and Bauchi), is 190 and 140 days respectively.

In the Jos polygon, the rainy period starts between the 1st and 10th of April and ends between the 11th and 20th of October. During the rains, crops are not expected to experience moisture stress enough as could affect yield notably, it can be regarded the safe growing period. The study area is in the Jos polygon.

Benoit (1975) has however, indicated that the onset of the rains could vary, the probability of rains commencing on the indicated dates are 50% and 30% for Jos and Bauchi.

3.3.2 Temperature

Maximum temperatures range from 23.5 to 30.9° C for Jos and Bauchi polygons respectively during the rainy season, while the minimum temperatures range from 19.6 to 22.8° C and 26.6 to 28.5° C for the polygons during the same season. Table 3.1 earlier referred to, contains temperature data for Jos. The highest temperature occurs during the months of March and April, with mean monthly temperature attaining 24.5° C. Mean monthly temperature decreases to 19.5° C in December which coincides with the harmattan period.

3.3.3 Relative humidity

The relative humidity data for Jos is contained in Table 3.1. The relative humidity (%) is lowest in January and February when the value for each month is 17% and reaches the peak in July and August with the value at 80% for each month. The relative humidity is directly linked with the trend in rainfall. It is lower for the period January to April during which the rainfall is low, while is highest for the period May to September when the rainfall is equally high; for the period of October to December, during which the rainfall is low again, the relative humidity is also low.

3.3.4 Pattern of radiation

According to Kowal and Knabe (1972), the pattern of radiation on the Jos Plateau equates with the pattern of rainfall with largest amount of solar radiation being received during the rainy season. There is a general drop in the amount of radiation from October to February. Peak intensities of radiation are attained around mid-day and the highest values are recorded in the rainy season, even though actual number of hours of mean daily sunshine is higher in the dry period of October to March, as shown in Table 3.1. The lowest peaks are recorded during the harmattan period. This can be attributed to the bright clouds which reduce effective radiation during harmattan.

The mean annual global radiation for Jos calculated from the sunshine hours on the basis of ten-day period for each month, has been recorded as 436 cal cm^{-2} yr^{-1} by Kowal and Knabe (1972). The net radiation is about 154.1 cal cm^{-2} day^{-1} while the mean daily sunshine hours is 7.3. The mean daily global radiation in Jos polygon is 301-424 cal cm^{-2} day^{-1} while that in the Bauchi polygon is 349 - 488 cal cm^{-2} day^{-1}, during the rainy period. The mean daily actual sunshine hours in the Jos polygon range from 3.71-7.20 hours while the values range from 4.86 - 4.88 hours in the Bauchi polygon, also during the rainy period (Hill, 1978).

3.3.5 Evapotranspiration

Evapotranspiration is good indicator of the depletion of soil water. It depends on temperature, relative humidity and wind. As contained in Table 3.1 the lower the relative humidity, the higher the Evapotranspiration. Evapotranspiration is consequently at its highest values during the dry season (October to April) when the relative humidity attains lowest values. Based on the rainfall data in Table 3.1, the annual rainfall (1403 mm) on the Plateau is a bit in excess of annual potential evaporation (1331 mm). During the dry season (October to April), Evaporation is higher than rainfall and water deficit could normally be expected in the soil during the period, while during the rains (May to September), there is some water surplus in the soil. Based on the evaporation data for Jos as contained in Table 3.1, the mean monthly figures for the Jos Plateau range from 78.5 mm to 145 mm, with an average of 110.9 mm.

3.4 Vegetation

Figure 3.2 shows the vegetation complexes of the Jos Plateau. The Jos Plateau's vegetation reflects interaction between climate, soil and the activities of men. Little of the original vegetation remains due to prolonged cultivation and current vegetation is essentially short time fallow. The original vegetal cover has been greatly changed by man's activities. Alford and Tuley (1974) and Hill (1978), have described the vegetation as consisting of six complexes which broadly reflect climate changes. The complexes give a structure within which soil-vegetation associations can be studied.

3.4.1 The Plateau complex

It exists in the middle portion of the climatic region, having a mean annual rainfall of 1,270-1,254 mm, *Adropogon pseudapricus* grassland and *Terminalis syzyium* shrub land dominate there. Ficus and Euphorbis shrub land occupy the rocky areas while scanty grasses occupy the shallow soils on iron pan, with species of *microichola, Sporobolus, etc.* Poorly drained areas carry *Hyparrheniarufa* plants while *Brax/chlaria* species are found on the soils formed basalt. A larger part of the Plateau falls within this vegetation complex.

3.4.2 The South West complex

The vegetational complex exists in the south-western part of the region with mean annual rainfall of 1,524-2,030 mm. A shrubland with *Adenodolichos* plants and a woodland with syzyglum, cyatheadregel amongst others, occur.

3.4.3 The West escarpment complex

For this type of vegetation, there is a typical reflection of the southern guinea zone. Annual rainfall (mean) here is less than that of the south-west vegetal type. Here we have Vitax woodland, riparian woodland and shrub land.

3.4.4 The toro complex

The vegetational type exists largely within Mangu low-lying areas, with the Plateau tilting mildly to the East. The area receives less rains than the Plateau complex. It carries a similar vegetal cover to that of the Plateau complex. There is *Combretum sericcum* shrub land, while in areas of intense cultivation, we have Parkial Daniella parkland.

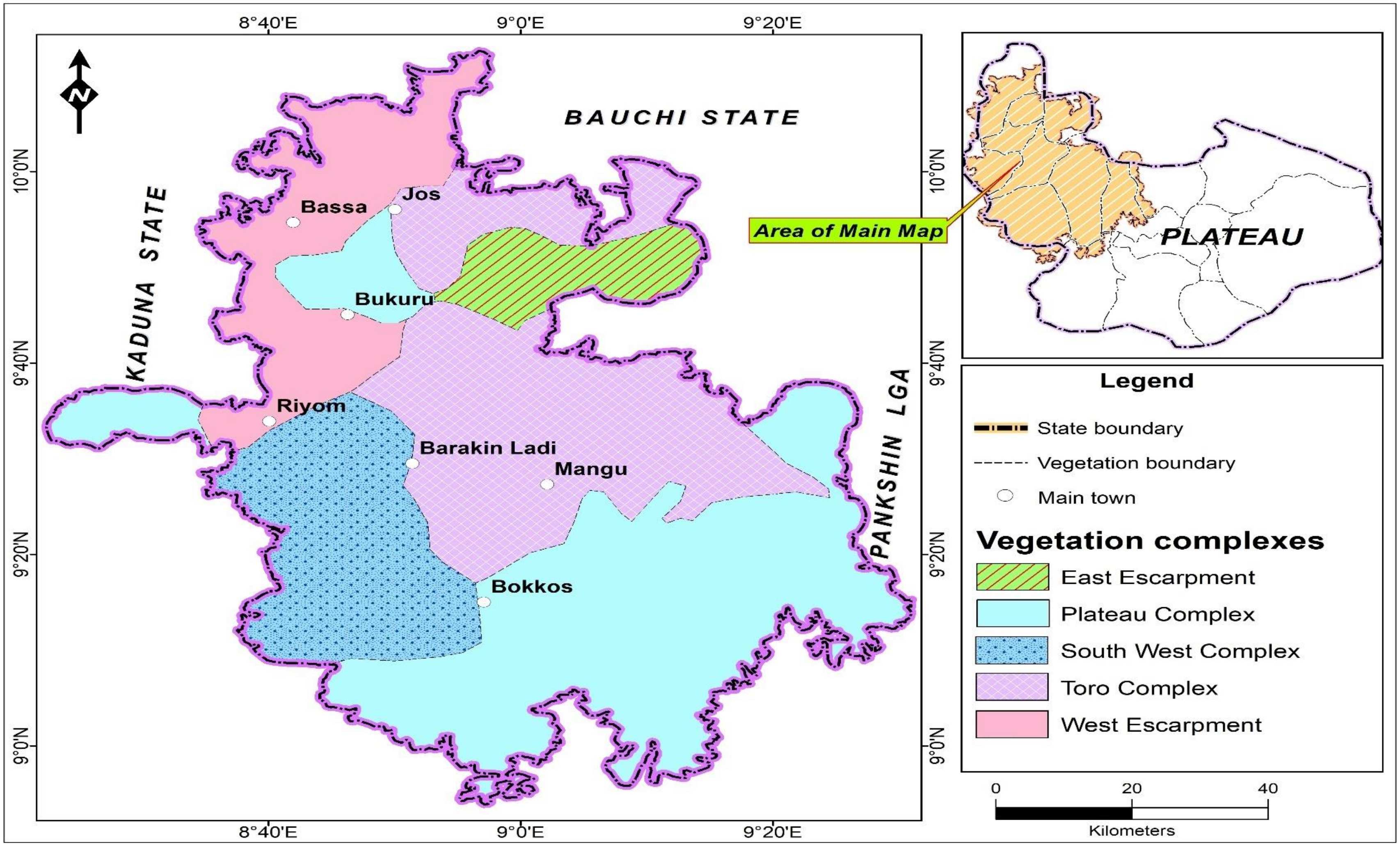

Figure 3.2: Vegetation complexes of the Jos Plateau (Modified from Hill, 1978)

3.4.5 The alluvial complex

Here, riparian woodland predominates.

3.5 Land use

3.5.1 Density and distribution

In terms of density of cultivation, there are areas with 60% or more cultivation, 59 - 35% cultivation, 34 - 10% cultivation and areas with less than 10% cultivation (Hill, 1978). Areas with 60% or more cultivation witness of prolonged cultivation with less fallow period. There is a considerable pressure on the land owing to population pressure. These areas are considered unsuitable for large mechanized farming projects due to the problems of land tenure and population displacement. A significant part of the project area falls in the category. Amongst such areas are those around Vom, Ta Hoss and Barakin-Ladi. Places with 59 - 35% cultivation, maintain a balance between the existing farming systems and available land. Some land around Bokkos in the study area, falls in this class.

Extensive, unused land, suitable for grazing, mechanized farming and resettlement schemes often abound under such land, provided other factors are favourable. Places with 34 - 10% cultivation, either have a significant amount of areas unsuitable for crops or there are fallow areas. Only a little portion of the study area falls under this class.

Low population characterise places with less than 10% cultivation and there is ample grazing land especially in the wet season. There is space for mechanized farming and resettlement schemes provided other factors are suitable. The study area has very little land falling in this class. Only the extensive areas of land in the hilly places near the boundaries have less than 10% cultivation. In terms of distribution of cultivation, intensive cultivation occurs over much of the Plateau especially in the basaltic areas of Riyom, Panyam, Vom and Miango. North east of Mangu also experiences intensive farming.

3.5.2 Farming systems

The agriculture of Jos Plateau has been described by Gosden (1980). It consists rain-dependent farming and small holdings. Acha (*Digitaria exiles*), is the main food crop and Acha system is the farming system.

Burlus millets, usually transplanted, follows acha. Other crops include finger millet and sorghum. Maize is popular in the southern part. Sweet potato, cocoyam and yams are cultivated for food. The sale of excess food crops fetches some cash. Vegetables cultivated in wet areas or with simple irrigation in the dry season, constitute a valuable source of income. Irish potatoes and maize are frequently grown for sale in the south and the practice is becoming increasingly popular. Cultivation by hand is still the popular practice but the use of tractor hire services is on the increase and there is isolated use of draught animals. Bulrus millet, Trish potato, finer millet and maize are grown on ridges while acha is normally cultivated on big ridges, cocoayam is also cultivated on elevated, large beds.

In most intensively cultivated areas such as Riyom, Ta-hoss, Vom, Miango and Mba, cultivation is continuous or for long periods and fallows periods are not more than two years. Four-year continuous cropping is followed by four or five-years fallow periods, in less intensively cultivated areas. Soil fertility is maintained through the application of manures and the employment of short fallow periods.

A large number of cattle is kept through the year most of which belong to the Fulanis while others belong to farmers. Farmers also keep some Muturu cattle. In the dry season, many of the Fulani cattle move to places with water and grass in the flood plains of River Benue and its tributaries.

There are slight differences within the main farming system because of ethnic, climatic or physical differences. There are below-subsistence places, in the northern part of Jos Plateau, in places such as Borno/Katanya by Lmainga/Forbore. Incomes from the farm have to be augmented with other jobs especially from tin mining. Low yields from the areas could be due attributed to prolonged nutrient mining of soils with low fertility. With only little use of fertilizers, the soils have lost their fertility. In Miango, Gindiri, Gwaras, Rim, Ta-Hoss and Chemso, farming meets the family needs but a little surplus is sold. Much of the land is tilled in these places. The low nutrient status of the soils shows yield is poor, limited use of fertilizers and a short fallow, indicate that the chance of enhancing the fertility of the soils is slim.

3.5.3 Open grazing

The Plateau has a unique advantage for cattle rearing. It receives more rains than the adjacent low land and it is tse-tse fly free throughout the year. However, opencast mining, has greatly reduced the available land for cattle rearing.

3.5.4 Forestry

Forestry activities in the region have been discussed by Hill (1978). A larger part of the rolling surface is without trees due to shifting cultivation and browsing cattle. The fragmented area marking the boundary of the region in the south and west, houses most of the forest reserves. Only a limited number of forest reserves are on the Plateau surface due to the shortage of land. There are mines reclamation areas planted to eucalyptus by the miners Reclamation unit. In addition, there are plantations commonly planted to Eucalyptus. There is also the practice of preserving economic trees normally found in the settlements, among rocks. *Khaya grandifolia* and *Canarium schweinfurthii* are common species.

3.5.5 Mining

Open cast tin mining has disturbed and degraded a large area of land on the Jos Plateau (Hill, 1978). Necessary law was made in 1945, stipulating a minimum of 70% rehabilitation by mining companies for a lease to be handed off. Some leases handed off before 1945 still requires rehabilitation. A large area of land is yet to be reclaimed because the miners are unwilling to hands off the leases because there are still some deposits of tin that could be profitable if price improves. The Mines Land Reclamation Unit (MALRU) established to rehabilitate leases prior to 1945 and together with the Department of Forestry, rehabilitate all degraded land through by planting trees. However, due to lack of staff and equipment, large areas of land abound that are yet to be reclaimed or planted. The practice of leveling the degraded land with heavy machinery compacts the soil and reduces growth of the trees.

Again, the excavations form reservoirs for water mainly used by the mining companies. Some of the reservoirs provide irrigation water for the growing of vegetables during the dry season. One unfortunate aspect of the reservoirs is that a number of lives have been lost in them by drowning during fishing or swimming.

3.5.6 Erosion

The special erosion problem of the Jos Plateau, has been reported by Jones (1975). He documented about 7,250 km of gully amounting to 100 million tons of soil lost. The gully is due to the high natural soil erodibility, tin mining, over grazing and bad tillage practices. Two prominent gullies in the study area are the Heipang gully and the Kuru gully. Sheet erosion too devastating on the Plateau.

3.6 Field studies

A reconnaissance survey of the Jos Plateau was undertaken. An area covering parts of Jos South, Riyom and Barkin Ladi Local Government Areas was selected for the collection of soil and rock samples. In the project area, soil management practices and other cultural practices are relatively uniform. The important crops are Irish potatoes, maize, millet, sorghum, acha (Hungry rice), cocoyam, sweet potatoes and a variety of vegetables.

Location of sites for the sinking of soil profile pits and the collection of soil and rock samples were based on three major and widespread parent materials on the Jos Plateau viz: Basalt, Granite and Unconsolidated deposits, which account for most of the soils used in agricultural production. Two toposequences of soils formed on each of the three parent materials were selected for sampling. Auger points information, visible rock types, physiography and vegetation, were used in the site selection for the soil profile pits. Five soil profile pits were dug in each toposequence at the crest, upper slope, middle slope, lower slope and valley bottom positions, along a line perpendicular to the crest of the landscape. Ten soil profile pits were dug on soils formed from each of the three parent materials; bringing the total number of soil profile pits to thirty (30). The profile pits were dug to the depth of at least 200 cm except where obstacles (lithic contacts, water table, etc.), were encountered. The soil profile pits from the first toposequence of the soils formed on Basalt were given identification numbers viz: JP-BST1-1 (Crest), JP-BST1-2 (Upper slope), BST1-3 (Middle slope), BST1-4 (Lower slope), BST1-5 (Valley bottom). Soil profile pits from the second toposequence of soils formed on Basalt were similarly given identification numbers as: JP-BST2-1 (Crest), BST2-2 (Upper slope), BST2-3 (Middle slope), BST2-4 (Lower slope), BST2-5 (Valley bottom).

Similarly, soil profile pits in respect of soils formed on Granite were given identification numbers as: JP-GNT1-1 (Crest), JP-GNT1-2 (Upper slope), JP-GNT1-3 (Middle slope), JP-GNT1-4 (Lower slope), JP-GNT1-5 (Valley bottom); JP-GNT2-1 (Crest), JP-GNT2-2 (Upper slope), JP-GNT2-3 (Middle slope), JP-GNT2-4 (Lower slope), JP-GNT2-5 (Valley bottom). There were five (5) soil profile pits per toposequence.

The soil profile pits in respect of soils formed on Unconsolidated deposits were given identification numbers as: JP-UDP1-1 (Crest), JP-UDP1-2 (Upper slope), JP-UDP1-3 (Middle slope), JP-UDP1-4 (Lower slope), JP-UDP1-5 (Valley bottom); JP-UDP2-1 (Crest), JP-UDP2-2 (Upper slope), JP-UDP2-3 (Middle slope), JP-UDP2-4 (Lower slope), JP-UDP2-5 (Valley bottom).

Samples of soils were collected from each pedogenic horizon of the soil profile pits. Samples of rock were collected from the soil profile pits as well as from the surface of the immediate surroundings. The samples were collected in clean, new polythene bags, labelled and stored in a well-ventilated apartment in the laboratory for processing and analysis.

3.7 Laboratory Studies

3.7.1 Parent rock characteristics

3.7.1.1 Rock texture

Texture of rocks were determined both visually and with the preparations of thin sections of the rocks. Pictures of the rocks were taken with a camera while those of the thin sections preparations of the rocks were taken with a camera through a petrographic microscope in accordance with the procedure described by Gribble (1984), to reveal the structures (component minerals and sizes of their cross sections). Fresh (rock) samples were trimmed to fit on a glass slide, the trimmed surface was lapped on a glass plate using water and silicon carbide 600 grits, this was done so as to have a very smooth surface for bonding with the glass slide, one surface of the glass slide was also lapped and made smooth for bonding with the sample. The sample was then bonded to the glass slide using expoxy on a hot plate and allowed to bond for 24 hours, the sample was then trimmed to 50 micron on the glass slide using the cut-off saw machine and later transferred to the lapping plate and lapped to 30 micron using silicon carbide and water; the slide was then studied under the petrographic microscope, revealing the cross sections of the crystals of the component minerals of the rock in focus. The picture of the revealed structure was taken with a camera.

3.7.1.2 Rock colour

Colours of parent rocks were determined through careful observations and with the aid of a colour chart (Munsel colour chart). Rock colours are helpful in the identification of rocks and in determining the richness or otherwise of rocks, in minerals.

3.7.2 Soil physical characteristics

Percentage of gravel

Total bulk sample taken from the field was weighed after which it was passed through a 2 mm sieve to separate the fine earth from the gravel. The gravel weight was recorded. The weight of gravel was subtracted from the weight of the bulk soil (Udo *et al*, 2009. The percentage of gravel was determined thus:

$$Percentage\ gravel = \frac{Weight\ of\ gravel}{Weight\ of\ bulk\ soil} \times 100 \ldots 3.1$$

Particle size distribution analysis

Particle size distribution was determined in accordance with the method by Day (1965); whereby the gravel contents (g) were determined by direct sieving and weighing; the sand, silt and clay were determined using the Boyoucous hydrometer with sodium Hexametaphosphate (calgon) used as the dispersing agent. Progressive time intervals were used to determine the sizes and amounts of the settling particles. Hydrometer readings were taken after 40 seconds and after 2 hours respectively after inverting the Bouyoucos cylinder several times and placement on the table each time. The reading obtained after 40 seconds indicated the grams of silt and clay in the suspension while the reading obtained after 2 hours indicated the grams of clay in suspension.

The weight of sand (g) was obtained by subtracting the weight of silt and clay (g) from the weight (g) of the soil sample used. The weight of silt was obtained similarly by difference. The percentages of sand, silt and clay in the soil sample were calculated accordingly.

Necessary corrections were made on the hydrometer readings based on the temperature of the suspension and the need to compensate for the added dispersing agent.

Bulk density

Bulk density was carried-out following the procedures by Anderson and Ingram (1993);
One - two centimeter of surface soil was removed from the level area where sample was to be measured; a 5cm diameter thin-sheet metal-tube of known weight (W_1) and volume (V) was inserted 5cm into the soil surface. The soil was excavated from around the tube and the soil beneath the tube bottom was cut. Excess soil was removed from the ends using a knife. The sample was then put in the oven and allowed to dry at 105° C for 2 days and weighed (W_2).
The bulk density was calculated as:

$$Bulk\ density = \frac{W_2 - W_{1\,(g/cm^3)}}{V} \ldots 3.2$$

Where:
W_1 is the weight of the empty metal tube (core sampler)
W_2 is the weight of the metal tube and the oven dried soil.
V is the volume of the metal tube.

3.7.3 Soil chemical characteristics

Soil reaction

Soil pH in water, was determined in 1:1 soil: liquid paste in accordance with the procedure by Udo *et al.* (2009). Twenty grams of air-dry soil was weighed into a 50 ml beaker and 20 ml of distilled water was added and allowed to stand for 30 minutes. The soil: water suspension was stirred with a glass rod and the electrodes of the pH meter were inserted into the partly settled suspension and the pH measured.

Exchange acidity

Exchange acidity was determined by the KCl extraction method following the procedure described by Udo *et al.* (2009). Five grams of the air-dry soil was weighed into a 50 ml centrifuge tube and 30 ml of 1M KCl was added and the centrifuge tube covered with a stopper and the mixture shaken for 1hr in a reciprocating shaker. The mixture was then centrifuged for 15 minutes at 2,000 rpm and the clear supernatant decanted into a 100 ml volumetric flask. Another 30 ml of MKCl was added to the same soil sample, shaken, centrifuged and the clear supernatant decanted into the same volumetric flask. The process was repeated a third time and the volume made to mark with 1M KCl. Twenty-five mililiters of KCl extract was pipetted into a 250 ml Erlenmeyer flask, approximately 100 ml distilled water was added, then 5 drops of phenolphthalein indicator was added and the solution was titrated with 0.01M NaOH to a permanent pink end point, with alternate stirring and standing.

One drop of 0.01M HCl was added to the same flask to bring the solution back to the colourless condition, then 10 ml of NaF was added and 1 or 2 drops of indicator and the solution was titrated with 0.01M HCl until the colour of the solution disappeared.

The total amount of acidity (H+A1), and the exchangeable A1, were determined from the titre values why the exchangeable H. was obtained by subtracting the exchangeable A1 from the total acidity.

Organic carbon

Organic carbon was determined using the Walkley-Black wet oxidation method following the procedure described by Udo *et al*. (2009). One gram of 0.5 mm Erlenmeyer flask, 10 ml of 1N $K_2Cr_2O_7$ Was pipetted into the flask and the flask was swirled gently to disperse the soil. 20 ml of Concentrated H_2SO_4 was rapidly added into the flask followed by vigorous swirling for one minute and the flask was allowed to stand on an asbestos sheet for about 30 minutes. 100 ml of distilled water was then added and the flask allowed to stand for another 30 minutes. Three - four drops of Barium Diphenylamine Sulphonate indicator were added into the flask and the mixture was titrated with 0.5N ferrous sulphate solution to red end point. The procedure was repeated for the blank titration but without soil. Percent organic carbon was calculated as follow:

$$\%\ Organic\ Carbon = \frac{N(V_1 - V_2)\ 0.3f}{W} \ldots 3.3$$

Where:

N = Normality of ferrous sulphate solution

V1 = ml ferrous ammonium sulphate required for the blank

V2 = ml ferrous ammonium sulphate required for the sample
W = mass of sample gram
f = correction factor = 1.33
% organic matter in soil = % Organic carbon x 1.729

Total nitrogen

The total percentage Nitrogen was determined by the macro-kjeldahl Method, in accordance with the procedure described by Udo *et al*. (2009), whereby the nitrogen in the sample was converted to ammonium (NH_4^+) through digestion with concentrated sulphuric acid (H_2SO_4), mercury catalyst and Potassium Sulphate (K_2SO_4). The ammonium nitrogen was determined from the amount of ammonia liberated when the digest was distilled with the 10 M N_aOH and the distillate collected was titrated with 0.01 M standard HCl, using H_3BO_3 indicator. Five grams of the soil sample, 20 ml of distilled water, 1 tablet of mercury catalyst, 10g K_2SO_4 and 30 ml of conc. H_2SO_4 were used in the digestion. About 150 ml of the distillate was collected for titration. The colour change at the end point was from green to pink.
The %N of the soil was calculated as follows:

$$\%N = \frac{T \times M \times 14}{wt. of\ soil\ used} \times 100 \ldots 3.4$$

Wherer:
T = titre value
M = molarity of HCl

Available phosphorus

Available phosphorous was evaluated by the Bray 1 method in accordance with the procedure by Bray and Kurtz (1945). Three grams of air-dried soil (passed through 2 mm sieve) was weighed into a 50 ml centrifuge tube 20 ml of extracting solution (Bray P-1 extracting solution) was added. The suspension was shaken for 1 minute on a mechanical shaker and then centrifuged for 15 minutes at 2,000 rpm. The clear solution was decanted into an acid-washed container. The phosphorus in the extract was determined with a spectrophotometer and the absorbance or transmittance obtained was matched with the corresponding P concentration on a standard curve prepared from standard P solution of known concentration.

Exchangeable cations

Exchangeable cations were determined by the batch method in accordance with the procedure described by Udo *et al* (2009). Five grams of air-dried soil was weighed into a 50 ml centrifuge tube, 30 ml of 1M NH_4OAC solution was added and shaken in a mechanical shaker for 2 hours. The content was centrifuged for 15 minutes at 2000 rmp and the clear supernatant was carefully decanted into a 100 ml volumetric flask. Another 30ml aliquot of NH_4OAC solution was added and shaken for 30 minutes, centrifuged and the leachate transferred to the same volumetric flask as before. The process was repeated a third time and the leachate was again transferred to the same volumetric flask and the volume made to mark with 1M NH_4OAC solution. Calcium and Magnesium in the leachate were determined with an Atomic Absorption Spectrophotometer while Na and K were determined with a flame photometer.

Base saturation

Base saturation percentages for the soils were determined by dividing the total exchangeable bases (Calcium, Magnesium, Potassium, Sodium) of the soils by the effective cation exchange capacity of the soils (Meq/100 g soil) and multiplying the results by 100.

Effective cation exchange capacity

Effective Cation Exchange Capacity was determined by the summation method involving NH_4OAC exchangeable bases plus the KCl exchange (able) acidity, in accordance with the procedures described by Udo *et al*. (2009). Five grams of air-dry soil was weighed into a 50 ml centrifuge tube, 30 ml of 1M KCl was added and the centrifuge tube was tightly covered with a rubber stopper and shaken for one hour on a reciprocating shaker. The content was centrifuged at 2000 rpm for 15 minutes and the clear supernatant was carefully decanted into a 100 ml volumetric flask. Another 30 ml of 1M KCl was added to the same soil sample and shaken for 30 minutes, centrifuged at 2000 rpm for 15 minutes and the clear supernatant decanted. The process was repeated a third time and the clear supernatant was again decanted into the same volumetric flask and the volume made up to mark with 1M KCl.

Twenty-five mililiters of 1M KCl extract was pipetted into a 250 ml Erlenmeyer flask, approximately 100 ml of distilled water was added and then 5 drops of phenolphthalein indicator; the solution was titrated with 0.01 M NaOH to a permanent pink end point, with alternate stirring and standing. The amount of base used was equivalent to the total amount of acidity (H+Al) in the aliquot taken.

Again, 5 g of air-dry soil was weighed into a 50 ml centrifuge tube; 30 ml of 1M NH_4OAC solution was added and shaken in a mechanical shaker for 2 hours. The content was centrifuged for 15 minutes at 2000 rpm and the supernatant was carefully decanted into a 100 ml volumetric flask. Another 30 ml aliquot of NH_4OAC solution was added and shaken for 30 minutes centrifuged and the leachate transferred to the same volumetric flask as before. The process was repeated a third time and the leachate was again transferred to the same volumetric flask and the volume made to mark with 1M NH_4OAC solution. Ca and Mg in the leachate were evaluated with Atomic Absorption Spectro-photometer, Na and K with a flame photometer.

The Effective Cation Exchange Capacity (ECEC), was obtained by adding the Exchange Acidity to the Total Exchangeable Bases

Available iron, manganese, copper, zinc

Available iron, manganese, copper and zinc were determined by the Hydrochloric acid extraction method, in accordance with the procedure described by Udo *et al*. (2009). Five grams of soil was weighed into a plastic bottle, and 50 ml of 0.1M HCl was added and the suspension shaken for 30 minutes in a reciprocating shaker. The suspension was filtered through whatman No. 42 filter paper and the Fe, Mn, Cu and Zn in the solution were determined with an atomic absorption spectrophotometer.

3.8 Soil classification

Soil classification was done according to the USDA (2014) soil taxonomy and the WRB 2014 soil classification systems. The properties of the soils were compared with those of duly described, relevant classes in the two soil classification systems and the classes that best reflected the properties of the soils in focus, were selected as the classes of the soils.

3.9 Land Capability Classification (LCC)

Productive potential of the soils studied was evaluated according to the Land capability classification system of the United States Soil Conservation Service. The qualities of the land of which the soils are components were assessed with those of the duly described capability classes of the system in focus and the soils were assigned the capability classes that best captured the qualities of the land housing the soils. The limitations or constraints responsible for placing the soils in the specific capability classes were indicated. Each of the land capability classes have subclasses with the same kind of dominant limitations for agricultural uses; the limitations recorgnised in the subclasses are risk of erosion (e), wetness, drainage or overflow (w); root-zone limitations (s), and climatic limitations (c). Table 3.2 presents the Land capability classification system of the United States Soil Conservation Service.

3.10 Land Suitability Classification (LSC)

Land suitability classification was done for maize and Irish potato for the soils in accordance with the system by (Sys, 1985). Land suitability classification was also done for citrus for the soils using the system employed by (Okafor, 2016). The qualities of the land of which the soils are integral parts, were painstakingly matched with the Land requirements for the affected crops and suitability classes were all allocated to the land based on the outcomes of the matching; the most limiting factor, determining the suitability classes of each land for the specific crop and also taking into consideration, temporary and permanent limitations.

Land requirements for the cultivation of maize, Irish potato and citrus, are as presented in Tables 3.3, 3.4 and 3.5 respectively.

3.11 Fertility capability classification

The fertility capability classification of each soil investigated was done in accordance with the recommendations by Sanchez *et al*., (2003). Top and sub soil texture and modifiers linked to soil reaction, soil physical, biological and mineralogical properties were identified and employed to classify the soils. Top soil texture considers 0-20cm depth and the sub soil texture considers any textural change within 50cm of the top soil. The constraints to soil fertility examined were: soil moisture stress, low nutrient reserves, high erosion risk, aluminium toxicity, high phosphorus fixation and waterlogging. Others included high leaching potential, cracking clays, gravel, shallow to rock, saline, sodic, amorphous/volcanic and high organic content. Table 3.6 presents the fertility capability soil classification system according to Sanchez *et al*., (2003).

Table 3.2: Land Capability Classes of the United States Conservation Service.

Classes	Characteristics and safe use of soils in the class
I	Soils have few limitations that restrict their use. They can be cropped intensively, used for pasture, range, woodlands or wildlife preserves. Soils are deep, well drained; nearly level land. Soils have high water holding capacity, need only ordinary crop management practices to maintain their productivity.
II	Soils have some limitations reducing their choice of plants or requiring moderate conservation practices. Soils can carry same crops as class I but require some conservation practices. Use of the soils may be limited by (i) gentle slopes, (ii) moderate erosion hazards, (iii) inadequate soil depth, (iv) less than ideal soil structure and workability, (v) slight to moderate alkali or saline conditions, (vi) restricted drainage. Management practices may include terracing, strip cropping, contour tillage, rotations with grasses and legumes, and grasses water ways.
III	Soils with severe limitations reducing plants choice or requiring special conservation practices or both. Land can support same crops as classes I and II. Extent of clean, cultivated land is restricted, just as the choice of crops to be used. Limitations results from (i) moderate steep slopes, (ii) high erosion hazards, (iii) very slow water permeability, (iv) shallow depth and restricted root zone, (v) low water holding capacity, (vi) low fertility, (vii) moderate alkali or salinity, (viii) unstable soil structure. Conservation practices employed for class II land, should be adopted and often in combination with restrictions in crops choice; tile or other drainage systems may be required too.
IV	Soils could be used for cultivation but with severe limitations on crops choice; very careful management may be needed. Alternative uses of the soils are more limited than for class III. Close-growing crops should be used while row crops should be avoided. Most limiting factors on the soils could include one or more of: (i) steep slopes, (ii) susceptibility to severe erosion, (iii) severe past erosion, (iv) shallow soils, (v) low water-holding capacity, (vi) poor drainage, (vii) severe alkalinity or salinity. Need for more frequent application of soils conservation measures in combination with severe limitations in crops choice.
V	Soils in class V to VIII are generally not suited to cultivation. Soils in clacc V are limited in safe use by constraints other than erosion hazards. Such include: (i) subject to frequent stream overflow, (ii) too short growing season, (iii) stony or rocky soils, (iv) ponded areas where drainage is impracticable. There is the possibility of improved pastures.
VI	Soils with extreme limitations, restricting use mainly to pasture or range woodland or widelife. Limitations are same with those of class IV land but are more rigid.
VII	Soils with very severe limitations, restricting use to grazing, woodland or wildlife. The physical limitations are same as for class VI but so strict that improvement of pasture is impracticable.
VIII	Soils should not be used for any kind of commercial cultivation; use is limited to recreation, wildlife, water supply or aesthetic purposes.

Source: Brady, 1974

Table 3.3: Land requirements for maize (Modified from Sys, 1985)

Land Qualities	Suitability Classes				
	S1	S2	S3	N1	N2
Climate (C)					
Annual rainfall (mm)	750 – 1,600	600 – 1,800	> 500	-	any
Length of growing seasons (days)	130 – 270	110 – 325	90 - 345	-	any
Mean temperature growing season (°C)	18 – 32	>16	>14	-	any
Mean relative humidity growing season (%)	24 – 75	-	-	-	-
Topography (t)					
Slope (%)	< 4	< 8	< 16	< 16	any
Wetness (w)					
Flooding	F0	F0	F0 or less	F0 or less	any
Drainage	Good	moderate or better	Poor aeric	Poor	poor
Physical soil characteristics (s)					
Texture/Structure	C+60s to SCL	C + 60v to LS	C + 60v to FS	C + 60v to FS	Cm to cS
Coarse fragments (%)	< 15	< 35	< 55	< 55	any
Soil depth (cm)	>75	>50	>20	>20	any
Fertility characteristics (f)					
Apparent CEC (meq/100g clay)	>16	any (-)	Any	-	-
Base saturation (%)	>35	>20	Any	-	-
Organic matter (% C, 0 - 15 cm)	>1.2	>0.8	Any	-	-

Table 3.4: Land requirements for Irish potato (Modified from Sys, 1985)

Land Qualities	Suitability Classes				
	S1	S2	S3	N1	N2
Climate (C)					
Monthly rainfall (mm)					
- 1st month	>45	>30	>20	-	any
- 2nd month	>80	>65	>50	-	any
- 3rd month	>80	>65	>50	-	any
- 4th month	>20	any	-	-	-
Mean temperature growing season (°C)	13 – 24	10 - 27	8 – 30	-	any
Topography (t)					
Slope (%)	< 4	< 8	< 16	< 16	any
Wetness (w)					
Flooding	No	no	F1 or less	F1 or less	any
Drainage	moderate or better	imperfect	Poor aeric	Poor	any
Physical soil characteristics (s)					
Texture/Structure	Co to SL	C – 60s to LS	C + 60v to FS	C + 60v to cS	any
Coarse fragments (%) s	< 3	< 15	< 35	< 35	any
D	< 15	< 35	< 55	< 55	any
Soil depth (cm)	> 60	>40	>20	>20	any
Fertility characteristics (f)					
Apparent CEC (meq/100g clay)	>16	any (-)	Any	-	-
Base saturation (%)	> 35	any	-	-	-
Organic matter (%C, 0 - 15 cm)	> 0.8	any	-	-	-

Table 3.5: Land requirements for citrus (Adapted from Okafor, 2016)

Land Qualities	Suitability Classes				
	S1	S2	S3	N1	N2
Climate (C)					
Annual rainfall (mm)	>1200	900 – 1200	700 – 900	700	<500
Relative Humidity (%)	30 - 60	60 – 80	80 – 90	<30, >90	<30, >90
Minimum temperature (°C)	20 - 30	15 – 20	13 – 15	< 13, >30	<13, >30
Maximum temperature (°C)	30 - 35	15 – 30	>35	>35	>35
Soil (s)					
Clay (g/kg)	150 - 250	100 – 150	<100, >400	<100, >400	<100, >400
Texture	SC, CL, SCL, LC, Fine SC, SiC	Coarse SCL, CL, SL	LS	S, C	S, C
Effective soil depth (cm)					
Depth to water table (cm)	100 - 200	80 – 100	50 – 80	< 50	< 50
Drainage	Well drained	Mod – imperfect	Poorly drained	Very poorly drained	Very poorly drained
Gravel (%) 0 – 40 cm	10 - 25	25 – 35	35 – 40	>40	>40
Topography (t)					
Slope (%)	0 - 6	6 – 10	>10	>10	-
Fertility (f)					
pH	5.0 – 6.5	6.5 – 7.0	< 5, >8	<4	<4
Organic matter (g/kg)	16 - 18	16	< 16	< 16	-
ECEC (cmol/kg)	20 - >40	10 – 20	4 – 10	< 4	< 4
Base saturation (g/kg)	800 - > 900	700 – 800	500 – 700	< 500	< 500

SC = Sandy clay; CL = Clay loam; Fine SC = Fine Sandy clay; SL = Sandy loam; LS = Loamy sand; S = Sand; C = Clay; SCL = sandy clay loam; cS = coarse sand; FS = fine sand; S1 = highly suitable; S2 = moderately suitable; S3 = marginally suitable; N1 = currently not suitable; N2 = permanently not suitable; C + 60s = Very fine clay, blocky structure; C – 60s = Clay, blocky structure; C + 60v = Very fine clay, vertisol structure; Cm = massive clay; Co = Clay, oxisol structure.

Table 3.6: Fertility capability soil classification systems

Fertility class and short description	Symbol	Definition and some interpretation
Type: Texture is the plow layer or 0-20cm depth whichever is shallower	S	Sandy top soil: Loamy sands and sands
	L	Loamy topsoil: <35%
	C	Clayey topsoil: > 35% but not loamy sand or sand
	O	Organic soil: 12% organic matter to a depth of 50 cm or more. Histosol and histic group
Substrata type: Used if there is textural change within top 50cm	S	Sandy subsoil
	L	Loamy subsoil
	C	Clayey Subsoil
	R	Rock or other hard root restricting layer within 50 cm
	R^-	As above but layer can be ripped, plowed or blasted to increase rooting depth
Modifiers		
Soil moisture stress	d	Dry season (>3 months)
Low nutrient reserves	k	Less 10% weatherable materials
High erosion risk	e	LC, SC, SL, R
Aluminium toxicity	a	>60% aluminium saturation (pH <4.5) pH 5.5 – 7.2
No major chemical limitations	i	Fixation by Fe and Al oxides
Waterlogging	g	
High leaching potential	e	
Calcareous	b	Micro-nutrients deficiencies
Cracking clays	v	
Gravel	r	
Shallow to rock	r++	
Saline	s	
Sodic	n	
Amorphous, volcanic	x	
High organic content (>30%)	X	
Sulpdic (cat clays)	c	
Low organic carbon saturation (<80%)	m	

Source: Sanchez *et al.*, (2003)

3.12 Statistical analysis

Some key soil characteristics that affect soil fertility and crop production, in respect to the soils formed from the different parent materials (Basalt, Granite and Unconsolidated deposits), were subjected to statistical analysis, using a Completely Randomized Block Design (CRBD), at 5% level of significance and employing Genstat 2005, edition computer programming, to determine whether there were significant differences or not, in the values of the characteristics, between the three soil groupings. The affected characteristics include Organic carbon, Total Nitrogen, Available phosphorus, Effective Cation Exchange Capacity and Exchangeable potassium. Variations in the values of the said characteristics amongst toposequences of soils formed on same parent materials, were also statistically analysed.

CHAPTER 4

RESULTS

4.1 Parent rocks

4.1.1 Rock texture

Granite consists of large crystals visible to the naked eyes, Plate 4.1a shows a piece of granite while Plate 4.1b shows a thin section preparation of granite revealing the cross sections of the crystals and the constituent minerals. Basalt consists of very tiny crystals, not visible to the naked eyes. Plate 4.2a shows a piece of basalt while Plate 4.2b shows the thin section preparation of basalt with the small cross sections of the crystals and the constituent minerals. Plate 4.3 shows a thin section preparation of a little piece of granite picked from one of the profile pits (Profile JP-UDP1-4) of the soils formed on Unconsolidated deposits, showing the cross sections of the crystals and the constituent minerals. The cross sections of the crystals are large which implies that the crystals are large.

4.1.2 Rock colour

Basalt is dark grey; Granite is whitish grey, and light grey or milk brown while Quartz is glassy in colour.

4.2 Soil morphological properties

4.2.1 Soils derived from Basalt

The soils occur on undulating to relatively flat land, depending on their slope positions in the Landscape. Plate 4.4 shows toposequence JP-BST1 of soils formed on Basalt, in Riyom, on the Jos Plateau. Boulders of Basalt scattered all over the land surface are a common feature especially in the Riyom/Ta-Hoss axis. Plate 4.5 shows pieces of Basalt at the crest of toposequence JP-BST1 of soils formed on Basalt in Riyom.

The soils were deep, well drained to imperfectly drained. Soils occurring at the crest, upper slope or mid-slope positions were usually well drained while those occurring in the lower slope or valley bottom positions could be imperfectly drained.

Plate 4.1a: A piece of Granite rock (The large crystals are visible to the naked eyes).

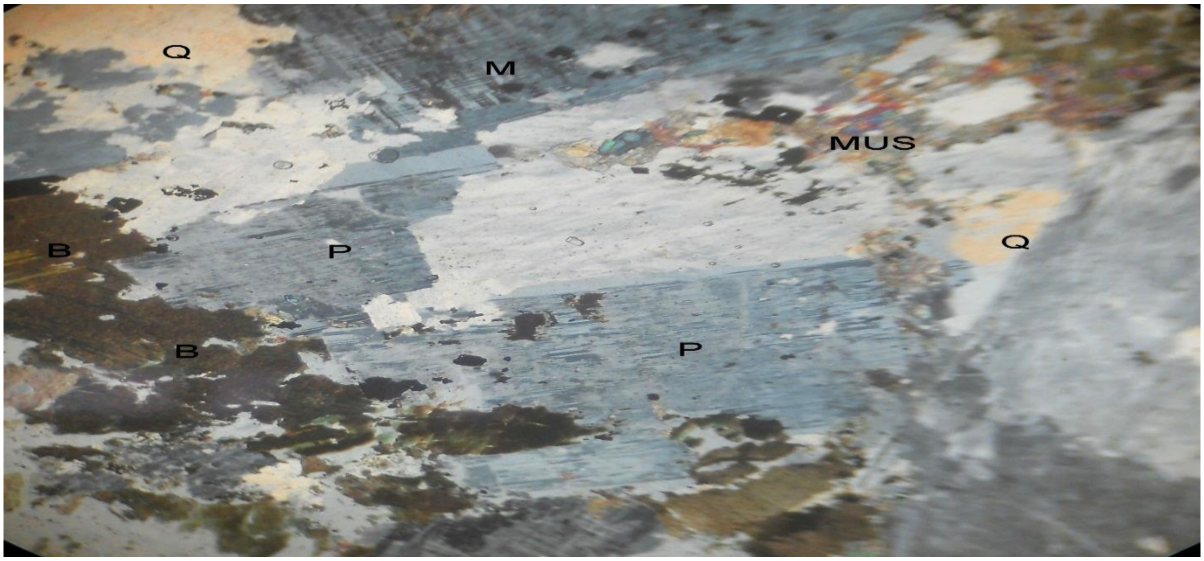

Plate 4.1b: A thin section preparation of Granite, showing the constituent minerals and cross sections of the crystals (The cross sections are large).

B= Biotite, MUS= Muscovite, Q= Quartz, P= Plagioclase

Plate 4.2a: A piece of Basalt (The crystals are not visible to the naked eyes).

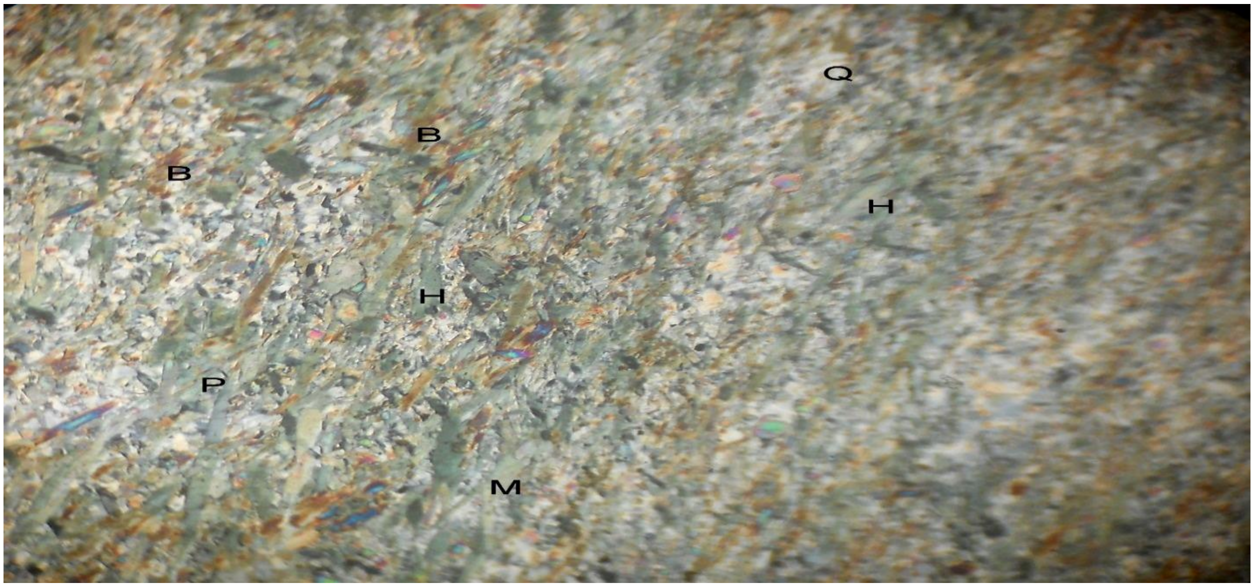

Plate 4.2b: A thin section preparation of Basalt showing the constituent minerals and cross sections of crystals (The cross sections are small).

B= Biotite, MUS= Muscovite, Q= Quartz, P= Plagioclase, H= Hornblend

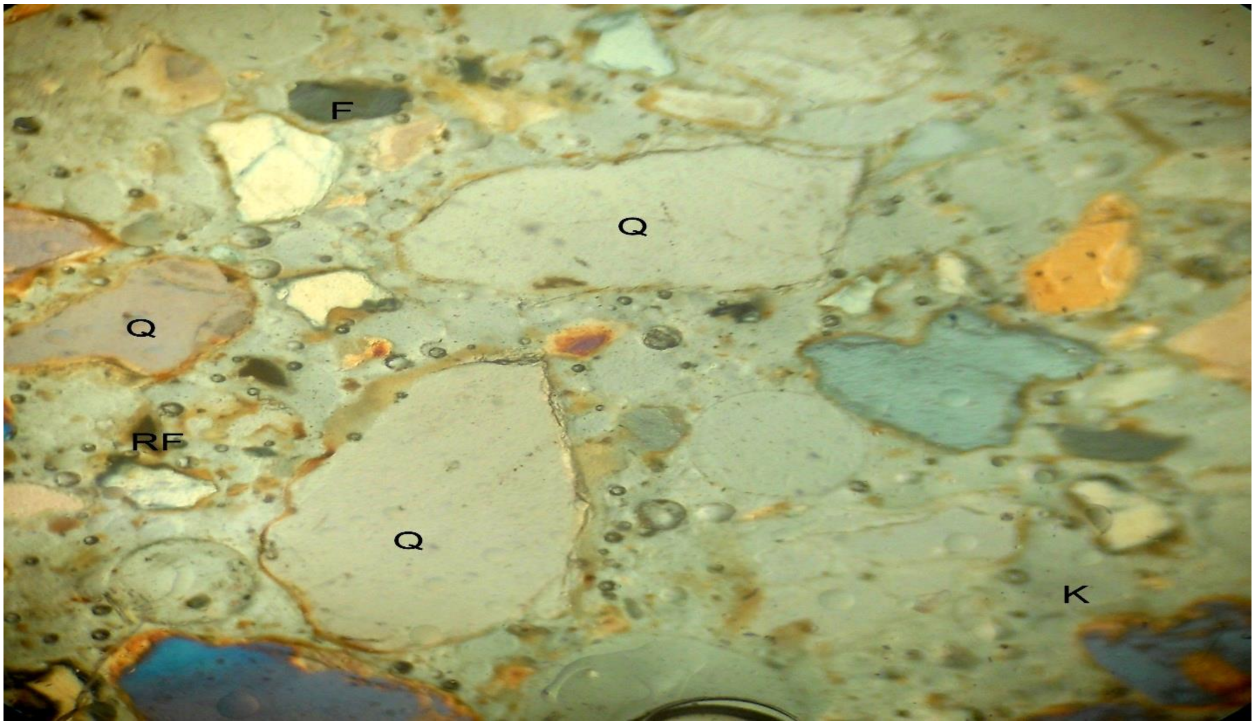

Plate 4.3: A thin section preparation of a little piece of Granite from profile pit JP-UDP1-4, derived from Unconsolidated deposits (The cross sections are large).

F = Feldspar Q = Quartz K = Kaolinite RF = Rock Fragment

Plate 4.4: Toposequence (JP-BST1) of soils derived from Basalt, in Riyom, on the Jos Plateau, Nigeria.

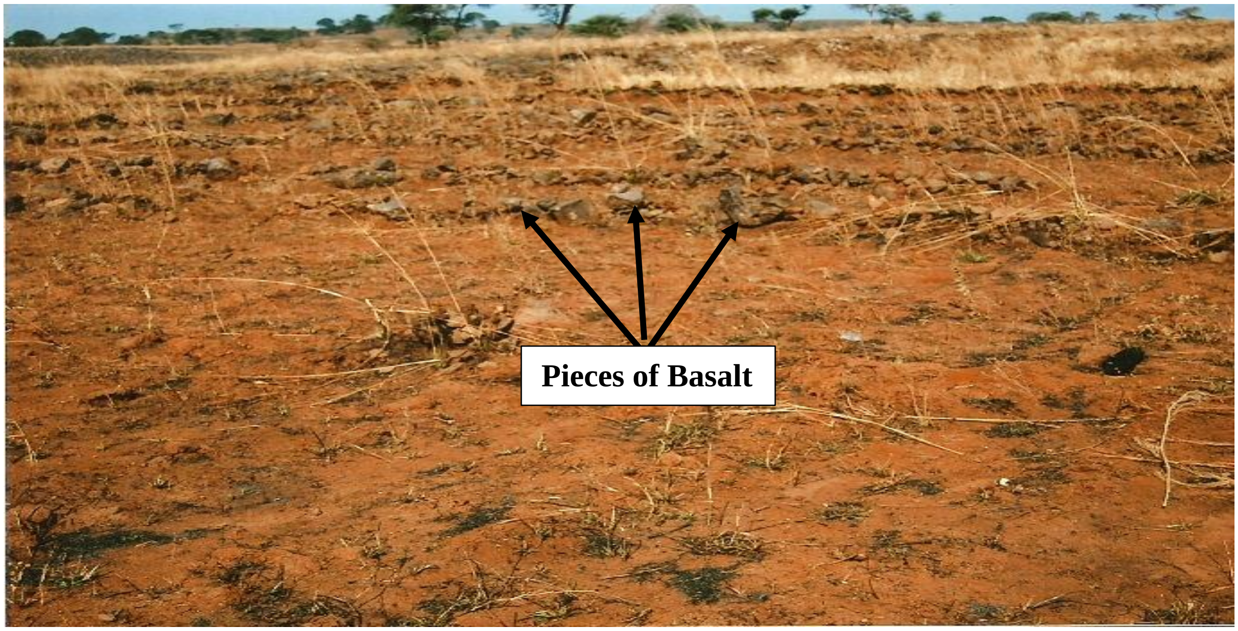

Plate 4.5: Pieces of Basalt at the crest of the toposequence (JP-BST1), of soils derived from Basalts in Riyom, on the Jos Plateau, Nigeria.

Weathered pieces of Basalt were observed in some of the soil profile pits especially in the crest, upper slope or mid-slope positions. Soils in the crest and upper slope positions were often shallow with parent material often encountered at a depth of between 82 cm and 137 cm.

The surface horizons of the soils when moist, had dark reddish brown (5YR 3/3), reddish brown (5YR 4/4), dark brown (10YR 3/3), or dark reddish grey (5YR 4/2) in colour. The sub-surface horizons when moist were reddish brown (5YR 4/4), dark red (2.5YR 3/6), red (2.5YR 5/6) or yellowish red (5YR 4/6). The surface horizons had moderate, medium sub-angular blocky or moderate, medium angular blocky structure while the sub-surface horizons had moderate, medium sub-angular, medium angular blocky or strong, medium angular blocky structure. The surface horizons were Loamy sand, Sandy loam, Loam, Clay loam or Sandy clay loam and Sandy clay in texture. The sub-surface horizons reflected all the textural classes encountered in the surface horizons and clay in addition. An ochric epipedon was common in the soils. Table 4.1 contains morphological properties of some of the soils formed on Basalt. Ten representative profile pits for the soils formed on Basalt, are as described in Appendix 1. Plate 4.6 and 4.7 show some of the soil profile pits dug in the toposequence JP-BST1 of soils formed on Basalt in Riyom while Plate 4.8 shows a profile pit dug in the toposequence JP-BST1-2 of soils formed on Basalt in Vom.

4.2.2 Soils derived from Granite

The soils occured on undulating, gently undulating or relatively flat land, depending on the slope position in the landscape. Granitic hills and outcrops were a common feature in the crest position of the landscape.

Occasionally, a few granitic outcrops could be encountered in the upper slope position. Plate 4.9 shows granitic rocks at the crest of a toposequence (JP-GNT2) of soils formed on Granite at Kasen, near Kuru on the Jos Plateau. The mid-slope, lower slope and valley bottom were usually devoid of rock outcrops. The land was adequately extensive. The soils were deep, well drained or imperfectly drained.

Table 4.1: Morphological properties of some of the soils derived from Basalt

Property	Soils					
	JP-BST1-2	JP-BST2-2	JP-BST1-3	JP-BST2-3	JP-BST1-4	JP-BST2-4
Thickness						
A Horizon	0-20	0-22	0-45	0-42	0-39	0-25
B Horizon	71	>146	92	>138	69	47
Colour						
A Horizon	5YR 4/4	5YR 3/3	5YR 4/3	5YR 3/4	5YR 4/4	5YR 3/3
B Horizon	5YR 4/6	5YR 4/6	5YR 4/4	5YR 4/3	5YR 4/6	5YR 4/3
Texture						
A Horizon	SCL	CL	SCL/LS	L	L	L
B Horizon	SCL	C/CL	L	CL	CL	L
Structure						
A Horizon	mmabk	mmabk	mmsbk	mmabk	Mmsbk	mmabk
B Horizon	mmabk	mmabk	mmsbk	mmabk	Mmabk	mmabk
Concretions						
A Horizon	-	-	-	-	-	-
B Horizon	-	-	-	-	-	-
Stoniness						
A Horizon	2	1	2	1	2	2
B Horizon	2	1	2	3	2	3

Plate 4.6: Profile Pit JP-BST-1, at the crest of toposequence (JP-BST1) of soils derived from Basalt, in Riyom, on the Jos Plateau, Nigeria (Parent material encountered at the depth of 82 cm).

Plate 4.7: Profile Pit JP-BST-3, in the mid slope position of the toposequence (JP-BST1) of soils derived from Basalt, in Riyom, on the Jos Plateau, Nigeria (Parent material encountered at the depth of 137 cm), the soil boundaries are diffuse

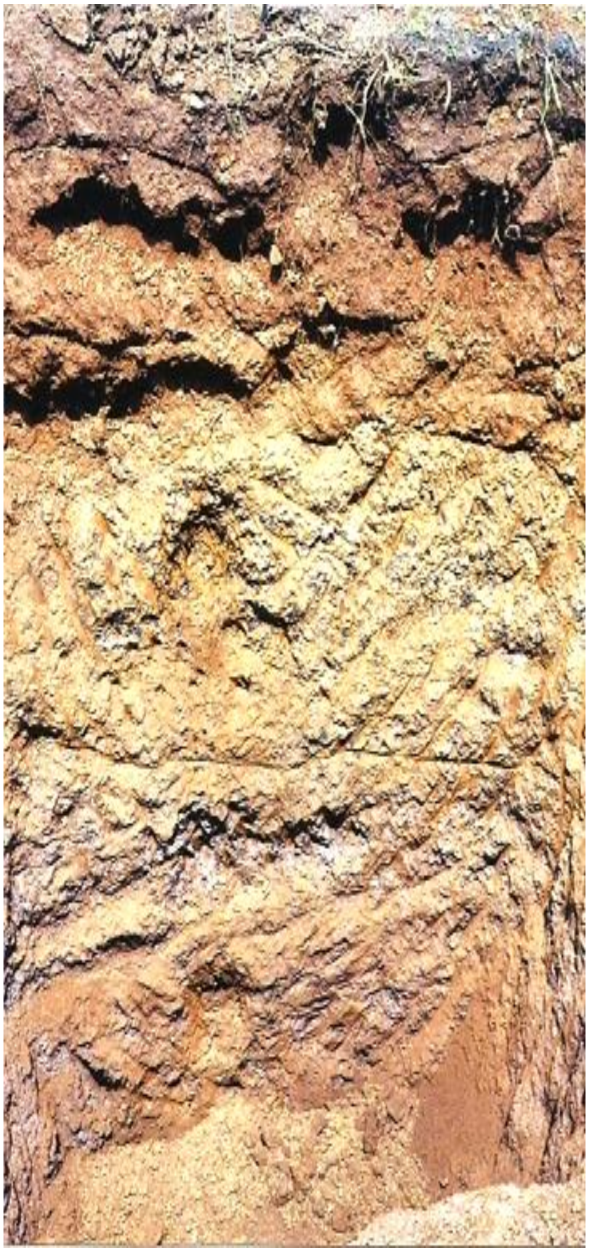

Plate 4.8: Profile Pit JP-BST2-4, at the foot slope position of toposequence (JP-BST2) of soils derived from Basalt, in Vom, on the Jos Plateau, Nigeria (The boundaries are diffuse).

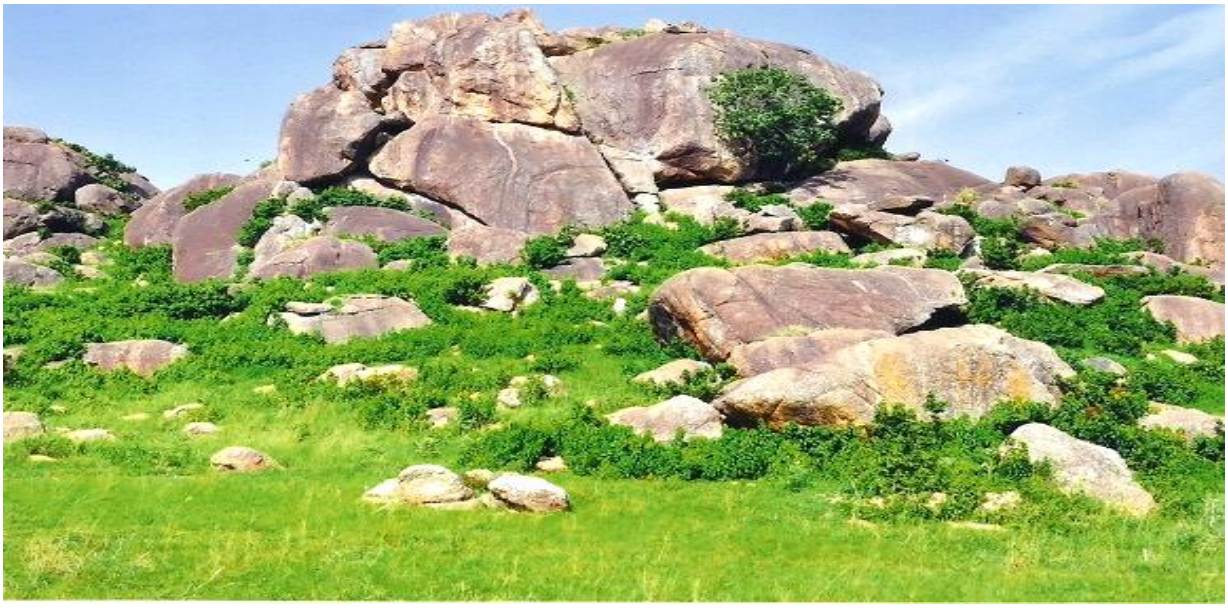

Plate 4.9: Granite rocks at the crest of toposequence (JP-GNT2) of soils derived from Granite, at Kasen, near Kuru, on the Jos Plateau, Nigeria.

Soils in the crest, upper slope or mid-slope positions were usually well drained while those in the lower slope and valley bottom positions were imperfectly drained. The gravels in the soil consisted largely of small pieces of Granite and Quartz.

The surface horizons of the soils were dark brown (7.5YR 4/4), strong brown (7.5YR 5/6), dark yellowish brown (10YR 4/4) or reddish yellow (7.5YR 6/8) in colour. The sub-surface horizons were strong brown (7.5YR 5/8), yellowish red (7.5YR 4/8), red (2.5YR 4/6) or grey (5YR 6/1). The soils had red (2.5YR 4/8), yellowish red (5YR 4/8), reddish yellow (7.5YR 7/8) or strong brown (7.5YR 5/8) mottles. All colours were for the moist soils unless otherwise stated. Some of the soils had plinthite.

The surface horizons of the soils had weak, medium sub-angular blocky, moderate, medium sub-angular blocky, moderate, medium angular blocky or strong, medium angular blocky structure. The sub-surface horizons had moderate, coarse angular blocky and strong, coarse angular blocky structure, in addition to most of the structural classes encountered in the surface horizons. The surface horizons had the texture of Loamy sand, Sandy loam, Loam, Sandy clay loam or Clay loam and Clay. The sub-surface horizons had all the textural classes observed in the surface horizons except Loamy sand. An ochric epipedon and an argillic horizon were common in the soils. Morphological properties of some of the soils formed on Granite is shown in Table 4.2. Plate 4.10 shows the toposequence of soils formed on Granite at Kasen, near Kuru, on the Jos Plateau. Ten representative profile pits for the soils formed on Granite, are as described in Appendix 2. Plate 4.11 shows a soil profile pit dug in a toposequence (JP-GNT1) of soils formed on Granite in Vom while plate 4.12 shows a profile pit dug in the toposequence (JP-GNT2) of soils formed on Granite at Kasen, near Kuru, all on the Jos Plateau.

4.2.3 Soils derived from Unconsolidated deposits

The soils occured on gently undulating or relatively flat land. The slope position within the landscape determines the undulating nature or otherwise, of the land. Rock outcrops were usually rare within the landscape and the land was usually very extensive and bounded by far away hills.

Table 4.2: Morphological properties of some of the soils derived from Granite

Property	Soils					
	JP-GNT1-2	JP-GNT2-2	JP-GNT1-3	JP-GNT2-3	JP-GNT1-4	JP-GNT2-4
Thickness						
A Horizon	0-20	0-13	0-19	0-43	0-4	0-55
B Horizon	>176	69	>181	>142	>194	85
Colour						
A Horizon	7.5YR 4/4	10YR 5/8	7.5YR 4/4	10YR 4/4	10YR 4/4	10YR 6/4
B Horizon	7.5YR 5/8	10R 5/6	7.5YR 5/6	10R 4/8	7.5YR 5/6	5YR 6/1
Texture						
A Horizon	CL	SCL	SCL	SL/SCL	CL	CL
B Horizon	C	L/SCL	C/CL	CL/SCL	C	CL
Structure						
A Horizon	mmsbk	mmsbk	mmsbk	wmsbk	Mmsbk	mmabk
B Horizon	smabk	mmabk	smabk	smabk/mcabk	Smabk	smabk
Concretions						
A Horizon	-	-	-	-	-	-
B Horizon	-	-	-	-	-	-
Stoniness						
A Horizon	2	2	2	1	3	1
B Horizon	3	2	3	2	2	2

Plate 4.10: Toposequence (JP-GNT2), of soils derived from Granite, at Kasen, near Kuru, on the Jos Plateau, Nigeria. The excavated point is the location of soil profile JP-GNT2-1; digging was in progress.

Plate 4.11: Profile Pit JP-GNT1-1, at the crest of toposequence (JP-GNT1), of soils derived from Granite, in Vom, on the Jos Plateau, Nigeria. The dark portion was the shadow cast by the sun on a side of the profile pit.

Plate 4.12: Profile Pit JP-GNT2-5, at the valley bottom of toposequence (JP-GNT2) of soils derived from Granite, at Kasen, near Kuru, on the Jos Plateau, Nigeria. The plough layer was sandy

The soils were deep, well drained or imperfectly drained. The drainage usually changes from the well drained class to imperfectly drained class as one gets to the lower slope and valley bottom positions, from the crest position of the landscape. The gravels in the soils consisted largely of small pieces of quartz and iron concretions.

The surface horizons of the soils were yellowish brown (10YR 5/6), brownish yellow (10YR 6/8), strong brown (7.5YR 5/4) or yellowish red (5YR 4/8). The sub-surface horizons were yellowish brown (10YR 5/8), reddish brown (2.5YR 5/4), strong brown (7.5YR 5/6) or dark yellowish brown (10YR 4/4) and light grey (10YR 7/1). The soils had red (2.5YR 4/6), yellowish red (5YR 4/6), light grey (5Y 7/2) or dark yellowish brown (10YR 4/6) mottles. Some of the soils had plinthite. The surface horizons had weak, medium sub-angular blocky, moderate, medium sub-angular blocky or strong, medium angular blocky structure while the sub-surface horizons had moderate, medium sub-angular blocky, strong, medium sub-angular blocky or strong, medium angular blocky structure. The surface horizons had the texture of loamy sand, sandy loam, loam, sandy clay loam or clay loam and clay.

The sub-surface horizons reflected all the textural classes observed in the surface horizons except clay. Table 4.3 contains morphological properties of some of the soils formed on Unconsolidated deposits. Plate 4.13 is a picture of a toposequence of soils formed on Unconsolidated deposits at Du, on the Jos Plateau. Ten representative profile pits for the soils formed on unconsolidated deposits, are as described in Appendix 3. Plates 4.14 and 4.15 show some soil profile pits dug in toposequence JP-UDP1 and JP-UDP2, of soils formed on Unconsolidated deposits at Du, and Bischi respectively, on the Jos Plateau. Figure 4.1 shows the physiognomy of the soils formed on Basalt in Riyom and of the soils formed on Granite at Kasen near Kuru and that of the soils formed on Unconsolidated deposits at Du near Bisichi. The slope of the soils formed on Basalt more gradual than that of the soils formed on Granite or Unconsolidated deposits.

Table 4.3: Morphological properties of some soils derived from Unconsolidated deposits

Property	Soils					
	JP-UDP1-2	JP-UDP2-2	JP-UDP1-3	JP-UDP2-3	JP-UDP1-4	JP-UDP2-4
Thickness						
A Horizon	0-19	0-18	0-11	0-33	0-33	0-32
B Horizon	>180	98	149	165	>157	>119
Colour						
A Horizon	7.5YR 5/6	7.5YR 5/4	10YR 5/8	10YR 5/4	5YR 5/8	5YR 4/8
B Horizon	7.5YR 5/6	7.5YR 5/6	2.5YR 4/6	5YR 5/6	5YR 4/8	7.5YR 6/8
Texture						
A Horizon	SL	SCL	SCL	SCL	L	L
B Horizon	CL	CL	CL	SCL	CL	CL
Structure						
A Horizon	wmsbk	wmsbk	mmsbk	mmsbk	wmsbk	wmsbk
B Horizon	smsbk	mmsbk	smsbk	smabk	smabk	smabk
Concretions						
A Horizon	-	-	-	-	-	-
B Horizon	-	-	-	-	-	-
Stoniness						
A Horizon	2	2	2	2	2	2
B Horizon	2	2	1	2	3	3

mmsbk = moderate, medium subangular blocky; smabk = strong, medium angular blocky; wmsbk = weak, medium sub-angular blocky; smsbk: strong, medium sub-angular blocky; mmabk = Moderate, Medium Angular Blocky; mcabk: Moderate, Coarse Angular Blocky; SCL = sandy clay loam; CL = clay loam; C = clay; L = loam; SL = sandy loam; LS = Loamy Sand; SCL = sandy clay loam

Plate 4.13: Toposequence JP-UDP1, of soils derived from unconsolidated deposits at Du, on the Jos Plateau, Nigeria.

Plate 4.14: Profile Pit JP-UDP1-3, in the mid slope position, of a toposequence JP-UDP1, of soils derived from Unconsolidated deposits at Du, on the Jos Plateau, Nigeria. The dark portions were shadows cast by the sun.

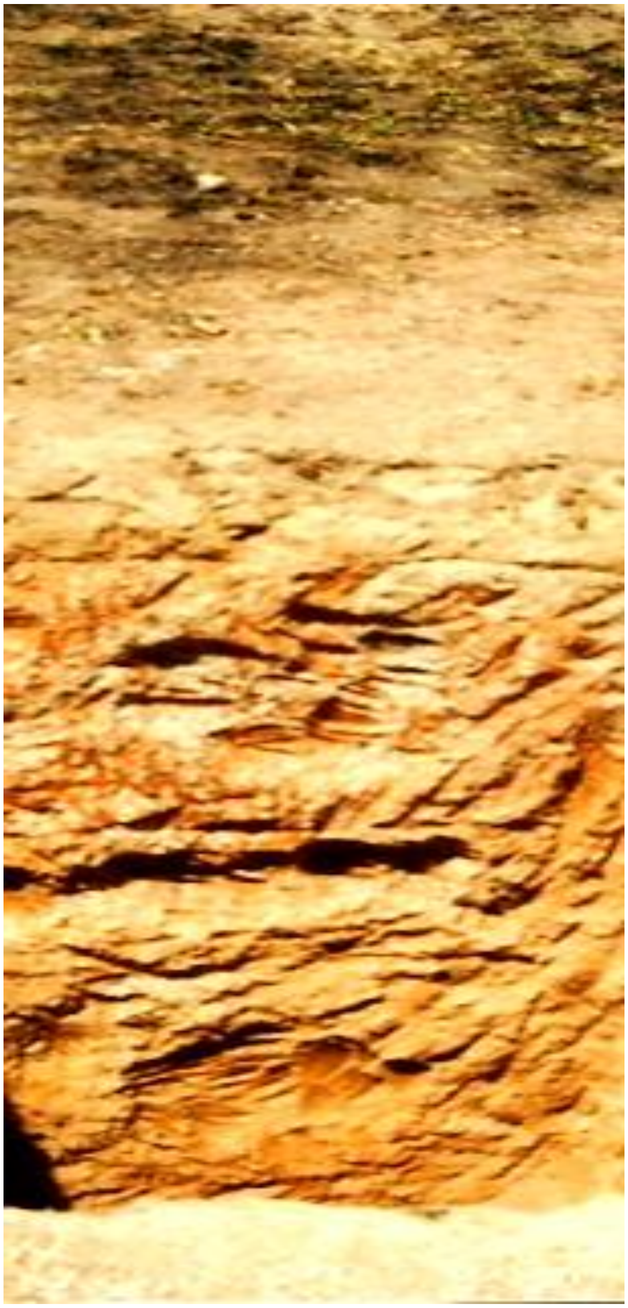

Plate 4.15: Profile Pit JP-UDP2-5, at the valley bottom, of toposequence JP-UDP2, of soils derived from Unconsolidated deposits at Bisichi, on the Jos Plateau, Nigeria.

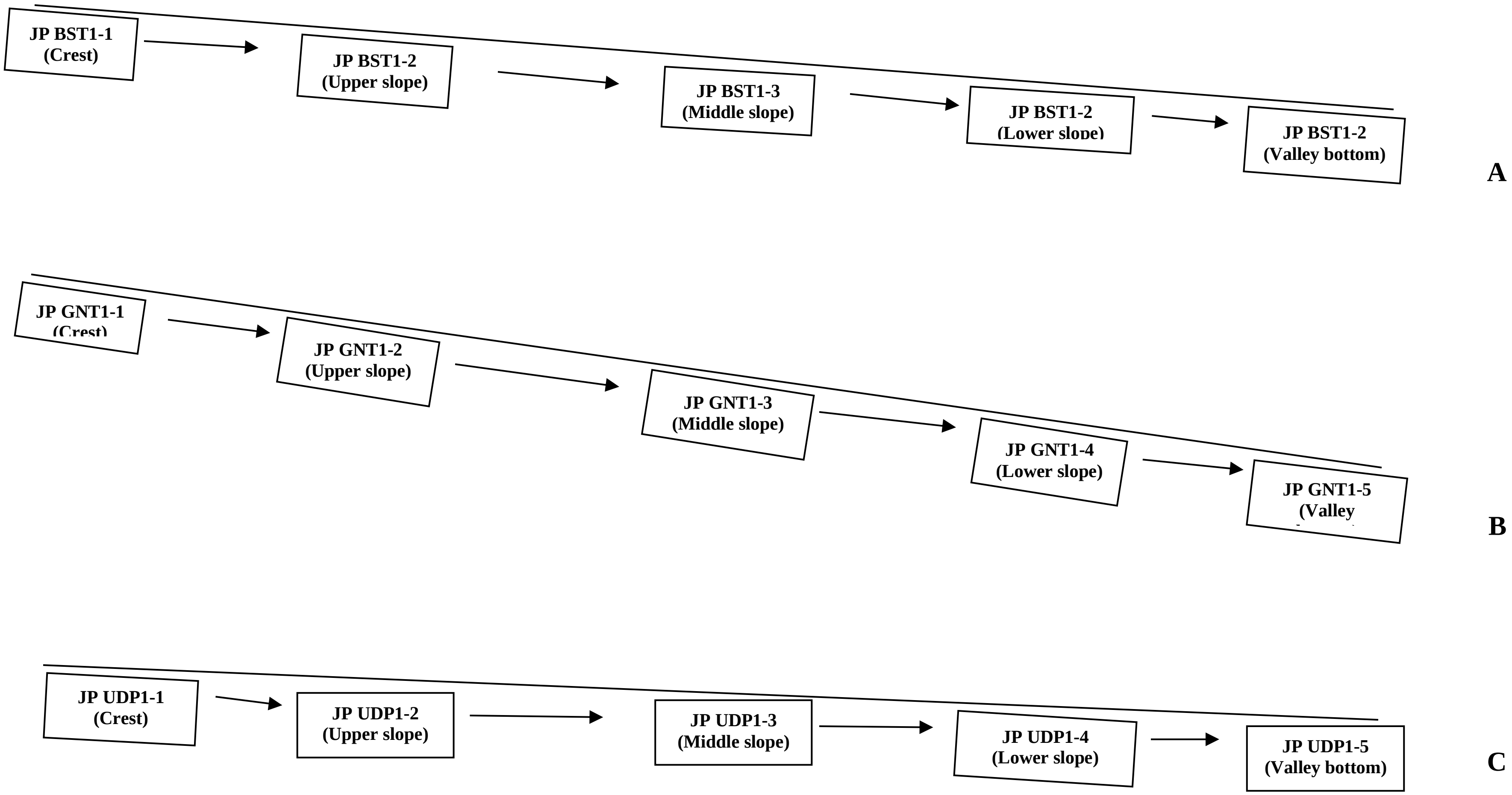

Figure 4.1: Physiognomy of soils derived from Basalt (A), Granite (B) and Unconsolidated deposits (C) at Riyom, Kasen and Du respectively on the Jos Plateau, with the locations of the soil profile pits.

4.3 Physical properties of the soils investigated

Tables 4.4, 4.5 and 4.6 contain some physical properties of representative profiles of the different soil groupings studied. The selected physical properties are: Bulk density, percentage of gravel, sand, silt, clay and textural class. Table 4.7 contains means, standard deviations and coefficients of variation of the selected physical properties of the soils.

Bulk density

Bulk density ranged from 1.0 g cm^{-3} to 1.63 g cm^{-3} with a grand mean of 1.29 g cm^{-3} for the soils formed on Basalt. Soils in the upper slope and valley bottom positions had the highest Bulk density with a mean of 1.33 g cm^{-3} each, while the soils of the middle slope position had the lowest Bulk density with a mean of 1.24 g cm^{-3}, Table 4.7 refers. Bulk density had the highest coefficient of variation of 15.40% for the soils of the crest physiographic position while the least coefficient of variation of 5.33% was for soils of the upper slope positions, the Table 4.7 refers. Soils of the crest and lower slope positions had same mean Bulk density of 1.28 g cm^{-3} each. The coefficients of variation for Bulk density did not differ much for the soils of the middle slope and valley bottom positions.

The soils formed on Granite had a Bulk density ranging from 1.15 g cm^{-3} to 1.60 g cm^{-3} with a grand mean of 1.38 g cm^{-3}. Soils of the upper slope and valley bottom positions, had the highest Bulk density with a meam of 1.42 g cm^{-3} each, while the soils of the crest positions had the least Bulk density with a mean of 1.33 g cm^{-3}.

The highest coefficient of variation of 13.29% for Bulk density was in respect of soils of the crest positions while the least coefficient of variation of 5.83% for Bulk density was recorded for the soils of the middle slope positions, Table 4.7 refers.

The soils formed on unconsolidated deposits had Bulk density ranging from 0.72 g cm^{-3} to 1.70 g cm^{-3} with a grand mean of 1.39 g cm^{-3}. Soils of the upper slope and lower slope positions, had the highest mean Bulk density of 1.46 g cm^{-3} each, while the soils of the valley bottom positions had the least mean Bulk density of 1.26 g cm^{-3}.

Table 4.4: Selected physical properties of the soils derived from Basalt (Toposequence JP-BST1)

Profile/	Physiographic	Depth	B.D	Clay	Silt	Sand	T.C	S. Wgt	G. Wgt	%G
Horizon	Position	cm	g cm^{-3}		g/kg				g	%
JP-BST1-1	Crest									
Ap		0-11	1.29	226	274	540	L	1488	522	35.08
A2		11-40	1.63	54	174	772	LS	1036	315	30.41
E		40-82	1.46	14	254	732	SL	938	416	44.35
C		82-142	1.28	186	394	540	L	1324	315	23.79
JP-BST1-2	Upper Slope									
Ap		0-20	1.30	306	214	540	SCL	868	368	42.40
B		20-47	1.32	46	374	580	SL	968	392	40.50
Bt		47-98	1.29	266	194	500	SCL	946	414	43.76
C		98-180	1.30	46	394	540	SL	1214	416	34.27
JP-BST1-3	Middle Slope									
Ap		0-20	1.22	274	174	552	SCL	927	169	18.23
A2		20-45	1.29	66	154	500	LS	1624	381	23.46
BA		45-80	1.28	106	174	552	LS	1244	208	16.72
Bt		80-137	1.20	226	394	502	L	1146	317	27.66
C		137	1.30	66	194	580	SL	967	280	28.96
JP-BST1-4	Lower Slope									
Ap		0-15	1.22	246	274	500	L	1290	490	37.98
E		15-39	1.51	94	174	732	LS	927	268	28.91
Bt		39-63	1.31	346	194	540	CL	1053	274	26.02
C1		63-108	1.42	34	274	672	SL	1115	322	28.88
C2		108-190	1.20	234	234	532	SCL	1320	298	22.58
JP-BST1-5	Valley Bottom									
Ap		0-22	1.25	114	434	452	SL	974	480	49.28
A2		22-56	1.38	74	254	672	SL	870	622	71.49
E		56-109	1.38	46	374	580	SL	896	321	35.83
C1		109-132	1.51	66	234	700	LS	805	404	50.19
C2		132-190	1.40	34	274	672	LS	1314	296	22.53

Table 4.4: Selected physical properties of the soils derived from Basalt (Toposequence JP-BST2)

Profile/	Physiographic	Depth	B.D	Clay	Silt	Sand	T.C	S. Wgt	G. Wgt	%.G
Horizon	Position	cm	g/kg	g/kg				g		%
JP-BST2-1	Crest									
Ap		0-22	1.30	346	194	460	SCL	590.53	77.62	13.14
BA		22-38	1.10	486	254	260	C	510.03	70.15	13.75
B1		38-73	1.40	245	514	241	SL	499.74	247.24	49.47
B2		73-120	1.10	226	234	540	SCL	552.77	145.20	32.59
Bt		120-170	1.0	486	274	240	C	694.89	226.44	32.59
JP-BST2-2	Upper Slope									
Ap		0-22	1.20	326	374	300	CL	535.90	63.76	8.41
Bt1		22-49	1.40	666	54	280	C	611.12	60.36	9.88
Bt2		49-100	1.40	400	248	352	CL	628.27	55.39	8.82
Bt3		100-168	1.40	350	300	350	CL	580.40	50.00	8.62
JP-BST2-3	Middle Slope									
Ap		0-24	1.40	240	408	352	L	788.15	108.73	13.8
AB		24-42	1.25	206	354	440	L	746.83	169.47	22.69
Bt		42-57	1.20	226	374	400	L	921.78	478.48	51.91
CB		57-105	1.10	66	354	580	SL	1496.86	1382.61	92.37
C		105-180	1.20	26	434	540	SL	878.19	468.74	53.38
JP-BST2-4	Lower Slope									
Ap		0-25	1.24	120	406	474	L	850.40	270.20	31.77
Bt		25-46	1.27	205	364	431	L	960.60	500.50	52.10
BC1		46-72	1.20	145	413	442	L	970.80	520.20	53.59
BC2		72-120	1.20	167	314	519	L	1110.30	603.50	54.36
C		120-179	1.24	34	463	503	SL	840.40	540.20	64.28
JP-BST2-5	Valley Bottom									
Ap		0-23	1.30	86	554	360	SL	879.06	309.99	35.26
A2		23-42	1.30	206	374	420	L	1049.15	604.25	57.59
B		42-78	1.20	66	454	480	SL	1049.25	638.15	60.82
Bt		78-123	1.30	266	274	460	SCL	1272.18	1036.21	81.45
C		123-180	1.30	40	494	466	SL	901.76	736.86	81.71

Table 4.5: Selected physical properties of the soils derived from Granite (Toposequence JP-GNT1)

Profile/	Physiographic	Depth	B.D	Clay	Silt	Sand	T.C	S. Wgt	G. Wgt	%.G
Horizon	Position	Cm	g/kg		g/kg			g		%
JP-GNT1-1	Crest									
Ap		0-19	1.20	254	74	672	SCL	335.01	472.51	58.51
BA		19-34	1.17	394	174	432	CL	393.43	394.40	50-06
Bt1		34-64	1.27	554	174	272	C	376.57	270.05	41.76
Bt2		64-100	1.22	554	254	192	C	415.66	356.56	46.17
C		100-200	1.16	134	434	392	L	340.87	333.86	49.49
JP-GNT1-2	Upper Slope									
Ap		0-20	1.34	294	254	452	CL	621.20	156.01	25.11
BA		20-63	1.42	334	114	552	SCL	569.30	99.78	17.53
Bt1		63-98	1.21	574	34	392	C	384.67	142.54	37.06
Bt2		98-117	1.31	454	274	272	C	426.87	217.03	50.84
Bt3		117-196	1.51	454	314	232	C	378.31	169.03	44.68
JP-GNT1-3	Middle Slope									
Ap		0-19	1.26	274	194	532	SCL	501.38	180.21	35.94
Bt1		19-65	1.29	454	214	332	C	602.61	107.34	17.81
Bt2		65-110	1.33	454	154	392	C	561.68	317.10	56.46
Bt3		110-170	1.40	394	254	352	CL	398.61	325.67	81.70
C		170-200	1.18	394	334	272	CL	505.29	242.05	47.9
JP-GNT1-4	Lower Slope									
Ap		0-6	1.22	274	294	432	CL	254.31	153.26	60.27
BA		6-15	1.32	314	234	452	CL	540.95	94.46	17.46
Bt1		15-68	1.41	454	274	272	C	486.63	113.07	23.24
Bt2		68-113	1.28	454	274	272	C	381.82	142.11	37.22
Bt3		113-200	1.31	394	334	272	CL	348.05	293.00	84.18
JP-GNT1-5	Valley Bottom									
Ap		0-14	1.59	254	314	432	L	547.41	230.51	42.11
Bt1		14-75	1.15	454	334	212	C	486.61	204.10	41.94
Bt2		75-112	1.30	314	214	472	CL	323.12	326.46	-
Bt3		112-196	1.23	374	414	212	CL	446.95	230.21	51.51

Table 4.5: Selected physical properties of the soils derived from Granite (Toposequence JP-GNT2)

Profile/	Physiographic	Depth	B.D	Clay	Silt	Sand	T.C	S. Wgt	G. Wgt	%.G
Horizon	Position	Cm	g/kg		g/kg			g		%
JP-GNT2-1	Crest									
Ap		0-25	1.50	186	154	660	SL	839.71	495.71	59.03
A2		25-66	1.60	86	394	520	SL	1256.14	825.64	65.73
Bt		66-110	1.50	166	394	440	L	855.30	451.38	52.77
JP-GNT2-2	Upper Slope									
Ap		0-13	1.60	206	134	660	SCL	1001.44	362.54	36.20
Bt		13-55	1.60	260	274	466	L	805.61	645.44	80.12
BC		55-82	1.3	200	394	406	L	838.64	348.07	41.50
C		82-165	1.50	86	434	480	SL	733.24	198.39	27.06
JP-GNT2-3	Middle Slpoe									
Ap		0-14	1.4	86	454	46	SL	879.87	348.12	39.56
AB		14-43	1.4	206	454	34	L	705.19	125.16	17.75
Bt1		43-87	1.3	326	234	44	CL	602.00	105.97	17.60
Bt2		87-110	1.5	226	214	56	SCL	718.88	234.32	32.60
Bt3		110-185	1.5	306	54	64	SCL	529.72	81.82	15.45
JP-GNT2-4	Lower Slope									
Ap		0-20	1.5	340	308	352	CL	675.18	103.80	15.37
AB		20-55	1.4	206	374	420	L	692.87	162.34	23.43
Bt1		55-67	1.5	386	254	360	CL	663.35	218.93	33.00
Bt2		67-140	1.3	286	274	440	CL	945.13	397.04	42.01
C		140-175	1.4	220	246	534	L	960.40	420.10	43.74
JP-GNT2-5	Valley Bottom									
Ap		0-12	1.5	12	124	506	LS	1247.03	384.50	30.83
A2		12-35	1.6	4	414	446	SL	992.16	581.36	58.60
AB		35-76	1.4	4	574	386	SiL	842.45	217.21	25.78
B		76-110	1.6	4	594	366	SiL	703.26	159.35	22.66
C		110-172	1.4	28	308	412	L	1162.93	613.56	52.76

Table 4.6: Selected physical properties of the soils derived from Unconsolidated deposits (Toposequence JP-UDP1)

Profile/	Physiographic	Depth	B.D	Clay	Silt	Sand	T.C	S. Wgt	G. Wgt	%.G
Horizon	Position	Cm	g/kg		g/kg			g		%
JP-UDP1-1	Crest									
Ap		0-17	1.52	182	16	658	SL	660.77	49.25	7.45
Bt1		17-46	1.20	342	32	338	CL	591.38	9.36	1.58
Bt2		46-90	1.09	342	32	338	CL	630.21	28.51	4.52
C1		90-133	1.39	42	22	738	LS	619.04	156.15	25.22
C2		133-190	1.37	142	32	538	SL	604.06	104.08	17.23
JP-UDP1-2	Upper Slope									
Ap		0-19	1.36	182	16	658	SL	553.63	122.75	22.17
Bt1		19-80	1.16	402	30	398	CL	489.42	180.73	36.93
Bt2		80-115	1.45	362	20	358	CL	594.40	230.48	38.78
Bt3		115-199	1.62	342	22	418	CL	574.10	157.67	27.46
JP-UDP1-3	Middle Slpoer									
Ap		0-11	1.02	202	18	618	SCL	647.50	116.83	18.04
Bt1		11-33	1.07	342	24	418	CL	578.61	61.33	10.60
Bt2		33-62	1.18	402	24	358	CL	660.56	72.53	10.98
Bt3		62-160	0.93	402	24	358	CL	633.80	173.77	27.42
C		160-200	1.55	202	38	418	L	446.33	226.21	50.68
JP-UDP1-4	Lower Slope									
Ap		0-33	1.40	248	294	458	L	604.80	148.47	24.55
B1		33-74	1.06	342	200	458	CL	576.20	285.03	49.47
B2		74-123	1.45	108	434	458	SL	479.67	159.71	33.30
Bt		123-166	1.55	348	294	358	CL	512.12	291.51	56.92
JP-UDP1-5	Valley Bottom									
Ap		0-12	1.17	408	314	278	CL	660.30	100.13	15.16
Bt1		12-57	0.85	408	334	258	CL	628.40	75.48	12.01
Bt2		57-115	0.72	308	334	358	CL	615.50	225.19	36.59
C		115-180	1.63	248	294	458	L	561.70	231.52	41.22

Table 4.6: Selected physical properties of the soils derived from Unconsolidated deposits (Toposequence JP-UDP2)

Profile/	Physiographic	Depth	B.D	Clay	Silt	Sand	T.C	S. Wgt	G. Wgt	%.G
Horizon	Position	Cm	g/kg	g/kg				g		%
JP-UDP2-1	Crest									
Ap		0-23	1.4	245	514	240	SiL	499.74	247.24	49.47
A2		23-54	1.6	86	374	540	SL	923.76	659.48	71.39
Bt1		54-81	1.4	166	174	660	SL	826.40	333.35	40.34
Bt2		81-107	1.5	180	148	672	SL	500.28	107.18	21.42
C		107-170	1.6	120	218	662	SL	787.34	123.42	15.68
JP-UDP2-2	Upper Slope									
Ap		0-18	1.6	206	174	620	SCL	641.63	162.16	25.27
Bt1		18-80	1.5	320	228	452	CL	651.68	136.89	21.01
Bt2		80-116	1.5	266	314	420	L	971.31	239.74	24.68
C		116-196	1.5	220	308	472	L	894.64	197.30	22.05
JP-UDP2-3	Middle Slope									
Ap		0-12	1.35	166	214	620	SL	1083.4	193.29	17.84
B		12-33	1.70	66	194	740	SL	812.48	78.50	9.66
Bt1		33-64	1.60	226	34	74	SCL	712.77	92.42	12.97
Bt2		64-160	1.50	280	188	522	SCL	711.99	157.49	22.12
C		160-198	1.50	186	374	440	L	832.18	452.62	54.39
JP-UDP2-4	Lower Slope									
Ap		0-32	1.5	266	314	42	L	754.57	134.79	17.86
B		32-73	1.6	126	534	34	L	657.79	340.19	51.72
Bt1		73-123	1.6	226	434	34	L	663.35	218.93	33.0
Bt2		123-192	1.5	286	254	46	CL	739.89	293.60	39.68
JP-UDP2-5	Valley Bottom									
Ap		0-14	1.4	266	214	520	SCL	722.35	110.91	15.35
Bt1		14-60	1.4	306	354	340	CL	705.34	101.44	14.38
Bt2		60-116	1.5	286	314	400	L	1062.71	363.87	59.08
C		116-185	1.4	20	434	546	SL	761.11	449.64	34.24

Foot Note: B.D- Bulk Density; T.C- Textural Class; S.Wgt: Soil Weight; G.Wgt- Gravel Weight; %G- Percentage Gravel.

Table 4.7: Mean, standard deviation and coefficient of variation of some physical properties of the soils studied

Soil/Parent material	Physiographic positions		BD	Clay	Silt	Sand	%GC
			g cm^{-3}		g kg^{-1}		%
Soils derived from Basalt	Crest	ẍ	1.28	252.11	285.11	480.56	30.57
		δ	0.20	165.81	105.88	200.96	12.29
		c.v	15.40	65.77	37.14	41.82	40.20
	Upper slope	ẍ	1.33	300.75	269.00	430.25	24.58
		δ	0.07	199.05	115.85	121.59	16.96
		c.v	5.33	66.19	43.07	28.26	68.99
	Middle slope	ẍ	1.24	150.20	301.40	499.80	34.92
		δ	0.08	86.24	108.69	81.79	24.94
		c.v	6.72	57.42	36.06	16.37	71.43
	Lower slope	ẍ	1.28	162.50	311.00	534.50	40.05
		δ	0.11	92.91	87.18	101.36	12.71
		c.v	8.62	57.18	28.03	18.96	31.73
	Valley bottom	ẍ	1.33	99.80	372.00	526.20	54.62
		δ	0.09	78.32	108.53	125.57	18.63
		c.v	6.92	78.48	29.17	23.86	34.11
Soils derived from Granite	Crest	ẍ	1.33	291.00	256.50	447.50	53.35
		δ	0.18	186.56	134.56	169.14	8.30
		c.v	13.29	64.11	52.46	37.80	15.56
	Upper slope	ẍ	1.42	318.00	247.33	434.67	40.01
		δ	0.15	134.41	119.04	139.26	18.82
		c.v	10.28	42.27	48.13	32.04	47.04
	Middle slope	ẍ	1.36	312.00	256.00	212.40	36.28
		δ	0.08	129.10	115.60	188.23	22.60
		c.v	5.83	41.38	45.16	88.62	62.29
	Lower slope	ẍ	1.36	332.80	286.60	380.60	37.99
		δ	0.10	86.78	45.03	75.83	23.92
		c.v	7.48	26.07	15.71	19.92	62.97
	Valley bottom	ẍ	1.42	160.89	365.56	382.67	40.77
		δ	0.18	191.70	162.52	112.17	13.34
		c.v	12.60	119.15	44.46	29.31	32.71
Soils derived from Unsonsolidated deposits	Crest	ẍ	1.41	184.70	156.20	538.40	25.43
		δ	0.16	99.79	171.14	173.66	22.16
		c.v	11.63	54.03	109.57	32.25	87.15
	Upper slope	ẍ	1.46	287.50	139.00	474.50	27.29
		δ	0.15	80.60	132.66	107.53	6.86
		c.v	10.02	28.04	95.44	22.66	25.12
	Middle slope	ẍ	1.34	247.40	113.20	456.60	23.47
		δ	0.27	108.37	122.55	184.52	16.32
		c.v	20.23	43.80	108.26	40.41	69.54
	Lower slope	ẍ	1.46	243.75	344.75	236.00	38.31
		δ	0.17	88.98	111.50	213.17	13.70
		c.v	12.00	36.51	32.34	90.32	35.75
	Valley bottom	ẍ	1.26	281.25	324.00	394.75	28.50
		δ	0.32	121.34	61.41	106.42	16.98
		c.v	25.50	43.14	18.95	26.96	59.56

The highest coefficient of variation of 25.50% for Bulk density was recorded for the soils of the valley bottom positions while the least (10.02%) was recorded for the soils of the upper slope positions.

The soils formed on Basalt had relatively lower Bulk density as compared to the soils formed on Granite and Unconsolidated deposits. The soils formed on Granite and Unconsolidated deposits, had about same Bulk density.

Percentage of gravel

Percentage of gravel ranged from 8.41% - 92.37% with a grand mean of 36.95% for the soils formed on Basalt. The soils in the valley bottom positions had the highest levels of gravel, with a mean of 54.62% while the soils in the upper slope positions had the least levels of gravel with a mean of 24.58%, Table 4.7 refers. Soils in the middle slope positions recorded the highest coefficient of variation of 31.73%, for gravel.

Percentage of gravel ranged from 15.37% - 84.18% with a grand mean of 41.68%, for the soils formed on Granite. The soils in the crest positions had the highest amounts of gravel, with a mean of 53.35% while the soils in the middle slope positions had the least amounts of gravel with a mean of 36.28%. soils in the other physiographic positions had amounts of gravel between the two stated limits but were quite high in gravel, Table 4.7 refers. Soils of the lower slope and middle slope positions, recorded the highest coefficient of variation of 62.97% and 62.29% respectively for gravel, while soils of the crest positions recorded the least (15.56%) for gravel.

The soils formed on Unconsolidated deposits had percentage gravel ranging from 1.58% - 71.39% with a grand mean of 28.60%. Soils of the lower slope positions had the highest amounts of gravel with a mean of 38.31% while soils of the middle slope positions had the least amounts, with a mean of 23.47%, Table 4.7 refers. Soils of the crest positions, recorded the highest coefficient of variation of 87.15% for gravel while soils of the upper slope positions recorded the least coefficient of variation of 25.12%. Coefficient of variation for gravel were high for most of the soils in the different physiographic positions.

The soils formed on Granite had the highest amounts of gravel followed by the soils formed on Basalt while soils formed on Unconsolidated deposits had the least amounts of gravel. There was no regular trend in the amounts of gravel in the soils, from the surface soils to the sub-soil, for all the three categories of soils investigated.

Particle size distribution

Sand

Sand ranged from 240-772 g/kg and a mean of 494.26 g/kg of the fine earth fraction of the soils formed on Basalt. Soils of the lower slope positions had the highest levels of sand having a mean of 534.50 g/kg while soils of the upper slope positions had the least levels, having a mean of 430.25 g/kg, when the sand contents of the soils of the different slope positions were compared together. Soils of the crest positions recorded the highest coefficient of variation of 41.82% for sand while soils of the middle slope positions recorded the lowest coefficient of variation of 16.37%, for sand, Table 4.7 refers.

The soils formed on Granite ranged in sand contents from 192-672 g/kg having a mean of 371.57 g/kg of the fine earth fraction. Soils of the crest positions had the highest levels of sand with a mean of 447.50 g/kg while those of the middle slope positions had the least, having a mean of 212.40 g/kg when all the soils of the different slope positions were compared together. Soils of the middle slope positions recorded the highest coefficient of variation of 88.62% for sand while soils of the lower slope positions recorded the least coefficient of variation (19.92%), for sand.

Sand ranged from 240-740 g/kg having a grand mean of 420.05 g/kg, of the fine earth fraction of the soils formed on Unconsolidated deposits. Soils of the crest positions had the highest levels of sand having a mean of 538.40 g/kg while soils of the lower slope positions had the least levels having a mean of 236 g/kg, when the soils in all the positions were compared together. Sand had the highest coefficient of variation of 90.32% for the lower slope soils while the coefficient of variation was least (22.66%) for the soils of the upper slope positions.

The soils formed on Basalt were notably higher in sand than the soils formed on Granite and Unconsolidated deposits. The soils formed on Unconsolidated deposits had the least amount of sand amongst the three categories of soils. The surface horizons of the soils generally were higher in sand than the sub-surface horizons, Table 4.4, 4.5 and 4.6 refer.

Silt

Silt ranged from 54-554 g/kg having a mean of 307.70 g/kg, of the fine earth fraction (< 2 mm) of the soils formed on Basalt. The soils of the valley bottom positions had the highest amount of silt with a mean of 372.00 g/kg while those of the upper slope positions had the least amounts, having a mean of 269.00 g/kg when compared with the soils of the other physiographic positions. The silt contents of the soils of the other positions did not differ much from one another, Table 4.7 refers. The highest coefficient of variation for silt (43.07%), was for the soils in the upper slope positions while the least (28.03%), was for the soils of the lower slope positions.

The range in silt for the soils formed on Granite was from 34-594 g/kg, and having a grand mean of 282.40 g/kg, of the fine earth fraction. Soils of the valley bottom positions had the highest amount of silt having a mean of 365.56 g/kg while the least amounts were in the soils of the upper slope positions, having a mean of 247.33 g/kg, Table 4.7 refers. The soils of the crest and middle slope positions had about same amounts of silt with means of 256.50 and 256.00 g/kg respectively. The highest coefficient of variation for silt (52.46%) was for the soils of the crest positions while the least (15.71%) was for the soils of the lower slope positions.

Silt ranged from 34-534 g/kg, and having a grand mean of 215.43 g/kg, of the fine earth fraction for the soils formed on Unconsolidated deposits. Soils of the lower slope positions had the highest amount of silt, having a mean of 344.75 g/kg while soils of the middle slope positions had the least amounts, having a mean of 113.20 g/kg. Silt had the highest coefficient of variation of 109.57% for the soils of the crest position and had the least coefficient of variation of 18.95% for the soils of the valley bottom positions.

The soils formed on Basalt had relatively higher amounts of silt than the soils formed on Granite but notably higher amounts than the soils formed on Unconsolidated deposits. The soils formed on Granite had notably higher amounts of silt than the soils formed on

Unconsolidated deposits. All the three categories of soils investigated were high in silt. In some of the soils especially those formed on Granite, silt tended to increase downwards in the soils while for others, no any regular trend was maintained. The uppermost horizons of most of the soils were constantly high in silt.

Clay

Clay ranged from 14-666 g/kg, and having a grand mean of 193.07 g/kg, of the fine earth fraction (< 2mm) of the soils formed on Basalt. Soils of the upper slope positions had the highest amount of clay, with a mean of 300.75 g/kg while soils of the valley bottom positions had the least amounts of clay having a mean of 99.80 g/kg. Soils of the crest positions had notable amounts of clay, having a mean of 252.11 g/kg, Table 4.7 refers. Soils of the middle and lower slope positions did not differ much in their clay contents with means of 150.20 and 162.50 g/kg respectively. Clay had the highest coefficient of variation of 78.48% for the soils of the valley bottom positions while the least coefficient of variation of 57.18% was in respect of soils of the lower slope positions. Clay ranged from 40-574 g/kg, and having a grand mean of 282.94 g/kg, for the soils formed on Granite. Soils of the lower slope positions had the highest amounts of clay with a mean of 332.80 g/kg while soils of the valley bottom positions had the least amounts of clay having a mean of 160.89 g/kg, Table 4.7 refers. Soils of the other physiographic positions had notable amounts of clay Table 4.7 refers. Clay had the highest coefficient of variation of 119.15%, for the soils of the valley bottom positions and the least coefficient of variation of 26.07% for the soils of the lower slope positions, the Table 4.7 refers. The coefficient of variation for the other physiographic positions were moderate to high.

Clay ranged from 20-408 g/kg, and having a grand mean of 248.92 g/kg, for the soils formed on Unconsolidated deposits. Soils of the upper slope positions had the highest amount of clay with a mean of 287.50 g/kg, while soils of the crest physiographic positions had the least amounts, with a mean of 184.70 g/kg, the Table 4.7 refers. The other physiographic positions had notable amounts of clay as shown in Table 4.7. Clay had the highest coefficient of variation of 54.03% for the soils of the crest positions while the least coefficient of variation of 28.04%, was in respect of soils of the upper slope positions, Table 4.7 refers. The coefficient of variation for clay for the soils of other physiographic positions were moderate.

The soils formed on Granite were notably higher in clay than the soils formed on Basalt and Unconsolidated deposits. The soils formed on Unconsolidated deposits were notably higher in clay than the soils formed on Basalt. The B horizons of most of the soils investigated were higher in clay than the other horizons; again, the uppermost horizons of the soils were high in clay.

4.4 Chemical properties of the soils investigated

Tables 4.8, 4.9 and 4.10, contain some chemical properties of representative soil profiles of the different soil groupings investigated, while Tables 4.11 contains means, standard deviation and coefficient of variation of the affected chemical properties. The chemical properties are soil reaction (pH), Exchangeable Acidity, Organic Carbon, Total Nitrogen, Available Phosphorus and Exchangeable Cations (Ca, Mg, K, Na). Others are Effective Cation Exchange Capacity, Base Saturation and micronutrients (Mn, Fe, Zn, Cu).

Soil reaction

pH in water ranged from 4.3 (extremely acid) to 6.7 (slightly acidic), with a mean of 5.22 (strongly acid), for the soils formed on Basalt. The soils in the different physiograhic positions were all strongly acidic with mean pH ranging from 5.18 to 5.33 except for the soils of the upper slope positions which were very stongly acidic with a mean pH of 4.97, Table 4.11 refers. Soil pH had the highest coefficient of variation of 12.78% for the soils of the crest physiographic positions and the least coefficient of variation of 5.02% for the soils of the lower slope physiographic position. The coefficient of variation for soil pH did not differ much for the soils of the other positions, Table 4.11 refers.

pH in water ranged from 4.4 (extremely acid) to 5.87 (moderately acid), with a grand mean of 5.20 (strongly acid), for the soils formed on Granite. All the soils in the different physiographic positions were strongly acidic with mean pH ranging from 5.09 to 5.35. The highest coefficient of variation of 9.77% for pH, was in respect of soils of the crest positions while the least coefficient of variation of 4.91%, was in respect of soils of the valley bottom positions, Table 4.11 refers.

Table 4.8: Chemical properties of the soils derived from Basalt (Toposequence JP-BST1) on the Jos Plateau

Horizon/	Depth	pH	O.C	TN	Avail.P	Ex. A	H^+	Al^{3+}	Ca	Mg	K	Na	ECEC	BS	Mn	Fe	Cu	Zn
Profile	cm	H_2O	g/kg		mg/kg					cmol/kg				%		g/kg		
JP-BST1-1																		
Ap	0-11	5.1	16.38	1.69	1.36	1.1	1.1	0.0	2.21	1.42	0.05	0.36	5.14	78.60	56.2	89.0	2.20	1.00
A2	11-40	5.3	17.22	1.78	1.22	1.1	1.1	0.0	2.19	1.26	0.10	0.33	4.98	77.91	40.7	69.3	1.32	0.29
E	40-82	5.5	15.54	1.61	0.18	0.5	0.5	0.0	2.05	0.34	0.10	0.41	3.40	85.29	27.4	55.1	0.99	0.21
C	82-142	5.4	4.62	0.48	0.66	1.3	1.3	0.0	2.02	0.27	0.03	0.41	4.03	67.74	9.6	42.6	1.77	0.23
JP-BST1-2																		
Ap	0-20	5.3	22.68	2.35	2.26	1.4	1.2	0.2	2.25	1.22	0.04	0.36	5.27	73.43	43.3	90.9	2.23	1.04
B	20-47	5.2	13.44	1.39	0.25	1.3	1.1	0.2	2.15	0.85	0.14	0.40	4.84	73.14	21.9	96.0	1.47	0.83
Bt	47-98	5.5	9.66	1.00	0.32	0.8	0.8	0.0	2.10	0.61	0.09	0.40	4.00	80.00	17.3	52.6	1.44	0.31
CB	98-180	5.5	5.46	0.57	0.01	0.8	0.8	0.0	2.09	0.38	0.13	0.33	3.73	78.55	8.0	85.0	0.23	0.35
JP-BST1-3																		
Ap	0-20	5.3	21.42	2.22	2.88	1.1	0.9	0.2	2.20	1.50	0.25	0.26	5.31	79.28	64.8	75.6	1.54	0.91
A2	20-45	5.4	10.92	1.13	0.02	0.8	0.8	0.0	2.24	1.18	0.11	0.29	4.62	82.68	29.3	67.9	1.52	0.31
BA	45-80	5.0	15.54	1.61	0.32	2.1	1.7	0.4	2.06	0.35	0.16	0.30	4.97	57.75	16.7	55.4	1.05	0.42
Bt	80-137	5.1	10.08	1.04	1.43	1.6	1.4	0.2	2.12	0.37	0.14	0.40	4.63	65.44	9.2	50.1	1.14	0.77
C	137	5.3	6.72	0.71	0.60	2.4	1.8	0.6	2.03	0.34	0.13	0.39	5.29	54.63	12.1	59.6	1.13	2.53
JP-BST1-4																		
Ap	0-15	5.0	19.74	2.04	2.95	2.1	2.0	0.1	2.25	1.28	0.13	0.22	5.98	64.88	74.5	55.0	3.34	3.12
A2	15-39	5.2	22.26	2.30	1.84	2.7	2.0	0.7	2.19	1.22	0.23	0.38	6.72	59.82	53.4	85.4	1.45	0.87
Bt	39-63	5.2	8.40	0.87	0.04	1.2	1.2	0.0	2.21	1.11	0.14	0.38	5.04	76.19	24.7	57.3	1.71	1.18
C1	63-108	5.0	10.08	1.04	1.01	3.3	2.3	1.0	2.05	0.74	0.16	0.26	6.51	49.31	21.3	47.5	0.97	0.28
C2	108-190	5.2	7.98	0.83	1.15	4.8	3.4	1.4	2.15	0.15	0.16	0.19	7.45	35.57	15.3	48.9	0.87	0.27
JP-BST1-5																		
Ap	0-22	5.4	21.42	2.22	10.08	2.3	1.5	0.8	2.20	0.58	0.10	0.38	5.56	58.63	61.4	137.0	2.87	1.49
A2	22-56	5.5	12.60	1.30	2.67	0.9	0.7	0.2	2.26	0.97	0.24	0.29	4.66	80.69	25.3	24.5	1.85	1.01
E	56-109	5.7	1.98	0.20	0.02	0.9	0.9	0.0	2.36	0.20	0.20	0.29	3.95	77.22	18.6	86.0	1.12	1.24
C1	109-132	5.6	2.10	0.22	1.56	0.4	0.4	0.0	2.25	0.26	0.26	0.35	3.52	88.64	65.4	125.0	1.29	0.64
C2	132-190	6.1	3.78	0.39	1.43	0.4	0.4	0.0	2.32	0.71	0.11	0.29	3.83	89.56	70.6	57.0	1.05	0.61

Table 4.8: Chemical properties of the soils derived from Basalt (Toposequence JP-BST2) on the Jos Plateau

Horizon/	Depth	pH	O.C	TN	Avail. P	Ex. A	H^+	Al^{3+}	Ca	Mg	K	Na	ECEC	BS	Mn	Fe	Cu	Zn
Profile	cm	H_2O	g/kg		mg/kg				cmol/kg					%		g/kg		
JP-BST2-1																		
Ap	0-22	5.9	27.20	2.81	0.44	5.5	1.3	4.2	7.76	1.36	1.85	0.43	16.9	67.46	5.20	162	1.31	0.71
BA	22-38	4.7	22.10	2.29	0.19	5.2	2.0	3.2	8.08	1.75	0.43	0.14	15.6	66.67	44.40	123	1.25	2.19
B1	38-73	4.8	6.45	0.67	0.07	7.8	4.6	3.2	8.13	1.56	0.83	0.21	18.53	57.91	41.50	125	0.59	0.40
B2	73-120	6.7	19.55	2.02	0.19	4.8	2.9	1.9	7.72	1.14	0.25	0.11	14.02	65.76	18.60	120	0.79	0.04
Bt	120-170	4.50	1.61	0.17	5.01	7.7	3.2	4.5	7.69	1.51	0.69	0.22	17.81	56.77	21.50	110	0.75	1.79
JP-BST2-2																		
Ap	0-22	4.3	23.05	2.90	0.05	3.6	1.9	1.7	8.31	1.23	1.27	0.46	14.87	75.79	0.40	208.0	2.24	5.50
Bt1	22-49	4.4	15.73	1.63	1.46	5.7	2.1	3.6	8.86	1.93	0.46	0.22	17.17	66.80	7.30	156.0	1.40	0.09
Bt2	49-100	4.6	9.78	1.01	1.59	5.7	1.9	3.8	8.16	1.16	0.26	0.16	15.44	63.08	21.00	115.0	0.78	0.05
Bt3	100-168	4.7	4.25	0.80	1.70	5.8	1.9	3.9	7.80	1.23	0.21	0.14	15.18	61.79	23.20	98.4	0.65	0.03
JP-BST2-3																		
Ap	0-24	4.5	25.39	2.63	4.00	4.5	1.4	3.1	8.21	1.16	0.65	0.20	14.72	69.43	42.80	24.10	0.67	2.84
AB	24-42	6.0	14.11	1.46	0.34	6.6	1.2	5.4	8.43	0.86	0.69	0.40	16.98	61.13	78.10	176.0	0.84	9.30
Bt	42-57	5.9	11.69	1.21	0.61	4.3	0.8	3.5	8.11	0.80	0.56	0.29	14.06	69.42	61.40	168.0	0.44	5.90
CB	57-105	5.6	0.76	0.08	6.22	5.2	0.4	4.8	8.36	1.99	0.79	0.29	16.63	68.73	24.90	232.0	0.16	1.90
C	105-180	5.2	8.06	0.83	9.71	8.0	1.8	6.2	8.51	2.52	1.18	0.18	20.39	60.79	12.00	276.0	0.21	2.95
JP-BST2-4																		
Ap	0-25	4.7	20.60	2.0	1.40	4.80	1.8	3.0	8.20	1.2	0.6	0.41	15.21	68.44	102.0	203.0	1.32	7.80
Bt	25-46	5.4	11.69	1.20	1.18	6.10	1.2	4.9	8.14	1.0	0.8	0.35	16.39	62.78	96.50	178.0	1.10	4.90
BC1	46-72	5.7	13.70	1.42	0.65	4.50	0.8	3.7	8.8	1.5	0.50	0.30	15.60	71.15	67.55	138.5	0.40	3.30
BC2	72-120	5.2	5.00	0.52	3.17	5.20	0.7	4.5	8.6	2.4	0.49	0.23	16.92	69.27	50.50	202.0	0.54	1.80
C	120-179	5.2	5.60	0.59	6.40	6.50	1.6	4.9	8.70	2.5	0.70	0.20	18.60	65.05	79.00	212.0	0.32	1.87
JP-BST2-5																		
Ap	0-23	4.8	14.51	1.50	0.57	5.4	1.2	4.2	8.33	1.26	0.48	0.29	15.76	65.74	142.0	261.0	1.27	6.64
A2	23-42	4.8	9.27	0.96	2.03	5.7	1.1	4.6	7.86	1.28	0.88	0.30	16.02	64.42	115.0	182.0	1.33	0.52
B	42-78	5.5	15.72	1.63	0.68	4.7	0.8	3.9	9.58	2.12	0.63	0.33	17.36	72.92	73.70	109.0	0.31	0.60
Bt	78-123	4.7	9.25	0.97	0.13	5.1	0.9	4.2	8.91	2.70	0.31	0.18	17.20	70.35	76.30	173.0	0.92	1.66
C	123-180	5.1	3.23	0.34	3.05	5.1	1.6	3.5	8.91	2.43	0.39	0.21	17.04	70.07	146.0	148.0	0.44	0.80

Table 4.9: Chemical properties of the soils derived from Granite (Toposequence JP-GNT1) on the Jos Plateau

Profile/	Depth	pH	O.C	TN	Avail. P	Ex. A	H^+	Al^{3+}	Ca	Mg	K	Na	ECEC	BS	Mn	Fe	Cu	Zn
Horizon	cm	H_2O	g/kg		mg/kg					cmol/kg				%		mg/kg		
JP-GNT1-1																		
Ap	0-19	5.42	29.26	2.80	9.67	1.85	1.85	0.00	6.13	3.94	0.20	0.52	12.64	85.36	64.3	203.0	1.85	1.48
BA	19-34	5.13	20.90	1.98	4.06	1.85	1.85	0.00	5.56	0.70	0.25	0.48	8.84	79.07	31.9	78.0	1.59	1.61
Bt1	34-64	5.34	16.83	1.57	1.30	5.75	3.15	2.60	6.04	1.10	0.22	0.61	13.72	58.09	26.2	52.0	1.45	1.38
Bt2	64-100	5.46	13.30	1.22	3.02	2.25	2.25	0.00	5.59	0.88	0.19	0.57	9.48	76.27	20.0	37.8	1.39	1.43
C	100-200	5.87	11.86	1.03	1.40	1.65	1.65	0.00	5.61	1.20	0.18	0.52	9.16	81.99	20.3	29.3	1.48	1.18
JP-GNT1-2																		
Ap	0-20	5.03	29.80	2.83	12.38	1.50	1.50	0.00	6.26	1.28	0.42	0.43	9.89	84.83	51.0	109.0	1.96	1.27
BA	20-63	5.82	26.20	2.47	7.07	9.85	1.60	8.25	6.86	4.12	0.36	0.48	21.67	54.55	24.5	85.0	2.16	1.36
Bt1	63-98	5.48	20.90	1.93	1.46	1.95	1.40	0.55	6.29	4.90	0.57	0.48	14.19	86.26	20.4	42.2	1.84	1.61
Bt2	98-117	5.49	19.80	1.84	3.28	9.90	1.40	8.50	5.71	3.29	0.77	0.57	20.24	51.09	17.7	34.3	1.70	1.41
Bt3	117-196	5.81	11.02	0.98	3.74	7.75	1.50	6.25	6.21	1.40	2.43	0.48	18.27	57.58	22.2	32.5	1.93	1.48
JP-GNT1-3																		
Ap	0-19	5.23	31.90	2.96	9.01	6.45	0.95	5.50	6.66	1.47	0.35	0.57	15.50	58.39	66.8	10.60	2.58	1.32
Bt1	19-65	5.47	26.98	2.58	4.11	5.95	0.70	5.25	8.66	2.19	0.27	0.52	17.59	66.17	16.8	26.3	2.02	1.16
Bt2	65-110	5.46	24.82	2.35	3.22	2.50	2.50	0.00	7.06	1.41	0.18	0.61	11.76	78.74	4.3	56.7	2.21	1.23
Bt3	110-170	5.48	12.30	1.12	3.02	3.90	1.65	2.25	6.26	0.97	0.19	0.57	11.89	67.20	13.6	25.4	2.15	1.33
C	170-200	5.54	9.88	0.86	2.13	6.90	2.50	4.40	5.99	0.95	0.23	0.52	14.59	52.71	13.7	61.7	2.21	1.64
JP-GNT1-4																		
Ap	0-6	5.37	48.26	3.38	14.40	5.95	0.70	5.25	14.57	6.41	1.28	0.48	28.69	79.26	204.0	331.0	3.25	1.56
BA	6-15	5.14	30.40	2.90	4.00	9.10	3.10	6.00	6.06	2.37	0.58	0.48	18.59	51.05	8.2	152.0	2.35	1.28
Bt1	15-68	5.42	11.40	1.01	3.02	5.15	1.75	3.40	6.44	2.53	0.87	0.48	15.47	66.71	4.0	53.0	2.40	1.61
Bt2	68-113	5.57	6.84	0.56	1.61	1.80	1.80	0.00	7.81	1.46	1.93	0.43	13.43	86.60	5.1	60.7	2.44	1.74
Bt3	113-200	5.50	4.94	0.38	2.60	1.25	1.25	0.00	6.16	1.27	0.53	0.57	9.78	87.22	13.7	45.6	2.39	1.80
JP-GNT1-5																		
Ap	0-14	5.51	17.86	1.61	10.66	0.75	0.75	0.00	8.61	1.96	0.31	0.61	12.24	93.87	59.9	148.0	4.16	1.36
Bt1	14-75	5.31	14.29	1.30	0.68	3.35	3.35	0.00	6.49	1.74	0.59	0.52	12.69	73.60	17.4	43.6	2.25	1.41
Bt2	75-112	5.26	13.30	1.20	5.77	1.75	1.75	0.00	7.01	1.10	0.53	0.61	11.00	84.09	23.5	66.7	3.10	1.29
Bt3	112-196	5.23	9.50	0.81	7.23	1.25	1.25	0.00	10.18	2.89	0.46	0.57	15.35	91.86	56.5	70.6	3.23	1.36

Table 4.9: Chemical properties of the soils derived from Granite (Toposequence JP-GNT2) on the Jos Plateau

Horizon/	Depth	pH	O.C	TN	Avail. P	Ex. A	H^+	Al^{3+}	Ca	Mg	K	Na	ECEC	BS	Mn	Fe	Cu	Zn
Profile	cm	H_2O	g/kg		mg/kg				cmol/kg					%	mg/kg			
JP-GNT2-1																		
Ap	0-25	4.4	22.58	2.42	10.22	3.9	1.9	2.0	7.06	0.26	0.80	0.29	12.31	68.32	6.50	27.30	0.50	0.65
A2	25-66	4.7	12.49	1.29	3.11	10.5	8.0	2.5	6.99	0.22	0.41	0.19	18.31	42.65	8.00	61.00	0.29	0.10
Bt	66-110	4.6	4.53	0.43	0.04	12.4	7.8	4.6	6.86	0.24	0.51	0.26	20.27	38.83	3.10	79.00	0.38	0.12
JP-GNT2-2																		
Ap	0-13	5.3	21.36	2.21	1.06	6.5	2.1	4.4	7.66	0.15	0.80	0.37	15.48	58.01	1.60	190.0	0.33	1.65
Bt	13-55	4.9	17.33	1.79	0.38	10.7	4.9	5.8	6.39	0.11	0.75	0.36	18.31	41.56	1.70	285.0	0.20	1.06
BC	55-82	4.6	0.32	0.04	0.05	12	9.2	2.8	6.86	0.17	0.49	0.22	19.74	39.21	1.50	74.0	0.31	0.38
C	82-165	5.7	10.83	1.13	4.38	11.4	6.1	5.3	7.88	0.20	1.45	0.32	21.25	46.35	3.00	90.0	0.21	3.49
JP-GNT2-3																		
Ap	0-14	4.9	18.28	1.89	0.11	3.8	1.4	2.4	7.44	1.05	0.27	0.14	12.7	70.08	0.80	134	0.79	0.03
AB	14-43	5.7	16.50	1.72	2.55	6.0	2.6	3.4	6.79	0.10	0.30	0.19	13.38	55.16	3.20	277	1.30	0.47
Bt1	43-87	4.8	11.69	1.21	0.22	11.9	5.8	6.1	7.19	0.23	0.65	0.26	20.23	41.18	4.20	102	0.52	1.58
Bt2	87-110	5.0	6.05	0.63	0.38	5.1	3.1	2.0	7.01	0.21	0.46	0.18	12.96	60.65	5.30	262	1.77	2.24
Bt3	110-185	5.2	10.20	1.06	0.09	6.5	2.1	4.4	7.24	0.18	0.25	0.16	14.33	54.64	5.00	103	0.58	0.23
JP-GNT2-4																		
Ap	0-20	4.8	22.95	2.37	3.81	5.9	2.3	3.6	8.96	1.02	0.60	0.26	16.74	64.76	2.1	25	0.44	0.57
AB	20-55	4.8	0.77	0.08	0.19	8.2	2.2	6.0	9.43	0.22	0.63	0.29	18.77	56.31	3.7	97	0.67	0.71
Bt1	55-67	5.8	9.69	1.00	1.05	5.7	1.6	4.1	9.31	0.63	1.45	0.34	17.43	67.30	21	107	0.47	8.00
Bt2	67-140	4.7	8.46	0.88	0.09	4.7	1.0	3.7	7.83	0.49	0.90	0.18	14.1	66.67	240	192	0.36	3.32
C	140-175	4.6	7.50	0.76	0.08	4.6	1.0	3.6	7.40	0.46	0.70	0.17	14.0	62.36	242	196	0.31	3.20
JP-GNT2-5																		
Ap	0-12	4.9	16.52	1.71	1.21	5.2	0.5	4.7	7.39	0.47	1.68	0.23	14.97	65.26	36.80	165	0.32	4.04
A2	12-35	4.8	10.08	1.04	0.89	8.8	3.5	5.3	7.16	0.16	0.32	0.17	16.61	47.02	18.30	101	0.23	0.31
AB	35-76	4.8	0.36	0.03	2.79	8.9	4.4	4.5	7.14	0.23	0.51	0.26	17.04	47.77	19.30	242	0.21	0.42
B	76-110	5.0	5.24	0.54	1.11	4.5	0.1	4.4	7.11	0.14	0.80	0.43	12.98	65.33	12.0	88	0.49	1.22
C	110-172	5.0	15.73	1.63	0.44	7.5	3.0	4.5	7.09	0.28	0.46	0.25	15.58	51.86	4.30	102	0.53	4.99

Table 4.10: Chemical properties of the soils derived from Unconsolidated deposits (Toposequence JP-UDP1) on the Jos Plateau

Horizon/	Depth	pH	O.C	TN	Avail. P	Ex. A	H^+	Al^{3+}	Ca	Mg	K	Na	ECEC	BS	Mn	Fe	Cu	Zn
Profile	cm	H_2O	g/kg		mg/kg	cmol/kg								%	mg/kg			
JP-UDP1-1																		
Ap	0-17	5.72	13.02	1.36	50.14	1.1	1.1	0.0	14.40	1.66	0.29	0.78	18.23	93.97	18.1	164.0	4.59	4.98
Bt1	17-46	5.54	14.65	1.53	19.35	0.9	0.9	0.0	10.80	1.41	0.16	0.70	13.97	93.56	7.3	56.6	5.83	2.58
Bt2	46-90	5.62	15.47	1.48	11.94	1.2	1.2	0.0	9.36	1.91	0.15	0.35	12.97	90.75	5.6	52.9	4.45	2.81
C1	90-133	5.48	14.25	1.38	4.85	1.0	1.0	0.0	10.70	1.72	0.18	0.43	14.03	92.87	8.4	80.5	2.89	4.02
C2	133-190	5.40	12.20	1.11	2.15	1.0	1.0	0.0	9.43	1.48	0.17	0.61	12.69	92.12	20.9	74.0	2.24	3.90
JP-UDP1-2																		
Ap	0-19	5.36	11.40	1.12	12.75	0.7	0.7	0.0	6.54	1.88	0.21	0.61	9.94	92.96	22.7	379.0	3.05	3.79
Bt1	19-80	5.42	10.58	1.01	4.24	0.8	0.8	0.0	11.83	1.55	0.16	0.48	14.82	94.60	8.9	70.8	2.44	3.60
Bt2	80-115	5.51	9.77	0.98	2.97	1.1	1.1	0.0	11.70	1.92	0.17	0.52	15.41	92.86	17.3	62.1	2.63	4.58
Bt3	115-199	5.38	9.36	0.96	3.04	0.9	0.9	0.0	12.70	2.24	0.17	0.57	17.78	94.94	56.0	77.3	2.66	5.68
JP-UDP1-3																		
Ap	0-11	5.72	17.91	1.87	10.17	2.1	2.1	0.0	6.94	1.88	0.09	0.22	11.00	80.91	33.3	308.0	4.54	5.69
Bt1	11-33	5.66	15.47	1.62	3.60	1.9	1.9	0.0	8.46	1.61	0.20	0.43	12.50	84.80	24.5	108.0	3.46	2.31
Bt2	33-62	5.75	17.09	1.77	13.35	1.8	1.8	0.0	12.48	2.57	0.20	0.70	17.75	89.86	8.3	63.1	3.70	3.14
Bt3	62-160	5.82	13.84	1.46	2.90	2.2	2.2	0.0	12.77	2.20	0.12	0.44	17.73	87.59	11.6	169.0	2.75	3.06
C	160-200	6.01	15.38	1.48	3.61	0.7	0.7	0.0	9.38	1.91	0.12	0.24	12.35	94.33	42.6	95.1	2.45	4.40
JP-UDP1-4																		
Ap	0-33	6.02	12.62	1.31	4.94	1.7	1.7	0.0	6.51	2.50	0.18	0.83	11.72	85.49	19.0	196.0	3.02	4.11
B1	33-74	5.98	11.80	1.30	4.10	0.9	0.9	0.0	12.82	1.69	0.14	0.35	15.9	94.33	6.8	54.8	5.48	3.87
B2	74-123	6.10	11.12	1.23	4.03	0.6	0.6	0.0	11.67	2.36	0.14	0.65	15.42	96.11	19.0	58.6	2.93	3.95
Bt	123-166	6.08	4.30	0.51	16.31	1.0	1.0	0.0	13.95	2.73	0.08	1.21	18.97	94.73	16.6	51.4	3.52	4.78
JP-UDP1-5																		
Ap	0-12	7.04	8.55	0.91	15.11	2.4	2.4	0.0	11.80	2.95	0.17	1.04	18.36	86.93	26.8	104.5	4.01	4.46
Bt1	12-57	6.05	6.42	0.74	16.45	1.8	1.8	0.0	8.73	1.86	0.14	0.83	13.36	86.53	7.6	28.6	4.33	2.51
Bt2	57-115	5.88	5.10	0.61	15.25	2.1	2.1	0.0	9.16	1.32	0.09	0.65	13.32	84.23	8.3	33.1	3.75	3.17
C	115-180	5.94	4.48	0.52	3.96	2.2	2.2	0.0	8.03	1.91	0.04	0.52	12.7	82.68	15.7	55.7	3.56	3.82

Table 4.10: Chemical properties of the soils derived from Unconsolidated deposits (Toposequence JP-UDP2) on the Jos Plateau

Horizon/	Depth	pH	O.C	TN	Avail. P	Ex. A	H^+	Al^{3+}	Ca	Mg	K	Na	ECEC	BS	Mn	Fe	Cu	Zn
Profile	cm	H_2O	g/kg		mg/kg	cmol/kg								%	mg/kg			
JP-UDP2-1																		
Ap	0-23	4.8	6.45	0.67	0.07	7.8	4.6	3.2	8.13	1.56	0.83	0.21	18.53	57.91	41.5	125	0.59	0.40
A2	23-54	4.5	2.42	0.25	4.70	9.6	4.2	5.4	7.11	0.18	0.47	0.30	17.66	45.64	2.8	92	0.48	0.36
Bt1	54-81	4.7	12.75	1.32	0.06	5.6	2.8	2.8	6.54	0.05	0.15	0.10	12.44	54.98	1.5	85	0.67	0.06
Bt2	81-107	4.4	16.15	1.67	2.16	9.2	3.0	6.2	7.16	0.17	0.24	0.14	16.91	45.59	1.5	84	0.54	0.02
C	107-170	4.8	1.28	0.13	0.83	11.7	3.5	8.2	6.81	0.16	0.16	0.10	18.93	38.19	1.6	78	0.37	1.05
JP-UDP2-2																		
Ap	0-18	4.6	22.57	2.33	12.01	4.9	1.8	3.1	7.71	0.25	1.01	0.32	14.19	65.47	6.40	506	0.76	2.15
Bt1	18-80	4.5	14.45	1.50	2.35	11.7	3.0	8.7	7.64	0.13	0.26	0.13	19.86	41.09	2.10	100	0.68	0.04
Bt2	80-116	4.9	0.70	0.03	1.40	9.1	3.5	5.6	8.03	0.45	0.57	0.28	18.43	50.62	5.90	95	0.37	2.30
C	116-196	4.8	6.80	0.20	0.13	5.1	1.5	3.6	7.91	0.46	0.92	0.42	14.81	65.56	4.70	117	0.65	2.67
JP-UDP2-3																		
Ap	0-12	4.8	28.37	2.42	4.71	5.6	1.1	4.5	7.01	0.31	0.86	0.21	13.99	59.97	7.9	459	0.36	1.18
B	12-33	4.7	3.22	0.33	0.09	13.9	8.3	5.6	7.21	0.31	0.33	0.19	21.94	36.65	7.4	143	0.66	1.01
Bt1	33-64	4.8	17.85	1.85	1.40	4.8	2.5	2.3	7.71	0.50	1.09	0.24	14.34	66.53	3.7	115	0.89	3.27
Bt2	64-160	4.6	6.82	0.21	1.14	6.4	1.7	4.7	7.46	0.33	0.23	0.19	14.61	56.19	3.5	104	0.47	0.03
C	160-198	4.9	8.87	0.92	1.65	7.6	2.1	5.5	7.56	0.31	1.39	0.41	17.27	56.00	22.4	81	0.34	0.92
JP-UDP2-4																		
Ap	0-32	4.6	0.68	0.10	1.52	8.5	3.8	4.7	7.09	0.29	0.71	0.26	16.85	49.56	4.0	299	0.73	1.15
B	32-73	5.1	14.88	1.54	0.44	3.3	1.6	1.7	7.31	0.15	0.29	0.10	11.15	70.40	2.1	149	0.92	0.52
Bt1	73-123	4.9	4.84	0.50	0.64	8.0	2.7	5.3	7.83	0.41	0.71	0.32	17.27	53.68	8.4	93	0.63	2.96
Bt2	123-192	4.8	16.52	1.71	0.70	5.9	2.9	3.0	7.74	0.43	1.23	0.43	15.73	62.49	9.2	100	0.71	4.20
JP-UDP2-5																		
Ap	0-14	4.8	12.43	1.80	2.60	4.3	1.5	2.8	7.39	0.62	0.22	0.11	12.64	65.98	6.8	134	1.05	0.51
Bt1	14-60	5.0	6.05	0.63	1.40	7.4	2.9	4.5	7.26	0.22	0.76	0.26	15.9	53.46	1.6	59	0.10	0.89
Bt2	60-116	4.9	14.51	1.50	4.57	11.6	8.2	3.4	6.84	0.17	0.29	0.14	19.04	39.08	1.0	63	0.49	2.06
BC	116-185	5.0	0.81	0.08	1.78	9.1	3.5	5.6	7.66	0.29	0.39	0.19	17.63	48.38	4.0	78	0.16	0.64

Foot Note: O.C- Organic Carbon; TN- Total Nitrogen; Avail.P- Available Phosphorus; Ex.A- exchangeable acidity; ECEC- effective cation exchange capacity; BS- base saturation.

Table 4.11: Mean, standard deviation and coefficient of variation of some chemical properties of the soil studied

Soil/Parent materials	Physiograhic positions		pH	O.C	TN	Avail.P	Ex.A	H^+	Al^{3+}	Ca	Mg	K	NA	ECEC	BS	Mn	Fe	Cu	Zn
			H_20	g kg^{-1}		mg/kg	cmol/kg								%	Mg/kg			
Soils derived from Basalt	Crest	ẍ	5.32	14.52	1.5	1.04	3.89	2	1.89	5.32	1.18	0.48	0.29	11.16	69.35	29.46	99.56	1.22	0.76
		δ	0.68	8.55	0.88	1.56	2.93	1.32	1.93	3.04	0.53	0.59	0.12	6.57	9.54	17.24	38.52	0.52	0.76
		c.v	12.78	58.88	58.67	150.00	75.32	66.00	102.12	57.14	44.92	122.92	41.38	58.87	13.76	58.52	38.69	42.62	100.00
	Upper slope	ẍ	4.97	14.26	1.55	0.85	3.14	1.4	1.36	4.85	1.08	0.34	0.31	10.06	72.97	17.8	112.74	1.31	1.17
		δ	0.52	6.7	0.82	0.9	2.32	0.55	1.71	3.37	0.47	0.43	0.12	6.05	6.12	13.18	48.26	0.72	1.95
		c.v	10.46	46.98	52.90	105.88	73.89	39.29	125.74	69.48	43.52	126.47	38.71	60.14	8.39	74.04	42.81	54.96	166.67
	Middle slope	ẍ	5.33	12.469	1.292	2.613	3.66	1.22	2.44	5.227	1.107	0.466	0.3	10.76	66.928	35.13	118.47	0.87	2.783
		δ	0.44	7.13	0.74	3.2	2.45	0.48	2.44	3.27	0.73	0.36	0.08	6.33	8.98	25.15	87.49	0.5	2.83
		c.v	8.26	57.18	57.28	122.46	66.94	39.34	100.00	62.56	65.94	77.25	26.67	58.83	13.42	71.59	73.85	57.47	101.69
	Lower slope	ẍ	5.18	12.51	1.28	1.98	4.12	1.7	2.42	5.33	1.31	0.39	0.29	11.44	62.25	58.48	122.76	1.2	2.54
		δ	0.26	6.35	0.64	1.83	1.74	0.8	2	3.34	0.7	0.26	0.08	5.48	11.84	30.87	71	0.88	2.36
		c.v	5.02	50.76	50.00	92.42	42.23	47.06	82.64	62.66	53.44	66.67	27.59	47.90	19.02	52.79	57.84	73.33	92.91
	Valley bottom	ẍ	5.32	9.39	0.97	2.22	3.09	0.95	2.14	5.5	1.25	0.36	0.29	10.49	73.82	79.43	130.25	1.25	1.52
		δ	0.46	6.66	0.69	2.95	2.3	0.41	2.08	3.42	0.89	0.25	0.06	6.56	10.21	43.31	67.45	0.72	1.84
		c.v	8.65	70.93	71.13	132.88	74.43	43.16	97.20	62.18	71.20	69.44	20.69	62.54	13.83	54.53	51.79	57.60	121.05
Soils derived from Granite	Crest	ẍ	5.12	16.47	1.59	4.1	5.02	3.56	1.46	6.23	1.07	0.35	0.43	13.09	66.32	22.54	70.93	1.12	0.99
		δ	0.5	7.66	0.77	3.82	4.23	2.72	1.73	0.65	1.22	0.22	0.16	4.25	17.96	19.65	57.01	0.62	0.62
		cv	9.77	46.51	48.43	93.17	84.26	76.40	118.49	10.43	114.02	62.86	37.21	32.47	27.08	87.18	80.38	55.36	62.63
	Upper slope	ẍ	5.35	17.51	1.69	3.76	7.95	3.3	4.65	6.68	1.74	0.89	0.41	17.67	57.72	15.96	104.67	1.18	1.52
		δ	0.43	8.95	0.85	3.93	3.92	2.81	3.04	0.71	1.88	0.66	0.11	3.84	17.09	16.39	83.24	0.88	0.83
		cv	8.04	51.11	50.30	104.52	49.31	85.15	65.38	10.63	108.05	74.16	26.83	21.73	29.61	102.69	79.53	74.58	54.61
	Middle slope	ẍ	5.28	16.86	1.64	2.48	5.9	2.33	3.57	7.03	0.88	0.32	0.37	14.49	60.49	13.37	105.87	1.61	1.12
		δ	0.3	8.51	0.79	2.73	2.54	1.44	1.91	0.73	0.7	0.14	0.2	2.68	10.56	19.52	94.71	0.76	0.69
		cv	5.68	50.47	48.17	110.08	43.05	61.80	53.50	10.38	79.55	43.75	54.05	18.50	17.46	146.00	89.46	47.20	61.61
	Lower slope	ẍ	5.17	15.12	1.33	3.09	5.24	1.67	3.57	8.4	1.69	0.95	0.37	16.7	68.82	74.38	125.93	1.51	2.38
		δ	0.42	14.59	1.13	4.25	2.43	0.73	2.12	2.5	1.84	0.46	0.14	5.01	12.04	107.09	93.94	1.15	2.17
		c.v	8.12	96.49	84.96	137.54	46.37	43.71	59.38	29.76	108.88	48.42	37.84	30.00	17.49	143.98	74.60	76.16	91.18
	Valley bottom	ẍ	5.09	11.43	1.1	3.42	4.67	2.07	2.6	7.58	1	0.63	0.41	14.27	68.96	27.56	114.1	1.61	1.82
		δ	0.25	5.74	0.56	3.64	3.17	1.53	2.48	1.13	0.99	0.42	0.18	2.11	18.18	19.45	61.45	1.57	1.6
		c.v	4.91	50.22	50.91	106.43	67.88	73.91	95.38	14.91	99.00	66.67	43.90	14.79	26.36	70.57	53.86	97.52	87.91

Table 4.11: Mean, standard deviation and coefficient of variation of some chemical properties of the soils studied cont'd

Soil/Parent materials	Physiograhic positions		pH	O.C	TN	Avail.P	Ex.A	H^+	Al^{3+}	Ca	Mg	K	NA	ECEC	BS	Mn	Fe	Cu	Zn
			H_20	g/kg		mg/kg	cmol//kg								%	mg/kg			
Soils derived from Unsonsolidated deposits	Crest	ẍ	5.1	10.86	1.09	9.63	4.91	2.33	2.58	9.04	1.03	0.28	0.37	15.64	70.56	10.92	89.2	2.27	2.02
		δ	0.5	5.45	0.55	15.49	4.35	1.46	3.1	2.45	0.78	0.22	0.25	2.65	23.9	12.76	32.9	2.07	1.87
		c.v	9.80	50.18	50.46	160.85	88.59	62.66	120.16	27.10	75.73	78.57	67.57	16.94	33.87	116.85	36.88	91.19	92.57
	Upper slope	ẍ	5.06	10.7	1.02	4.86	4.29	1.66	2.63	9.26	1.11	0.43	0.42	15.66	74.76	15.5	175.9	1.66	3.1
		δ	0.4	6.25	0.72	4.8	4.24	1.05	3.26	2.4	0.87	0.35	0.16	3.07	21.87	17.77	168.91	1.13	1.72
		c.v	7.91	58.41	70.59	98.77	98.83	63.25	123.95	25.92	78.38	81.40	38.10	19.60	29.25	114.65	96.03	68.07	55.48
	Middle slope	ẍ	5.28	14.48	1.39	4.26	4.7	2.44	2.26	8.7	1.19	0.46	0.33	15.35	71.28	16.52	164.52	1.96	2.5
		δ	0.56	7.01	0.7	4.25	3.97	2.13	2.54	2.2	0.92	0.47	0.17	3.3	18.94	13.51	124.36	1.6	1.75
		c.v	10.61	48.41	50.36	99.77	84.47	87.30	112.39	25.29	77.31	102.17	51.52	21.50	26.57	81.78	75.59	81.63	70.00
	Lower slope	ẍ	5.45	9.6	1.03	4.09	3.74	1.9	1.84	9.37	1.32	0.44	0.52	15.38	75.85	10.64	125.23	2.24	3.19
		δ	0.65	5.64	0.58	5.26	3.28	1.13	2.24	2.95	1.11	0.41	0.36	2.68	19.24	6.7	86.43	1.78	1.55
		c.v	11.93	58.75	56.31	128.61	87.70	59.47	121.74	31.48	84.09	93.18	69.23	17.43	25.37	62.97	69.02	79.46	48.59
	Valley bottom	ẍ	5.58	7.29	0.85	7.64	5.11	3.08	2.04	8.36	1.17	0.26	0.47	15.37	68.41	8.98	69.49	2.18	2.26
		δ	0.79	4.43	0.55	6.69	3.78	2.16	2.32	1.59	1.01	0.23	0.35	2.69	19.33	8.56	35.45	1.89	1.5
		c.v	14.16	60.77	64.71	87.57	73.97	70.13	113.73	19.02	86.32	88.46	74.47	17.50	28.26	95.32	51.01	86.70	66.37

Foot note: ẍ = mean, δ = standard deviation, c.v = coefficient of variation pH in water ranged from 4.4 (extremely acid) to 7.04 (neutral), with a grand mean of 5.30 (strongly acid) for the soils formed on Unconsolidated deposits. All the soils in the different physiographic positions except the soils of the valley bottom physiographic positions, were strongly acidic with mean pH ranging from 5.06 to 5.45, while soils of the valley bottom physiographic positions, were moderately acidic with mean pH of 5.58. Soil pH had the highest coefficient of variation of 14.16%, for soils of the valley bottom physiographic positions while the least coefficient of variation of 7.91% was in respect of soils of the upper slope physiographic positions, Table 4.11 refers. The coefficient of variation of 11.93% for soil pH and in respect of soils of the lower slope positions, was the second highest.

The pH of some of the soils formed on Basalt and Granite was constantly higher in the lower horizons than it was for the overlying, upper horizons, however, for the soils formed on Unconsolidated deposits, the pH showed no specific trend down the soil profile. All the three categories of soils investigated were acidic, with their mean pH being in the strongly acidic bracket.

Exchange acidity

Exchange acidity ranged from 0.4-8.0 cmol/kg, and having a grand mean of 3.58 cmol/kg, for the soils formed on Basalt. Soils of the lower slope positions had the highest Exchange Acidity, having a mean of 4.12 cmol/kg while soils of the valley bottom positions had the least, having a mean of 3.09 cmol/kg. Soils of the crest and middle slope positions did not differ much in their Exchange Acidity with means of 3.89 cmol/kg and 3.66 cmol/kg respectively. Exchange Acidity had the highest coefficient of variation of 75.32% for soils of the crest positions while the least coefficient of variation of 42.23%, was recorded for soils of the lower slope positions. The coefficients of variation for Exchange Acidity were generally high for soils of the different physiographic positions, Table 4.11 refers.

Exchange Acidity ranged from 0.75-12.4 cmol/kg, and had a grand mean of 5.76 cmol/kg, for the soils formed on Granite. Soils of the upper slope positions had the highest Exchange Acidity, having a mean of 7.95 cmol/kg while soils of the valley bottom positions had the lowest, having a mean of 4.67 cmol/kg, Table 4.11 refers. Soils of the crest and lower slope positions did not differ much in their Exchange Acidity with means of 5.02 cmol/kg and 5.24

cmol/kg, respectively. Exchange Acidity had the highest coefficient of variation of 84.26% for the soils of the crest positions while the lowest coefficient of variation of 43.05%, was recorded for soils of the middle slope positions, Table 4.11 refers. Coefficient of variation for Exchange Acidity for the soils were moderate to very high.

Exchange Acidity ranged from 0.6-13.9 cmol/kg, and had a grand mean of 4.55 cmol/kg, for the soils formed on Unconsolidated deposits. Soils of the valley bottom positions had the highest Exchange Acidity, having a mean of 5.11 cmol/kg, while soils of the lower slope positions had the lowest, having a mean of 3.74 cmol/kg, Table 4.11 refers. Soils of the upper and middle slope positions did not differ much in their Exchange Acidity. Coefficient of variation for Exchange Acidity was highest for soils of the upper slope positions (98.77%) and lowest for soils of the valley bottom positions (73.97%). The coefficient of variation for Exchange Acidity were generally very high for the soils of the different physiographic positions. Exchange Acidity was notably higher for the soils formed on Granite than those formed on Basalt and Unconsolidated deposits, similarly, Exchange Acidity was notably higher for the soils formed on Unconsolidated deposits than those formed on Basalt.

Exchangeable Hydrogen ranged from 0.4-4.6 cmol/kg, and had a grand mean of 1.45 cmol/kg, for the soils formed on Basalt. Soils of the crest positions had the highest amounts of exchangeable Hydrogen having a mean of 2.0 cmol/kg, while the lowest amounts were recorded in the soils of the valley bottom positions having a mean of 0.95 cmol/kg. Soils of the upper and middle slope positions did not differ much in their amounts of exchangeable Hydrogen, Table 4.11 refers.

The coefficient of variation for exchangeable Hydrogen was highest (66%) for the soils of the crest positions and lowest (39.29%) for soils of the upper slope positions. Coefficients of variation for exchangeable Hydrogen for the soils, were moderate to high, Table 4.11 refers.

Exchangeable Aluminium ranged from 0.0-6.2 cmol/kg, and had a grand mean of 2.05 cmol/kg, for the soils formed on Basalt. The soils in the middle slope positions had the highest amounts of exchangeable Aluminium having a mean of 2.44 cmol/kg, while soils of the upper slope positions had the lowest amounts having a mean of 1.36 cmol/kg. Soils of the lower slope positions had the second highest amounts of exchangeable Aluminium, with a mean of 2.42 cmol/kg, next to the soils of the middle slope positions.

Coefficient of variation for Aluminium was highest (125.74%), for soils of the upper slope positions, while it was lowest (82.64%) for soils of the lower slope positions, Table 4.11 refers. The coefficients of variation for exchangeable Aluminium were very high for soils of all the physiographic positions. Exchangeable Aluminium accounted for a relatively higher proportion of the ExchangeAcidity of the soils formed on Basalt.

Exchangeable Hydrogen ranged from 0.1-9.2 cmol/kg, with a grand mean of 2.59 cmol/kg, for the soils formed on Granite. Exchangeable Hydrogen was highest for soils of the crest positions, having a mean of 3.56 cmol/kg, while it was lowest for the soils of the lower slope positions having a mean of 1.67 cmol/kg, Table 4.11 refers. Soils of the middle slope and valley bottom positions did not differ much in exchangeable Hydrogen levels while soils of the upper slope positions had higher levels than the soils of the two physiographic positions. Coefficient of variation for exchangeable Hydrogen was highest (85.15%) for soils of the upper slope positions and lowest (43.71%) for soils of the lower slope positions. Coefficient of variation for exchangeable Hydrogen for soils of all the physiographic positions were generally high.

Exchangeable Aluminium ranged from 0.0-8.5 cmol/kg, and had a mean of 3.17 cmol/kg for the soils formed on Granite. Soils of the upper slope positions had the highest amounts having a mean of 4.65 cmol/kg, while soils of the crest positions had the lowest amounts having a mean of 1.46 cmol/kg. Soils of the middle and lower slopes positions had about same levels of exchangeable Aluminium having a mean of 3.57 cmol/kg each, while soils of the valley bottom positions had less.

Exchangeable Aluminium had the highest coefficient of variation of 118.49% for soils of the middle slope positions and the lowest coefficient of variation of 53.50%, for soils of the middle slope positions, Table 4.11 refers. The coefficient of variation for Aluminium for soils of all the physiographic positions, were generally high. Exchangeable Aluminium contributed relatively more, to the exchange acidity of the soils formed on Granite than exchangeable Hydrogen.

Exchangeable Hydrogen ranged from 0.6-8.3 cmol/kg, and had a grand mean of 2.28 cmol/kg, for the soils formed on Unconsolidated deposits. Soils of the valley bottom positions had the highest amounts, having a mean of 3.08 cmol/kg, while soils of the upper slope positions had the lowest amounts with a mean of 1.66 cmol/kg. Soils of the crest and middle slope positions did not differ much in their amounts of exchangeable Hydrogen with means of 2.33 0.6 cmol/kg and 2.44 0.6 cmol/kg respectively, Table 4.11 refers. The highest coefficient of variation 87.30% for exchangeable Hydrogen, was recorded in respect of soils of the middle slope positions while the lowest coefficient of variation of 59.47%, was recorded in respect of soils of the lower slope positions. Coefficients of variation for exchangeable Hydrogen for soils of all the physiographic positions were high.

Exchangeable Aluminium ranged from 0.0-8.7 cmol/kg, and had a grand mean of 2.27 cmol/kg, for the soils formed on Unconsolidated deposits. Soils of the upper slope positions had the highest amounts with a mean of 2.63 cmol/kg, while soils of the lower slope positions had the lowest amounts, having a mean of 1.84 cmol/kg. Soils of the crest and middle slopes positions had about same amounts of exchangeable Aluminium while soils of the valley bottom positions had relatively less exchangeable Aluminium than the soils of the said two physiographic positions, Table 4.11 refers.

The highest coefficient of variation 123.95% for exchangeable Aluminium was recorded for soils of the upper slope positions while the lowest coefficient of variation of 112.39%, was recorded for the soils of the middle slope positions. The coefficients of variation for exchangeable Aluminium were very high for soils of all the physiographic positions. Exchangeable Aluminium and exchangeable Hydrogen contributed about same proportions to the exchange Acidity of the soils formed on Unconsolidated deposits with grand means of 2.27 cmol/kg and 2.28 cmol/kg respectively.

Organic carbon

Organic carbon ranged from 0.76-27.20 g/kg, and had a grand mean of 12.63 g/kg, for the soils formed on Basalt. Soils of the crest positions were highest in organic carbon with a mean of 14.52 g/kg while soils of the valley bottom positions were lowest, with a mean of 9.39 g/kg. Soils of the middle and lower slopes positions had about same amounts of organic carbon with means of 12.47 and 12.51 g/kg respectively, while soils of the upper slope positions had higher amounts than the soils of the two physiographic positions referred to; Table 4.11 refers. Coefficient of variation for carbon had its highest value of 70.93% for soils of the valley bottom positions and the lowest of 46.98% for soils of the upper slope positions, Table 4.11 refers. Organic carbon had about same coefficient of variation for soils of the crest and middle slope positions with values of 58.88% and 57.18% respectively.

Organic carbon ranged from 0.32-48.26 g/kg, and had a grand mean of 15.48 g/kg, for the soils formed on Granite. Soils of the upper slope positions were highest organic carbon, with a mean of 17.51 g/kg while soils of the valley bottom positions had lowest, with a mean of 11.43 g/kg, Table 4.11 refers. Soils of the crest and middle slope positions had about same amounts of organic carbon with means of 16.47 and 16.86 g/kg respectively while soils of the lower slope positions had less, having a mean of 15.12 g/kg. Organic carbon had the highest coefficient of variation of 96.49%, for soils of the lower slope positions while it had the lowest value (46.51%), for soils of the crest positions. The other physiographic positions had about same magnitude of coefficients of variation for organic carbon.

Organic carbon ranged from 0.68-28.37 g/kg, and had a grand mean of 10.59 g/kg. for the soils formed on Unconsolidated deposits. Soils of the middle slope positions were highest in organic carbon, with a mean of 14.48 g/kg while soils of the valley bottom positions were lowest, with a mean of 7.29 g/kg. Soils of the crest and upper slope positions had about same amounts of organic carbon, with means of 10.86 and 10.70 g/kg respectively while soils of the lower slope positions had relatively less, Table 4.11 refers. The highest coefficient of variation for organic carbon (60.77%), was recorded for soils of the valley bottom positions while the lowest (48.41%), was recorded for soils of the middle slope positions, Table 4.11

refers. The coefficients of variation for organic carbon did not differ much for the soils of the upper and lower slope positions, while the amount was less for soils of the crest positions.

The soils formed on Granite were notably higher in organic carbon than those formed on Basalt and Unconsolidated deposits. Similarly, the soils formed on Basalt, were notably higher in organic carbon than the soils formed on Unconsolidated deposits. The surface horizons of the soils were generally higher in organic carbon than the sub-surface horizons. Most of the soils had moderate (10-14 g/kg) to high (14-20 g/kg) levels of organic carbon. However, some of the soils were very low or low in organic carbon.

Total nitrogen

Total Nitrogen was in the range 0.08-2.90 g/kg, and having a grand mean of 1.32 g/kg, for the soils formed on Basalt. Soils of the upper slope positions had the highest amounts of Nitrogen with a mean of 1.55 g/kg while soils of the valley bottom physiographic positions had the lowest amounts, having a mean of 0.97 g/kg. Soils of the other physiographic positions did not differ much in their amounts of Total Nitrogen Table 4.11 refers. Total Nitrogen had the highest coefficient of variation of 71.13%, for soils of the valley bottom positions while the lowest coefficient of variation of 50% was recorded for soils of the lower slope positions. The coefficients of variation for Total Nitrogen for soils of the crest and middle slope positions did not differ much, while the coefficient of variation for Total Nitrogen for soils of the upper slope physiographic positions was relatively less than for the two physiographic positions referred to, Table 4.11 refers.

Total Nitrogen ranged from 0.03-3.38 g/kg, and had a grand mean of 1.47 g/kg, for the soils formed on Granite. Soils of the upper slope positions had the highest amounts of Total Nitrogen having a mean of 1.69 g/kg while soils of the valley bottom positions had the lowest amounts, having a mean of 1.1 g/kg, Table 4.11 refers. Soils of the crest and middle slope positions had about same amounts of Total Nitrogen, with means of 1.59 and 1.64 g/kg respectively, while soils of the lower slope positions had less amounts with a mean of 1.33 g/kg. Coefficient of variation for Total Nitrogen was highest (84.96%), for soils of the lower slope positions and lowest (48.17%), for soils of the middle slope positions. The coefficients of variation for Total Nitrogen for soils of the other physiographic positions did not differ much from one another, Table 4.11 refers.

Total Nitrogen was in the range 0.03-2.42 g/kg and had a grand mean of 1.08 g/kg for the soils formed Unconsolidated deposits. Soils of the middle slope positions had the highest amounts of Total Nitrogen having a mean of 1.39 g/kg while soils of the valley bottom positions had the lowest amounts with a mean of 0.85 g/kg, Table 4.11 refers. Soils of the crest, upper and lower slope positions did not differ much in their amounts of Total Nitrogen. Total Nitrogen had the highest coefficient of variation of 70.59% for soils of the upper slope positions while it had the lowest coefficient of variation of 50.36% for soils of the middle slope positions. The soils of the other physiographic positions had varying coefficients of variation for Total Nitrogen, between the two extremes.

The soils formed on Granite and Basalt were relatively higher in Total Nitrogen than the soils formed on Unconsolidated deposits while the soils formed on Granite and Basalt, had about same levels of Total Nitrogen. Most of the soils investigated were inadequate in Total Nitrogen, being in the low to medium range (0.6 g/kg to 2.0 g/kg). Some of the soils however, had high levels of Total Nitrogen. The surface horizons of the soils were generally higher in Total Nitrogen than the sub-surface horizons.

Available phosphorus

Available phosphorus was in the range 0.01-10.08 mg/kg, and having a grand mean of 1.74 mg/kg, for the soils formed on Basalt. Soils of the middle slope positions had the highest amounts of available phosphorus having a mean of 2.613 mg/kg while soils of the upper slope positions had the lowest amounts, with a mean of 0.85 mg/kg. Soils of the lower slope and valley bottom positions did not differ much in available phosphorus having means of 1.98 and 2.22 mg/kg respectively, while soils of the crest positions, had notably less, Table 4.11 refers. Available phosphorus had the highest coefficient of variation of 150% for soils of the crest positions and the lowest coefficient of variation of 92.43%, for soils of the lower slope positions. The coefficients of variation for available phosphorus for the other physiographic positions were also very high, Table 4.11 refers.

Available phosphorus was in the range 0.04-14.40 mg/kg, and had a grand mean of 3.37 mg/kg, for the soils formed on Granite. Soils of the crest positions had the highest amounts of available phosphorus having a mean of 4.1 mg/kg, while soils of the middle slope positions had the lowest amounts with a mean of 2.48 mg/kg. Soils of the lower slope and valley bottom positions did not differ much in available phosphorus having means of 3.09 and 3.42 mg/kg respectively, while soils of the upper slope physiographic positions had higher available phosphorus, with a mean of 3.76 mg/kg, Table 4.11 refers.

The coefficient of variation for available phosphorus was highest (137.54%) for soils of the lower slope positions and lowest (93.17%), for soils of the crest positions. The coefficients of variation for available phosphorus for the other physiographic positions were also very high, Table 4.11 refers.

Available phosphorus was in the range 0.06-50.14 mg/kg and having a grand mean of 6.10 mg/kg for the soil formed on Unconsolidated deposits. Soils of the crest positions had the highest amounts of available phosphorus having a mean of 9.63 mg/kg while soils of the lower slope positions had the lowest amounts, with a mean of 4.09 mg/kg. Soils of the other positions had means, available phosphorus ranging from 4.26 to 7.64 mg/kg, Table 4.11 refers.

The coefficient of variation for available phosphorus was highest (160.85%) for soils of the crest positions and lowest (87.57%), for soils of the valley bottom positions. The coefficients of variation for available phosphorus for the soils of the other positions were also very high ranging from (98.77%) to (128.61%).

The soils formed on Unconsolidated deposits were notably higher in available phosphorus than both the soils formed on Basalt and Granite. Similarly, the soils formed on Granite were notably higher in available phosphorus than the soils formed on Basalt. Most of the soils investigated were very low (< 3 mg/kg) or low (3-7 mg/kg) in available phosphorus. The surface horizons of the soils were generally higher in available phosphorus than the sub-surface horizons.

Exchangeable cations

Exchangeable calcium was in the range 2.02-9.58 cmol/kg and had a grand mean of 5.25 cmol/kg, for the soils formed on Basalt. Soils of the valley bottom positions had the highest amounts of exchangeable calcium having a mean of 5.5 cmol/kg, while soils of the upper slope positions had the least amounts with a mean of 4.85 cmol/kg. Soils of the other physiographic positions did not differ much in their amounts of exchangeable calcium, Table 4.11 refers. Exchangeable calcium had the highest coefficient of variation (69.48%), for soils of the upper slope positions and the lowest coefficient of variation (57.14%), for soils of the crest positions. The coefficients of variation for exchangeable calcium for the soils of the other positions, were almost at par, the Table 4.11 refers.

Exchangeable calcium was in the range 5.56-14.57 cmol/kg, and having a grand mean of 7.18 cmol/kg for the soils formed on Granite. Soils of the lower slope positions had the highest amounts of exchangeable calcium having a mean of 8.4 cmol/kg while soils of the crest positions had the lowest amounts, with a mean of 6.23 cmol/kg. Soils of the upper and middle slopes positions, had about same amounts of exchangeable calcium with means of 6.68 cmol/kg and 7.03 cmol/kg respectively, while soils of the valley bottom positions had a mean exchangeable calcium of 7.58 cmol/kg. The highest coefficient of variation (29.76%) for exchangeable calcium, was recorded for soils of the lower slope positions, while the lowest (10.38%), was recorded for soils of the middle slope positions, Table 4.11 refers. The coefficients of variation for exchangeable calcium for the soils of the crest and upper slope physiographic positions did not differ much from each other while the coefficient of variation for exchangeable calcium for soils of the valley bottom positions was relatively higher than for soils of the crest and upper slope positions referred to.

Exchangeable calcium was in the range 6.51-14.40 cmol/kg and with a grand mean of 8.95 cmol/kg, for the soils formed on Unconsolidated deposits. Soils of the lower slope positions had the highest amounts of exchangeable calcium having a mean of 9.37 cmol/kg, while soils of the valley bottom positions had the lowest amounts with a mean of 8.36 cmol/kg. Soils of the crest and upper slope positions did not differ much in their amounts of exchangeable calcium with means of 9.04 cmol/kg and 9.26 cmol/kg respectively. Soils of the middle slope positions had relatively less exchangeable calcium than the soils of the two physiographic positions just referred to, Table 4.11 refers.

The highest coefficient of variation for exchangeable calcium (31.48%), was recorded for soils of the lower slope positions while the lowest (19.02%), was recorded for soils of the valley bottom positions, Table 4.11 refers. The coefficients of variation for exchangeable calcium for the soils of the other physiographic positions, did not differ much from one another, the Table 4.11 refers.

The soils formed on Unconsolidated deposits were notably higher in exchangeable calcium than the soils formed on Basalt and Granite while the soils formed on Granite were notably higher in exchangeable calcium than the soils formed on Basalt. Most of the soils investigated had low to moderate (2-10 cmol/kg) levels of exchangeable calcium.

Exchangeable magnesium was in the range 0.15-2.70 cmol/kg and having a grand mean of 1.19 cmol/kg, for the soils formed on Basalt. Soils of the lower slope positions had the highest amounts of exchangeable magnesium with a mean of 1.31 cmol/kg while soils of the upper slope positions had the lowest amounts having a mean of 1.08 cmol/kg. Soils of the crest and middle slopes positions had about same amounts of exchangeable magnesium with means of 1.18 cmol/kg and 1.11 cmol/kg respectively, the Table 4.11 refers. Soils of the valley bottom positions had relatively more exchangeable magnesium than soils of the crest and middle slope positions, the Table 4.11 refers. Exchangeable magnesium had the highest coefficient of variation (71.20%), for soils of the valley bottom positions and the lowest coefficient of variation (43.52%), for the soils of the upper slope positions. Coefficients of variation for exchangeable magnesium for soils of the other physiographic positions varied but were within the highest and lowest limits, Table 4.11 refers.

Exchangeable magnesium was in the range 0.10-6.41 cmol/kg, and with a grand mean of 1.28 cmol/kg for the soils formed on Granite. Soils of the upper slope positions had the highest amounts of exchangeable magnesium having a mean of 1.74 cmol/kg while soils of the middle slope positions had the lowest amounts with a mean of 0.88 cmol/kg, Table 4.11 refers. Soils of the crest and valley bottom positions had about same amounts of exchangeable magnesium with means of 1.07 cmol/kg and 1.0 cmol/kg respectively while soils of the lower slope positions had higher amounts than soils of the crest and valley bottom positions. The coefficient of variation for exchangeable magnesium was highest (114.02%) for soils of the crest positions and lowest (79.55%), for soils of the middle slope positions. The coefficients of variation for exchangeable magnesium for the soils of the other physiographic positions did not differ much from one another and were very high too.

Exchangeable magnesium was in the range 0.05-2.95 cmol/kg and having a grand mean of 1.61 cmol/kg for the soils formed on Unconsolidated deposits. Soils of the lower slope positions had the highest amounts of exchangeable magnesium having a mean of 1.32 cmol/kg while soils of the crest positions had the least amounts with a mean of 1.03 cmol/kg. Soils of the other physiographic positions did not differ much from one another, in their amounts of exchangeable magnesium, Table 4.11 refers.

The coefficient of variation for exchangeable magnesium was highest (86.32%) for soils of the valley bottom positions and lowest (75.73%), for soils of the crest positions. The coefficients of variation for exchangeable magnesium for soils of the upper and middle slope positions did not differ much from each other in amounts while the coefficient of variation for exchangeable magnesium for the soils of the lower slope positions, was higher than for both the soils of the upper slope positions as well as the middle slopes positions.

The soils formed from Basalt and Granite did not differ much in their levels of exchangeable magnesium. The soils formed on Unconsolidated deposits were higher in exchangeable magnesium than those from Basalt and Granite. Most of the soils had low to moderate (0.3-3.0 cmol/kg) levels of exchangeable magnesium.

Exchangeable potassium was in the range 0.03-1.85 cmol/kg and with a grand mean of 0.41 cmol/kg for the soils formed on Basalt. Soils of the crest positions had the highest amounts of exchangeable potassium with a mean of 0.48 cmol/kg while soils of the upper slope physiographic position had the lowest amounts, having a mean of 0.34 cmol/kg. Soils of the lower slope and valley bottom positions had about same amounts of exchangeable potassium with means of 0.39 and 0.36 cmol/kg respectively, while soils of the middle slope positions had relatively higher amounts of exchangeable potassium than soils of the lower slope and valley bottom positions, Table 4.11 refers. The coefficient of variation for exchangeable potassium was highest (126.47%) for soils of the upper slope positions while the lowest value (66.67%), was recorded for soils of the lower slope positions. The coefficients of variation for exchangeable potassium for soils of the other physiographic positions varied but were all high or very high, Table 4.11 refers.

Exchangeable potassium was in the range 0.18-2.43 cmol/kg and with a grand mean of 0.63 cmol/kg, for the soils formed on Granite. Soils of the lower slope positions had the highest amounts of exchangeable potassium having a mean of 0.95 cmol/kg, while soils of the middle slope positions had the lowest amounts, with a mean of 0.32 cmol/kg. Soils of the upper slope positions had notable amounts of exchangeable potassium with a mean of 0.89 cmol/kg while soils of the remaining positions had less amounts of exchangeable potassium than soils of the upper slope positions, Table 4.11 refers.

Exchangeable potassium had the highest coefficient of variation (74.16%), for soils of the upper slope positions and the lowest coefficient of variation (43.75%) for soils of the middle slope positions, Table 4.11 refers. The coefficients of variation for exchangeable potassium for the soils of the other physiographic positions are as contained in Table 4.11.

Exchangeable potassium was in the range 0.04-1.39 cmol/kg and with a grand mean of 0.37 cmol/kg, for the soils formed on Unconsolidated deposits. Soils of the middle slope positions had the highest amounts of exchangeable potassium having a mean of 0.46 cmol/kg, while soils of the valley bottom positions had the lowest amounts with a mean of 0.26 cmol/kg. Soils of the upper and lower slopes positions had about same amounts of exchangeable potassium, while soils of the crest positions had less amounts of exchangeable potassium than soils of the upper and lower slopes positions.

The highest coefficient of variation for exchangeable potassium (102.17%) was in respect of soils of the middle slope positions while the lowest (78.57%) was recorded for soils of the crest positions. The coefficients of variation for exchangeable potassium for soils of the other positions are as contained in the Table 4.11.

The soils formed on Granite were notably higher in exchangeable potassium than the soils formed on Basalt and Unconsolidated deposits. The soils formed on basalt and Unconsolidated deposits hard about same levels of exchangeable potassium. Most of the soils investigated had low to moderate (0.2-0.6 cmol/kg) levels of potassium.

Exchangeable sodium was in the range 0.11-0.46 cmol/kg, with a grand mean of 0.30 cmol/kg for the soils formed on Basalt. The amounts of exchangeable sodium for soils of all the physiographic positions did not differ much from one another with means ranging from 0.29 cmol/kg to 0.31 cmol/kg, Tables 4.11 refers. The highest coefficient of variation for exchangeable sodium (41.38%), was recorded for soils of the crest positions while the lowest (20.69%) was recorded for soils of the valley bottom positions. The coefficients of variation for exchangeable sodium for the soils of the other physiographic positions as contained in the Table 4.11.

Exchangeable sodium was in the range 0.14-0.61 cmol/kg and had a grand mean of 0.40 cmol/kg for the soils formed on Granite. The soils of the different physiographic positions did not differ much from one another in their amounts of exchangeable sodium, with means ranging from 0.37 cmol/kg to 0.43 cmol/kg, Table 4.11 refers. The coefficient of variation for exchangeable sodium was highest (54.05%) for soils of the middle slope positions and lowest (26.83%) for soils of the upper slope positions, Table 4.11 refers. The coefficients of variation for exchangeable sodium for soils of the other physiographic positions, are as contained in the Table 4.11.

Exchangeable sodium was in the range 0.10-1.21 cmol/kg and having a grand mean of 0.42 cmol/kg for the soils formed on Unconsolidated deposits. Soils of the lower slope positions had the highest amounts of exchangeable sodium having a mean of 0.52 cmol/kg while soils of the middle slope positions had the lowest amounts, having a mean of 0.33 cmol/kg, Table 4.11 refers. Soils of the crest and upper slope positions had about same levels of exchangeable sodium while soils of the valley bottom positions had higher levels than soils of the crest and upper slopes positions, Table 4.11 refers.

The highest coefficient of variation for exchangeable sodium (74.47%) was recorded for soils of the valley Bottom positions while the lowest coefficient of variation (38.10%) was in respect of soils of the upper slope positions. The values for soils of the other physiographic positions are as contained in the Table 4.11.

Some of the soils formed on Basalt especially in the Vom area, had higher exchangeable calcium and magnesium than soils formed on Granite and Unconsolidated deposits, whereas, some soils formed on Basalt especially around Riyom, were generally lower in exchangeable calcium and magnesium than those formed on Granite and Unconsolidated deposits.

The range in Effective Cation Exchange Capacity was 3.40-20.39 cmol/kg, with a grand mean of 10.78 cmol/kg, for the soils formed on Basalt. Soils of the lower slope positions had the highest amounts of Effective Cation Exchange Capacity having a mean of 11.44 cmol/kg while soils of the upper slope positions had the lowest amount with a mean of 10.06 cmol/kg. Soils of the other positions did not differ much from one another in their levels of Effective Cation Exchange Capacity, Table 4.11 refers. The coefficient of variation for Effective Cation Exchange Capacity had its highest amount (62.54%), for soils of the valley bottom physiographic positions, while the lowest amount (47.90%), was recorded for soils of the lower slope positions. The coefficients of variation for Effective Cation Exchange Capacity for the soils of the other physiographic positions, did not differ much from one another, Table 4.11 refers.

The range in Effective Cation Exchange Capacity was 8.84-28.69 cmol/kg, with a grand mean of 15.24 cmol/kg for the soils formed on Granite. Soils of the upper slope positions had the highest ECEC having a mean of 17.67 cmol/kg while soils of the crest positions had the lowest Effective Cation Exchange Capacity with a mean of 13.09 cmol/kg. Soils of the middle slope and valley bottom positions had about same levels of Effective Cation Exchange Capacity while soils of the lower slope positions, had higher Effective Cation Exchange Capacity than soils of the middle slope and valley bottom positions, Table 4.11 refers.

Effective Cation Exchange Capacity had its highest coefficient of variation (32.47%) for the soils of the crest positions and the lowest (14.79%), for soils of the valley bottom positions,

Table 4.11 refers. The coefficients of variation for Effective Cation Exchange Capacity for soils of the upper and middle slopes positions did not differ much from each other while the coefficient of variation for soils of the lower slope positions, was notably higher than the values recorded for soils of the upper and middle slopes positions, Table 4.11 refers.

Effective cation exchange capacity was in the range 9.94-21.94 cmol/kg and with a grand mean of 15.48 cmol/kg, for the soils formed on Unconsolidated deposits. Soils of the different physiographic positions did not differ much from one another in their Effective Cation Exchange Capacity, Table 4.11 refers. The highest coefficient of variation (21.50%) for Effective Cation Exchange Capacity, was recorded for soils of the middle slope positions while the lowest coefficient of variation (16.94%) was recorded for soils of the crest positions. The coefficient of variation for Effective Cation Exchange Capacity for soils of the lower slope and valley bottom positions did not differ much from each other but that of soils of the upper slope positions, was relatively higher than the coefficients of variation for soils of the lower slope and valley bottom positions.

The soils formed on Granite had notably higher Effective Cation Exchange Capacity than the soils formed on Basalt but had about same level of Effective Cation Exchange Capacity with the soils formed on Unconsolidated deposits. Most of the soils investigated had low to moderate (6-25 cmol/kg) Effective Cation Exchange Capacity. Most of the soils formed on Basalt in the Riyom area had very low Effective Cation Exchange Capacity while most of the soils formed on Basalt in Vom area had moderate Effective Cation Exchange Capacity that was relatively at par with the Effective Cation Exchange Capacity of the soils formed on Granite and Unconsolidated deposits.

Base saturation percentage ranged from 35.57% to 89.56%, with a grand mean of 69.10%, for the soils formed on Basalt. Soils of the valley bottom positions had the highest Base saturation percentages with a mean of 69.10% while soils of the lower slope positions had the lowest Base saturation percentages with a mean of 62.25%. Soils of the other physiographic positions did not differ much from one another in their Base saturation percentages, Table 4.11 refers.

The highest coefficient of variation (19.02%) for Base saturation percentage, was recorded in the soils of the lower slope positions while the lowest (8.39%), was recorded in soils of the upper slope positions, Table 4.11 refers. The coefficients of variation for Base saturation percentage for soils of the other physiographic positions, did not differ much from one another, Table 4.11 refers.

Base saturation percentage ranged from 38.83% to 93.87%, with a grand mean of 64.46% for the soils formed on Granite. Soils of the valley bottom positions had the highest Base saturation percentages with a mean of 68.96% while soils of the upper slope positions had the lowest, with a mean of 57.72%. Soils of the upper and lower slopes positions did not differ much in their Base saturation percentages while soils of the middle slope positions had relatively less Base saturation percentages than soils of the upper and lower slopes positions, Table 4.11 refers.

The highest coefficient of variation (29.61%) for Base saturation percentage, was recorded in soils of the upper slope positions while the lowest (17.46%) was recorded in the soils of the middle slope positions, Table 4.11 refers. The coefficients of variation for Base saturation percentage for soils of the other physiographic positions, are as contained in the Table 4.11.

Base saturation percentage ranged from 36.65% to 96.11%, with a grand mean of 72.17% for the soils formed on Unconsolidated deposits. Soils of the lower slopes positions had the highest Base saturation percentages with a mean of 75.85% while soils of the valley bottom positions, had the lowest with a mean of 68.41%. The base saturation percentages of the soils of the other positions, did not differ much from one another Table 4.11 refers.

Base saturation percentage had its highest coefficient of variation (33.87%), in the soils of the crest positions and its lowest (25.37%) in the soils of the lower slope positions. The coefficients of variation for base saturation percentage for the soils of the other physiographic positions, did not differ much from one another, Table 4.11 refers.

Micronutrients

Extractable manganese was in the range 0.4-146 g/kg and had a grand mean of 44.06 g/kg, for the soils formed on Basalt. Soils of the valley bottom positions had the highest levels of extractable manganese with a mean of 79.43 g/kg, while soils of the upper slope positions had the lowest levels having a mean of 17.8 g/kg, Table 4.11 refers. The extractable manganese of the soils of the other physiographic positions varied and are as contained in the Table 4.11.

The highest coefficient of variation for manganese (74.04%) was in respect of soils of the upper slope positions and the lowest (52.79%), was in respect of soils of the lower slope positions. The coefficients of variation for manganese for soils of the other physiographic positions are as contained in the Table 4.11.

Extractable manganese was in the range 0.80-242 g/kg, with a grand mean of 30.76 g/kg for the soils formed on Granite. Soils of the lower slope positions had the highest levels ofextractable manganese having a mean of 74.38 g/kg while soils of the middle slope positions had the lowest levels with a mean of 13.37 g/kg, Table 4.11 refers. The mean amounts of extractable manganese for the soils of the other physiographic positions are as contained in the Table 4.11.

The coefficient of variation for manganese was highest (146%), for soils of the middle slope positions while the lowest coefficient of variation (70.57%), was recorded in the soils of the valley bottom positions. The coefficients of variation for manganese for soils of the other physiographic positions were also high, Table 4.11 refers.

Extractable manganese was in the range 1.0-56.0 g/kg and having a grand mean of 12.51 g/kg, for the soils formed on Unconsolidated deposits. Soils of the middle slope positions had the highest levels of manganese having a mean of 16.52 g/kg, while soils of the valley bottom positions had the lowest levels, having a mean of 8.98 g/kg. Soils of the crest and lower slope positions had about same levels of extractable manganese while soils of the upper slope positions had notably more extractable manganese than the soils of the crest and lower slope positions Table 4.11 refers.

The highest coefficient of variation (116.85%) for extractable manganese, was recorded in soils of the crest positions while the lowest (62.97%) was recorded in soils of the lower slope positions. The coefficients of variation for extractable manganese for soils of the other physiographic positions were also high, Table 4.11 refers.

The soils formed on Basalt were notably higher in extractable manganese than the soils formed on Granite and Unconsolidated deposits; similarly, the soils formed on Granite had notably higher extractable manganese than the soils formed on unconsolidated deposits. All the soils investigated had moderate to high levels of manganese.

Extractable iron was in the range 24.10-276 g/kg and with a grand mean of 116.76 g/kg for the soils formed on Basalt. Soils of the valley bottom positions had the highest levels of iron with a mean of 130.25 g/kg, while soils of the crest positions had the lowest levels and having a mean of 99.56 g/kg. Soils of the other physiographic positions had high levels of iron, Table 4.11 refers. The coefficient of variation for iron was highest (73.85%) for the soils of the middle slope positions and lowest (38.69%) for the soils of the crest positions. The coefficients of variation for iron for the other positions were moderate, Table 4.11 refers.

Extractable iron was in the range 1.42-331 g/kg and having a grand mean of 104.3 g/kg for soils formed on Ganite. Soils of the lower slope positions had the highest levels of iron, with a mean of 125.93 g/kg, while soils of the crest positions had the lowest levels having a mean of 70.93 g/kg. Soils of the upper and middle slopes positions had about same levels of extractable iron, while soils of the valley bottom positions had higher levels of extractable iron than soils of the upper and middle slopes physiographic positions, Table 4.11 refers.

The coefficient of variation for extractable iron was highest (89.46%) for soils of the middle slope positions and lowest (53.86%), for soils of the valley bottom positions, Table 4.11 refers.

Extractable iron was in the range 28.6-506.0 g/kg and having a grand mean of 124.87 g/kg for the soils formed on Unconsolidated deposits. Soils of the upper slope positions had the highest levels of extractable iron having a mean of 175.9 g/kg, while soils of the valley bottom positions had the lowest levels, with a mean of 69.49 g/kg. The mean extractable iron for soils of the other physiographic positions are as contained in Table 4.11. Extractable iron had the highest coefficient of variation (96.03%) in the soils of the upper slope positions and the lowest (36.88%), in the soils of the crest positions, Table 4.11 refers.

The soils formed on Unconsolidated deposits, had notably higher levels of extractable iron than the soils formed on Granite but did not differ much from the soils formed on Basalt in levels of extractable iron. The soils formed on Basalt had notably higher levels of extractable iron than the soils formed on Granite. All the three groups of soils investigated were high in extractable iron.

Extractable copper ranged from 0.16 g/kg to 3.34 g/kg, with a grand mean of 1.17 g/kg, for the soils formed on Basalt. Soils of the various positions were relatively at par in their extractable copper contents, the only exceptions were the soils of the middle slope positions which had less, with a mean extractable copper of 0.87 g/kg, Table 4.11 refers. The highest coefficient of variation for copper (73.33%), was recorded in the soils of the lower slope positions while the lowest (42.62%), was recorded in the soils of the crest positions, Table 4.11 refers.

Extractable copper was in the range 0.20-85.0 g/kg and had a grand mean of 1.41 g/kg for soils formed on Granite. Soils of the crest and upper slope positions had about same levels of extractable copper with means of 1.12 and 1.18 g/kg respectively, while soils of the middle slope, lower slope and valley bottom positions had notably higher extractable copper with means of 1.61, 1.51 and 1.61 g/kg respectively. The coefficient of variation for extractable copper was highest (97.52%) for soils of the valley bottom positions and lowest (47.20%), for soils of the middle slope positions, Table 4.11 refers.

Extractable copper was in the range 0.10-5.48 g/kg and had a grand mean of 2.06 g/kg, for the soils formed on Unconsolidated deposits. Soils of the crest positions had the highest levels of extractable copper, having a mean of 2.27 g/kg while soils of the upper slope positions had the lowest levels, with a mean of 1.66 g/kg. The mean extractable copper for soils of the other positions are as presented in the Table 4.11. The highest coefficient of variation for copper (91.19%), was recorded in soils of the crest positions while the lowest (68.07%), was recorded in soils of the upper slope positions. The coefficients of variation for extractable copper for soils of the other physiographic positions were also high, Table 4.11 refers.

The soils formed on Unconsolidated deposits were notably higher in extractable copper than the soils formed on Basalt and Granite; similarly, the soils formed on Granite were notably higher in extractable copper than the soils formed on Basalt. The soils generally had low to moderate levels of copper.

Extractables zinc was in the range 0.04 g/kg to 9.30 g/kg and having a grand mean of 1.75 g/kg, for the soils formed on Basalt. Soils of the middle slope positions had the highest levels of extractable zinc, with a mean of 2.78 g/kg, while soils of the crest positions, had the lowest levels, having a mean of 0.76 g/kg. The mean extractable zinc for soils of the other positions are as presented in the Table 4.11. Extractables zinc had the highest coefficient of variation (166.67%) in the soils of the upper slope physiographic positions and the lowest coefficient of variation (92.91%), in the soils of the lower slope physiographic positions. The coefficients of variation for extractable zinc for the soils of the other physiographic positions were also very high and are as presented in the Table 4.11.

Extractables zinc was in the range 0.03-42.20 g/kg and having a grand mean of 1.57 g/kg for the soils formed on Granite. Soils of the lower slope positions had the highest levels of extractables zinc with a mean of 2.38 g/kg while soils of the crest physiographic positions had the lowest levels having a mean of 0.99 g/kg. the mean extractable zinc for soils of the other physiographic positions are as presented in the Table 4.11.

The highest coefficient of variation for extractable zinc (91.1 8%), was recorded in soils of the lower slope positions while the lowest coefficient of variation (54.61%), was recorded in soils of the upper slope positions. The coefficients of variation for extractable zinc for soils of the other physiographic positions were all high, Table 4.11 refers.

Extractable zinc was in the range 0.02-5.69 g/kg and having a grand mean of 2.61 g/kg, for the soils formed on Unconsolidated deposits. Soils of the lower slope positions had the highest levels of extractable zinc with a mean of 3.19 g/kg while soils of the crest positions had the lowest levels of extractable zinc, having a mean of 2.02 g/kg. soils of the other physiographic positions had moderate levels of extractable zinc, Table 4.11 refers.

The highest coefficient of variation for extractable zinc (92.57%), was recorded in soils of the crest positions while the lowest (48.59%), was recorded in soils of the lower slope positions. The coefficients of variation for extractable zinc for soils of the other physiographic positions were moderate or high, Table 4.11 refers.

The soils formed on Unconsolidated deposits had notably higher extractable zinc than the soils formed on Basalt and Granite while the soils formed on Basalt had notably higher extractables zinc than the soils formed on Granite. The soils investigated generally had low to moderate levels of extractable zinc.

4.5 Soil classification

In the USDA Soil Taxonomy (2014) system, the soils have been classified as follows:

4.5.1 Soils derived from Basalt

Soil profiles JP-BST1-1and JP-BST1-5 have less than 8% clay between 20cm and 50cm depth of the soils and have no argillic, kandic or natric horizon; they are in the order of Inceptisols. They have an ustic moisture regime and belong to the suborder of Ustepts. They belong to the great group of Haplustepts.

Soil profile JP-BST1-1 has more than 35% clay by volume, particles 2.0 mm or larger in diameter and its fine earth fraction contains 30% or more particles of 0.02 to 2.0 mm in diameter; it belongs to the subgroup of Vitrandic Haplustepts. Soil profile JP-BST1-5 in normal years is saturated with water in one or more layers within 100cm of the mineral soil surface for 20 or more consecutive days and 30 or more cumulative days; it is an Oxyaquic Haplustept.

Soil profiles JP-BST1-2 and JP-BST2-2 have a kandic horizon because of the high clay contents and a decrease in organic carbon down the profile; they have not less than 35% Base Saturation at a depth of 125 cm below the upper boundary of the kandic horizon; they are in the order of Alfisols. They have ustic moisture regime, they belong to the suborder of Ustalfs, they have a kandic horizon and belong to the great group of kandiustalfs. The soils have 5% or more (by volume) plinthite in one or more horizons within 150cm of the mineral soil surface, they belong to the subgroup of Plinthic Kandiustalfs.

Soil profiles JP-BST1-3, JP-BST1-4, JP-BST2-3 and JP-BST2-4, have an argillic horizon because of their high clay contents and do not have less than 35% Base Saturation at a depth of 125cm below the upper boundary of the argillic horizon; they belong to the order of Alfisols. They have an ustic moisture regime and belong to the suborder of Ustalfs; they all belong to the Great Group of Haplustalfs. The soils in normal years are saturated with water in one or more layers within 100 cm of the mineral soil surface for 20 or more consecutive days and 30 or more cumulative days; they are oxyaquic Haplustalfs.

Soil profiles JP-BST2-1 and JP-BST2-5, have a kandic horizon because of the clay contents of the affected horizons and do not have less than 35% Base saturation at a depth of 125 cm below the upper boundary of the kandic horizon; they are Alfisols. They have an ustic moisture regim and belong to the suborder of Ustalfs. They have a kandic horizon and are Kandiustalfs. Soil profile JP-BST2-5 has in one or more horizons within 75 cm of the mineral surface, redox depletions and also aquic conditions for some time in normal years; it is an aquic Kandiustalf. Soil profile JP-BST2-1 has 5% or more (by volume) plinthite in one or more horizons within 150 cm of the mineral soil surface, it is a Plinthic Kandiustalf.

4.5.2 Soils derived from Granite

Soil profiles JP-GNT1-1, JP-GNT1-2, JP-GNT1-3, JP-GNT1-4 and JP-GNT1-5, all have a kandic horizon with an accumulation of clay and have not less than 35% Base Saturation at a depth of 125cm below the upper boundary of the kandic horizon; they belong to the order of Alfisols. The soils have ustic moisture regime, they belong to the suborder of Ustalfs. They have a kandic horizon and belong to the great group of Kandiustalfs. Soil profiles JP-GNT1-1, JP-GNT1-2 and JP-GNT1-3, have 5% or more (by volume) plinthite in one or more horizons within 150 cm of the mineral soil surface; they belong to the subgroup of Plinthitic Kandiustalfs. Soil profiles JP-GNT1-4 and JP-GNT1-5 have in one or more horizons within 75cm of the mineral surface, redox depletions and also aquic conditions for some time in normal years; they belong to the subgroup of Aquic Kandiustalf. Soil profiles JP-GNT2-1 and JP-GNT2-2 have an argillic horizon with clay accumulation; they are in the order of Alfisols; they have ustic moisture regime and belong to the suborder of Ustalfs. They have a kandic horizon and belong to the great group of Kandiustalfs. The Soils have 5% or more (by volume) plinthite in one or more horizons within 150 cm of the mineral soil surface; they are plinthic Kandiustalfs.

Soil profiles JP-GNT2-3 and JP-GNT2-4 have an argillic horizon with clay accumulation and do not have less than 35% Base Saturation at a depth of 125 cm below the upper boundary of the argillic horizon; they are Alfisols. They have an ustic moisture regime and are Ustalfs. They belong to the Great Group of Haplustalfs. The soils in normal years are saturated with water in one or more layers within 100 cm of the mineral soil surface for 20 or more consecuve days and 30 or more cumulative days; they are oxyaquic Haplustalfs. Soil profile JP-GNT2-5 has less than 8% clay between 20 cm and 50 cm depth; it is in the order of Inceptisols. It has an ustic moisture regime and belongs to the suborder of Ustepts. It belongs to the great group of Haplustepts. The soil has in one or more horizons within 75 cm of the mineral surface, redox depletions and also aquic conditions for some time in normal years; it belongs to the subgroup of Aquic Haplustepts.

4.5.3 Soils derived from Unconsolidated deposits

Soil profiles JP-UDP1-1 and JP-UDP1-3 have an argillic horizon with clay accumulation and do not have a Base saturation percent of less than 35, at a depth of 125cm below the upper boundary of the argillic horizon; they belong to the order Alfisols. The soils have an ustic moisture regime and belong to the suborder of Ustalfs; they have a kandic horizon and belong to the great group of kandiustalfs. The soils belong to the subgroup of Typic Kandiustalfs.

Soil profiles JP-UDP1-2, JP-UDP1-4, JP-UDP1-5 have a kandic horizon with clay accumulation and the Base Saturation percentage at a depth of 125cm below the upper boundary of the kandic horizon is not less than 35, the soils belong to the order of Alfisols. They have an ustic moisture regime; they belong to the suborder of Ustalfs. They have a kandic horizon and belong to the great group of Kandiustalfs. Soil profile JP-UDP1-2 has 5% or more (by volume) plinthite in one or more horizons within 150cm of the mineral soil surface; it belongs to the subgroup of Plinthic Kandiustalfs. Soil profiles JP-UDP1-4 and JP-UDP1-5 have in one or more horizons within 75cm of the mineral surface, redox depletions and also aquic conditions for some time in normal years; they belong to the subgroup of aquic kandiustalfs.

Soil profiles JP-UDP2-1, JP-UDP2-2, JP-UDP2-3, JP-UDP2-4 and JP-UDP2-5, have an argillic horizon and do not have less than 35% Base Saturation at a depth of 125cm below the upper boundary of the argillic horizon; they are Alfisols. They have an ustic moisture regime and are Ustalfs. they belong to the great group of Haplustalfs. Soil profile JP-UDP2-1 has a sandy particle size class throughout the entire argillic horizon, it is a Psammentic Haplustalf. Soil profiles JP-UDP2-2 and JP-UDP2-3 have an argillic horizon with a base saturation (by sum of cations) of less than 75 % throughout; they are Ultic Haplustalfs. Soil profiles JP-UDP2-4 and JP-UDP2-5 have in one or more horizons within 75 cm of the mineral soil surface, redox depletions and also aquic conditions for some time in normal years; and an argillic horizon that has a base saturation (by sum of cations) of less than 75% throughout; they are Aquultic Haplustalfs. Table 4.12 contains the classification of the soils in both the USDA Soils Taxonomy (2014) and WRB (2014) systems. The classes to which the soils fall, cut across soils formed from the three parent materials (Basalt, Granites and Unconsolidated deposits) and are not limited to soils formed from any of the three parent materials. This is an indication that the soils share some things in common; for example, the parent materials are largely igneous in origin, the soils share climate and vegetation in common and some of them share slope positions in common.

4.6 Land capability classification

Table 4.13 presents the land capability classes into which the soils investigated were classified. The soils belonged to land capability classes II to IV, they were capable for the cultivation of arable crops and some other land uses. Their capabilities diminishing from class II to IV. The soils in the crest positions in the landscapes were only marginally suitable for the cultivation of arable crops because of erosion hazards; they fall into class IV land, while soils in classes II and III fall into good and moderate arable land respectively. A major limitation of the soils for arable use, is the hazard of erosion (e) which in turn depends on the slope of the land. Soils in the crest, upper slope and mid slope positions in the landscape are prone to higher hazards from erosion than soils located in the lower slopes and valley bottoms in the landscapes. Therefore, the placement of the soils into land capability classes had been on the basis of the severity of erosion largely.

Table 4.12: Classification of the soils studied

Soil Profiles	Slope Position	USDA Soil Taxonomy (2014)	WRB (2014)
Soils derived from Basalt			
JP-BST1-1	Crest	Vitrandic Haplustept	Ferralic Cambisol (Vitrandic)
JP-BST1-2	Upper Slope	Plinthic Kandiustalf	Plinthic Lixisol (Vitrandic)
JP-BST1-3	Middle Slope	Oxyaquic Haplustalf	Ferric Lixisol (Dystric)
JP-BST1-4	Lower Slope	Oxyaquic Haplustalf	Ferric Lixisol (Dystric)
JP-BST1-5	Valley Bottom	Oxyaquic Haplustept	Gleyic Cambisol (Fluventic)
JP-BST2-1	Crest	Plinthic Kandiustalf	Ferric Lixisol (Dystric)
JP-BST2-2	Upper Slope	Plinthic Kandiustalf	Plinthic Lixisol (Vitrandic)
JP-BST2-3	Middle Slope	Oxyaquic Haplustalf	Ferric Lixisol (Vitrandic)
JP-BST2-4	Lower Slope	Oxyaquic Haplustalf	Ferric Lixisol (Fluventic)
JP-BST2-5	Valley Bottom	Aquic Kandiustalf	Gleyic Lixisol (Fluventic)
Soils derived from Granite			
JP-GNT1-1	Crest	Plinthic Kandiustalf	Humic Nitisol (Dystric)
JP-GNT1-2	Upper Slope	Plinthic Kandiustalf	Humic Nitisol (Dystric)
JP-GNT1-3	Middle Slope	Plinthic Kandiustalf	Humic Nitisol (Vitrandic)
JP-GNT1-4	Lower Slope	Aquic Kandiustalf	Humic Nitisol (Dystric)
JP-GNT1-5	Valley Bottom	Aquic Kandiustalf	Humic Nitisol (Vitrandic)
JP-GNT2-1	Crest	Plinthic Kandiustalf	Ferric Lixisol (Dystric)
JP-GNT2-2	Upper Slope	Plinthic Kandiustalf	Ferric Lixisol (Dystric)
JP-GNT2-3	Middle Slope	Oxyaquic Haplustalf	Ferric Lixisol (Dystric)
JP-GNT2-4	Lower Slope	Oxyaquic Haplustalf	Ferric Lixisol (Dystric)
JP-GNT2-5	Valley Bottom	Aquic Haplustept	Gleyic Cambisol (Dystric)
Soils derived from Unconsolidated deposits			
JP-UDP1-1	Crest	Typic Kandiustalf	Ferric Lixisol (Fluventic)
JP-UDP1-2	Upper Slope	Plinthic Kandiustalf	Ferric Lixisol (Vitrandic)
JP-UDP1-3	Middle Slope	Typic Kandiustalf	Ferric Lixisol (Fluventic)
JP-UDP1-4	Lower Slope	Aquic Kandiustalf	Gleyic Lixisol (Vitrandic)
JP-UDP1-5	Valley Bottom	Aquic Kandiustalf	Gleyic Lixisol (Vitrandic)
JP-UDP2-1	Crest	Psammentic Haplustalf	Ferric Lixisol (Dystric)
JP-UDP2-2	Upper Slope	Ultic Haplustalf	Ferric Lixisol (Dystric)
JP-UDP2-3	Middle Slope	Ultic Haplustalf	Ferric Lixisol (Dystric)
JP-UDP2-4	Lower Slope	Aquultic Haplustalf	Ferric Lixisol (Dystric)
JP-UDP2-5	Valley Bottom	Aquultic Haplustalf	Ferric Lixisol (Dystric)

Table 4.13: Land capability classes of the soils of the Jos Plateau studied.

Soil Profiles	Slope Position	Land Capability classes
Soils derived from Basalt		
JP-BST1-1	Crest	IVe-3
JP-BST1-2	Upper Slope	IIIe-2
JP-BST1-3	Middle Slope	IIIe-2
JP-BST1-4	Lower Slope	IIe-1
JP-BST1-5	Valley Bottom	IIw-1
JP-BST2-1	Crest	IIIe-2
JP-BST2-2	Upper Slope	IIIe-2
JP-BST2-3	Middle Slope	IIe-1
JP-BST2-4	Lower Slope	IIe-1
JP-BST2-5	Valley Bottom	IIw-1
Soils derived from Granite		
JP-GNT1-1	Crest	IVe-3
JP-GNT1-2	Upper Slope	IIIe-2
JP-GNT1-3	Middle Slope	IIIe-2
JP-GNT1-4	Lower Slope	IIe-1
JP-GNT1-5	Valley Bottom	IIw-1
JP-GNT2-1	Crest	IVe-3
JP-GNT2-2	Upper Slope	IIIe-2
JP-GNT2-3	Middle Slope	IIIe-2
JP-GNT2-4	Lower Slope	IIIe-1
JP-GNT2-5	Valley Bottom	IIw-1
Soils derived from Unconsolidated deposits		
JP-UDP1-1	Crest	IVe-3
JP-UDP1-2	Upper Slope	IIIe-2
JP-UDP1-3	Middle Slope	IIIe-1
JP-UDP1-4	Lower Slope	IIe-1
JP-UDP1-5	Valley Bottom	IIw-1
JP-UDP2-1	Crest	IVe-3
JP-UDP2-2	Upper Slope	IIIe-2
JP-UDP2-3	Middle Slope	IIIe-1
JP-UDP2-4	Lower Slope	IIe-1
JP-UDP2-5	Valley Bottom	IIw-1

In the valley bottoms however, wetness (w), formed the main basis of allocating the soils into land capability classes. The parent materials of the soils influenced the slopes of the land in which they occurred; most of the soils derived from Granite occurred at relatively higher slopes than those derived from Basalt and Unconsolidated deposits.

4.7 Land suitability classification

Tables 4.14, 4.15 and 4.16 Present the non-parametric suitability classes of the soils formed on Basalt, Granite and Unconsolidated deposits respectively, for maize production. The limitations that placed the soils in their respective classes were mainly physical soil characteristics (s) and fertility characteristics (f); other less frequent ones were climate (c), topography (t) and wetness (w).

Three of the soils formed on Basalt (Soil profiles JP-BST2-1, JP-BST2-2 and JP-BST2-4) were moderately suitable for the production of maize; six (Soil profiles JP-BST1-1, JP-BST1-2, JP-BST1-3, JP-BST1-4, JP-BST1-5 and JP-BST2-3) were marginally suitable while one (Soil profile JP-BST2-5) was not suitable. One of the soils formed on Granite (Soil profile JP-GNT2-3) was moderately suitable for maize production, seven (Soil profiles JP-GNT1-1, JP-GNT1-2, JP-GNT1-3, JP-GNT1-4, JP-GNT1-5, JP-GNT2-4 and JP-GNT2-5) were marginally suitable while two (Soil profiles JP-GNT2-1 and JP-GNT2-2) are unsuitable. Seven of the soils formed on Unconsolidated deposits (Soil profiles JP-UDP1-1, JP-UDP1-2, JP-UDP1-3, JP-UDP1-5, JP-UDP2-2, JP-UDP2-3 and JP-UDP2-5) were moderately suitable for maize production; three (Soil profiles JP-UDP1-4, JP-UDP2-1, and JP-UDP2-4) were marginally suitable.

The soils formed on Unconsolidated deposits were more suitable for maize production than the soils formed on Basalt or Granite; similarly, the soils formed on Basalt were more suitable than the soil formed on Granite for maize production. The actual and potential suitability classes of the soils are same but limitations that can be overcome are not included in the potential suitability classes.

Table 4.14: Land suitability classification (Non-parametric) for maize, under soils derived from Basalt

Land Qualities	Soil Profiles									
	JP-BST1-1	JP-BST1-2	JP-BST1-3	JP-BST1-4	JP-BST1-5	JP-BST2-1	JP-BST2-2	JP-BST2-3	JP-BST2-4	JP-BST2-5
Climate (C)										
Annual rainfall (mm)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)
Length of growing season (days)	153 (S1)	153 (S1)	153 (S1)	153 (S1)	153 (S1)	153 (S1)	153 (S1)	153 (S1)	153 (S1)	153 (S1)
Mean temperature growing season (°C)	22.5 (S1)	22.5 (S1)	22.5 (S1)	22.5 (S1)	22.5 (S1)	22.5 (S1)	22.5 (S1)	22.5 (S1)	22.5 (S1)	22.5 (S1)
Mean relative humidity growing season (%)	74.2 (S1)	74.2 (S1)	74.2 (S1)	74.2 (S1)	74.2 (S1)	74.2 (S1)	74.2 (S1)	74.2 (S1)	74.2 (S1)	74.2 (S1)
Topography (t)										
Slope (%)	3-5 (S2)	2-3 (S1)	2 (S1)	2-3 (S1)	2 (S1)	3-5 (S2)	2-4 (S2)	2-3 (S1)	1-2 (S1)	0-1 (S1)
Wetness (w)										
Flooding	Fo (S1)	Fo (S1)	Fo (S1)	Fo (S1)	Fo (S1)	Fo (S1)	Fo (S1)	Fo (S1)	Fo (S1)	Fo (S1)
Drainage	Mod. (S2)	Good (S1)	Good (S1)	Good (S1)	Good (S1)	Good (S1)	Good (S1)	Good (S1)	Mod. (S2)	Mod. (S2)
Physical soil characteristics (s)										
Texture/Structure	LS-L(S2)	SL-SCL(S1)	LS-SCL(S2)	LS-SCL(S2)	LS-SCL(S2)	SL-C (S1)	CL-C (S1)	SL-L (S2)	SL-L (S2)	SL-SCL (S1)
Coarse fragments (%)	33.4 (S3)	40.23 (S3)	23.00 (S2)	28.87 (S2)	45.86 (S3)	28.30 (S2)	8.93 (S1)	46.83 (S3)	51.22 (S3)	63.37 (N2)
Soil depth (cm)	142 (S1)	180 (S1)	137 (S1)	190 (S1)	190 (S1)	170 (S1)	168 (S1)	180 (S1)	179 (S1)	180 (S1)
Fertility characteristics (f)										
Apparent ECEC (meq/100g clay)	4.39 (S3)	4.46 (S3)	4.96 (S3)	6.34 (S3)	4.30 (S3)	16.57 (S1)	15.82 (S1)	15.59 (S1)	16.54 (S1)	16.67 (S1)
Base saturation (%)	77.38 (S1)	76.28 (S1)	67.95 (S1)	57.15 (S1)	78.94 (S1)	62.91 (S1)	68.55 (S1)	67.18 (S1)	67.33 (S1)	68.70 (S1)
Organic matter (%C, 0 - 15 cm)	1.68 (S1)	2.27 (S1)	2.14 (S1)	1.97 (S1)	2.14 (S1)	2.72 (S1)	2.30 (S1)	2.53 (S1)	2.06 (S1)	1.45 (S1)
Suitability class:										
Actual	S3sf	S3sf	S3f	S3f	S3sf	S2ts	S2tf	S3s	S2ws	N2s
Potential	S3s	S3s	S3	S3	S3s	S2ts	S2t	S3s	S2s	N2s

Table 4.15: Land suitability classification (Non-parametric) for maize, under soils derived from Granite

Land Qualities	Soil Profiles									
	JP-GNT1-1	JP-GNT1-2	JP-GNT1-3	JP-GNT1-4	JP-GNT1-5	JP-GNT2-1	JP-GNT2-2	JP-GNT2-3	JP-GNT2-4	JP-GNT2-5
Climate (C)										
Annual rainfall (mm)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)
Length of growing season (days)	153 (S1)	153 (S1)	153 (S1)	153 (S1)	153 (S1)	153 (S1)	153 (S1)	153 (S1)	153 (S1)	153 (S1)
Mean temperature growing season (°C)	22.5 (S1)	22.5 (S1)	22.5 (S1)	22.5 (S1)	22.5 (S1)	22.5 (S1)	22.5 (S1)	22.5 (S1)	22.5 (S1)	22.5 (S1)
Mean relative humidity growing season (%)	74.2 (S1)	74.2 (S1)	74.2 (S1)	74.2 (S1)	74.2 (S1)	74.2 (S1)	74.2 (S1)	74.2 (S1)	74.2 (S1)	74.2 (S1)
Topography (t)										
Slope (%)	3-6 (S2)	2-4 (S2)	3 (S1)	1-2 (S1)	1-2 (S1)	3-4 (S2)	2-3 (S1)	1-2 (S1)	0-1 (S1)	0-1 (S1)
Wetness (w)										
Flooding	Fo (S1)	Fo (S1)	Fo (S1)	Fo (S1)	Fo (S1)	Fo (S1)	Fo (S1)	Fo (S1)	Fo (S1)	Fo (S1)
Drainage	Gd (S1)	Gd (S1)	Gd (S1)	Gd (S1)	Mod (S2)	Gd (S1)	Gd (S1)	Gd (S1)	Pr. (S3)	Pr. (S3)
Physical soil characteristics (s)										
Texture/Structure	L-SCL (S1)	CL-C (S1)	CL-C (S1)	CL-C (S1)	L-C (S1)	SL-L (S1)	SL-SCL(S1)	SL-SCL(S1)	L-CL (S1)	LS-L (S2)
Coarse fragments (%)	49.2 (S3)	35.04 (S3)	48.00 (S3)	44.47 (S3)	45.18 (S3)	59.17 (N2)	46.22 (S3)	24.59 (S2)	31.51 (S2)	38.12 (S3)
Soil depth (cm)										
Fertility characteristics (f)										
Apparent ECEC (meq/100g clay)	10.76 (S2)	16.85 (S1)	14.26 (S2)	17.19 (S1)	12.82 (S2)	16.96 (S1)	18.69 (S1)	14.72 (S2)	16.20 (S1)	15.43 (S2)
Base saturation (%)	76.15 (S1)	66.86 (S1)	64.64 (S1)	74.16 (S1)	85.85 (S1)	49.93 (S1)	46.28 (S1)	56.34 (S1)	63.48 (S1)	55.44 (S1)
Organic matter (%C, 0 - 15 cm)	2.92 (S1)	2.98 (S1)	3.19 (S1)	4.82 (S1)	1.60 (S1)	2.25 (S1)	2.13 (S1)	1.82 (S1)	2.29 (S1)	1.65 (S1)
Suitability class										
Actual	S3s	S3s	S3s	S3s	S3s	N2s	N2s	S2s	S3w	S3ws
Potential	S3s	S3s	S3s	S3s	S3s	N2s	N2s	S2s	S2s	S3s

Table 4.16: Land suitability classification (Non-parametric) for maize, under soils derived from Unconsolidated deposits

Land Qualities	Soil Profiles									
	JP-UDP1-1	JP-UDP1-2	JP-UDP1-3	JP-UDP1-4	JP-UDP1-5	JP-UDP2-1	JP-UDP2-2	JP-UDP2-3	JP-UDP2-4	JP-UDP2-5
Climate (C)										
Annual rainfall (mm)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)
Length of growing season (days)	153 (S1)	153 (S1)	153 (S1)	153 (S1)	153 (S1)	153 (S1)	153 (S1)	153 (S1)	153 (S1)	153 (S1)
Mean temperature growing season (°C)	22.5 (S1)	22.5 (S1)	22.5 (S1)	22.5 (S1)	22.5 (S1)	22.5 (S1)	22.5 (S1)	22.5 (S1)	22.5 (S1)	22.5 (S1)
Mean relative humidity growing season (%)	74.2 (S1)	74.2 (S1)	74.2 (S1)	74.2 (S1)	74.2 (S1)	74.2 (S1)	74.2 (S1)	74.2 (S1)	74.2 (S1)	74.2 (S1)
Topography (t)										
Slope (%)	3-5 (S2)	2-3 (S1)	2-3 (S1)	2 (S1)	2 (S1)	4-5 (S2)	3-4 (S2)	2-3 (S1)	1-2 (S1)	0-1 (S1)
Wetness (w)										
Flooding	Fo (S1)	Fo (S1)	Fo (S1)	Fo (S1)	Fo (S1)	Fo (S1)	Fo (S1)	Fo (S1)	Fo (S1)	Fo (S1)
Drainage	Gd (S1)	Gd (S1)	Gd (S1)	Mod (S2)	Mod (S2)	Gd (S1)	Gd (S1)	Gd (S1)	Mod. (S2)	Mod. (S2)
Physical soil characteristics (s)										
Texture/Structure	LS-CL (S1)	SL-CL (S1)	L-SCL (S1)	SL-CL (S1)	L-CL (S1)	SL-SiL (S1)	L-SCL (S1)	SL-SCL (S1)	L-CL (S1)	SL-SCL (S1)
Coarse fragments (%)	11.2 (S1)	31-33 (S2)	23.54 (S2)	41.06 (S3)	26.24 (S2)	39.66 (S3)	23.25 (S2)	23.39 (S2)	35.56 (S3)	30.76 (S2)
Soil depth (cm)	190 (S1)	195 (S1)	200 (S1)	166 (S1)	180 (S1)	170 (S1)	196 (S1)	198 (S1)	192 (S1)	185 (S1)
Fertility characteristics (f)										
Apparent ECEC (meq/100g clay)	14.37 (S2)	14.48 (S2)	14.26 (S2)	15.50 (S2)	14.43 (S2)	16.89 (S1)	16.82 (S1)	16.43 (S1)	15.25 (S2)	16.30 (S1)
Base saturation (%)	92.65 (S1)	93.84 (S1)	87.49 (S1)	92.66 (S1)	85.09 (S1)	48.46 (S1)	55.68 (S1)	55.06 (S1)	59.03 (S1)	51.72 (S1)
Organic matter (%C, 0 - 15 cm)	1.30 (S1)	1.14 (S2)	1.66 (S1)	1.26 (S1)	0.74 (S3)	0.64 (S3)	2.25 (S1)	2.83 (S1)	0.07 (S3)	1.24 (S1)
Suitability class										
Actual	S2tf	S2sf	S2sf	S3s	S2wsf	S3sf	S2ts	S2s	S3sf	S2wsf
Potential	S3t	S2s	S2s	S3s	S2s	S3s	S2ts	S2s	S3s	S2s

Table 4.17, 4.18 and 4.19 present the non-parametric suitability classes of the soils formed on Basalt, Granite and Unconsolidated deposits respectively, for Irish potato production. The main limitations that placed the soils in their respective classes were physical soil characteristics (s) and fertility characteristics (f); other includes climate (c), topography (t) and wetness (w). One of the soils formed on Basalt (Soil profile JP-BST2-2) was moderately suitable, four (Soil profiles JP-BST1-1, JP-BST1-3, JP-BST1-4 and JP-BST2-1) were marginally suitable and five (Soil profiles JP-BST1-2, JP-BST1-5, JP-BST2-3, JP-BST2-4 and JP-BST2-5) were not suitable for Irish potato production. Three of the soils formed on Granite (Soil profiles JP-GNT1-2, JP-GNT2-3 and JP-GNT2-4) were marginally suitable while the other seven (Soil profiles JP-GNT1-1, JP-GNT1-3, JP-GNT1-4, JP-GNT1-5, JP-GNT2-1, JP-GNT2-2 and JP-GNT2-5) were not suitable for Irish potato production.

One of the soils formed on Unconsolidated deposit (Soil profile JP-UDP1-1) was moderately suitable, eight (Soil profiles JP-UDP1-2, JP-UDP1-3, JP-UDP1-4, JP-UDP1-5, JP-UDP2-2, JP-UDP2-3, JP-UDP2-4 and JP-UDP2-5) were marginally suitable while one (Soil profile JP-UDP2-1) was unsuitable for Irish potato production. The soils formed on Unconslidated deposits, were more suitable for Irish potato production than the soils formed on Basalt or Granite; the soils formed on Basalt were more suitable for Irish potato production than soils formed on Granite. The actual and potential suitability classes are same for each soil.

Tables 4.20, 4.21 and 4.22 present the non-parametric suitability classes of the soils formed on Basalt, Granite and Unconsolidated deposits, for the production of citrus.

Again, the limitations that placed the soils in their respective classes were mainly physical soil characteristics (s) and fertility characteristics (f); other less frequent ones are climate (c), topography (t) and wetness (w).

Five of the soils formed on Basalt (Soil profiles JP-BST1-1, JP-BST1-3, JP-BST1-4, JP-BST2-1 and JP-BST2-3) were marginally suitable for the production of citrus while the remaining five (Soil profiles JP-BST1-2, JP-BST1-5, JP-BST2-2, JP-BST2-4 and JP-BST2-5) were not suitable.

Table 4.17: Land suitability classification (Non-parametric) for Irish potato, under soils derived from Basalt

Land Qualities	Soil Profiles									
	JP-BST1-1	JP-BST1-2	JP-BST1-3	JP-BST1-4	JP-BST1-5	JP-BST2-1	JP-BST2-2	JP-BST2-3	JP-BST2-4	JP-BST2-5
Climate (C)										
Monthly rainfall (mm)										
- 1st Month	94.70 (S1)	94.70 (S1)	94.70 (S1)	94.70 (S1)	94.70 (S1)	94.70 (S1)	94.70 (S1)	94.70 (S1)	94.70 (S1)	94.70 (S1)
- 2nd Month	190.80 (S1)	190.80 (S1)	190.80 (S1)	190.80 (S1)	190.80 (S1)	190.80(S1)	190.80 (S1)	190.80 (S1)	190.80 (S1)	190.80 (S1)
- 3rd Month	228.10 (S1)	228.10 (S1)	228.10 (S1)	228.10 (S1)	228.10 (S1)	228.10(S1)	228.10 (S1)	228.10 (S1)	228.10 (S1)	228.10 (S1)
- 4th Month	323.90 (S2)	323.90 (S2)	323.90 (S2)	323.90 (S2)	323.90 (S2)	323.90(S2)	323.90 (S2)	323.90 (S2)	323.90 (S2)	323.90 (S2)
Mean temperature growing season (°C)	23.40 (S1)	23.40 (S1)	23.40 (S1)	23.40 (S1)	23.40 (S1)	23.40 (S1)	23.40 (S1)	23.40 (S1)	23.40 (S1)	23.40 (S1)
Topography (t)										
Slope (%)	3-5 (S2)	2-3 (S1)	2 (S1)	2-3 (S1)	2 (S1)	3-5 (S2)	2-4 (S2)	2-3 (S1)	1-2 (S1)	0-1 (S1)
Wetness (w)										
Flooding	no (S1)	no (S1)	no (S1)	no (S1)	no (S1)	no (S1)	no (S1)	no (S1)	no (S1)	no (S1)
Drainage	Gd. (S1)	Gd. (S1)	Gd. (S1)	Gd. (S1)	Mod. (S1)	Gd. (S1)	Gd. (S1)	Gd. (S1)	Mod. (S1)	Imp. (S2)
Physical soil characteristics (s)										
Texture/Structure	L-LS(S2)	SCL-SL(S1)	SCL-LS(S2)	SCL-LS(S2)	SL-LS(S2)	C-SL (S1)	C-CL (S1)	L-SL (S2)	L-SL (S1)	SCL-SL (S1)
Coarse fragments (%) s	32.74 (S3)	41.14 (N2)	20.84 (S3)	33.44 (S3)	60.38 (N2)	13.44 (S2)	9.14 (S2)	18.24 (S3)	41.93 (N2)	46.42 (N2)
d	34.07 (S2)	39.01 (S3)	24.44 (S2)	25.82 (S2)	36.18 (S3)	38.21 (S3)	8.72 (S1)	65.88 (N2)	57.41 (N2)	77.66 (N2)
Soil depth (cm)	142 (S1)	180 (S1)	137 (S1)	190 (S1)	190 (S1)	170 (S1)	168 (S1)	105 (S1)	179 (S1)	180 (S1)
Fertility characteristics (f)										
Apparent CEC (meq/100g clay)	4.38 (S3)	4.46 (S3)	4.96 (S3)	6.34 (S3)	4.30 (S3)	16.57 (S1)	15.82 (S2)	15.59 (S2)	16.54 (S1)	16.67 (S1)
Base saturation (%)	77.38 (S1)	76.28 (S1)	67.95 (S1)	57.15 (S1)	78.94 (S1)	62.91 (S1)	68.55 (S1)	67.17 (S1)	67.33 (S1)	68.70 (S1)
Organic matter (%C, 0 - 15 cm)	1.63 (S1)	2.26 (S1)	2.14 (S1)	1.97 (S1)	2.14 (S1)	2.72 (S1)	2.30 (S1)	2.53 (S1)	2.06 (S1)	1.45 (S1)
Suitability class:										
Actual	S3sf	N2s	S3sf	S3sf	N2s	S3s	S2ctsf	N2s	N2s	N2s
Potential	S3s	N2s	S3s	S3s	N2s	S3s	S2cts	N2s	N2s	N2s

Table 4.18: Land suitability classification (Non-parametric) for Irish potato, under soils derived from Granite

Land Qualities	Soil Profiles									
	JP-GNT1-1	JP-GNT1-2	JP-GNT1-3	JP-GNT1-4	JP-GNT1-5	JP-GNT2-1	JP-GNT2-2	JP-GNT2-3	JP-GNT2-4	JP-GNT2-5
Climate (C)										
Monthly rainfall (mm)										
- 1st Month	94.70 (S1)	94.70 (S1)	94.70 (S1)	94.70 (S1)	94.70 (S1)	94.70 (S1)	94.70 (S1)	94.70 (S1)	94.70 (S1)	94.70 (S1)
- 2nd Month	190.80 (S1)	190.80 (S1)	190.80 (S1)	190.80 (S1)	190.80 (S1)	190.80(S1)	190.80 (S1)	190.80 (S1)	190.80 (S1)	190.80 (S1)
- 3rd Month	228.10 (S1)	228.10 (S1)	228.10 (S1)	228.10 (S1)	228.10 (S1)	228.10(S1)	228.10 (S1)	228.10 (S1)	228.10 (S1)	228.10 (S1)
- 4th Month	323.90 (S2)	323.90 (S2)	323.90 (S2)	323.90 (S2)	323.90 (S2)	323.90(S2)	323.90 (S2)	323.90 (S2)	323.90 (S2)	323.90 (S2)
Mean temperature growing season (°C)	23.40 (S1)	23.40 (S1)	23.40 (S1)	23.40 (S1)	23.40 (S1)	23.40 (S1)	23.40 (S1)	23.40 (S1)	23.40 (S1)	23.40 (S1)
Topography (t)										
Slope (%)	3-6 (S2)	2-4 (S2)	3 (S1)	1-2 (S1)	1-2 (S1)	3-4 (S2)	2-3 (S1)	1-2 (S1)	0-1 (S1)	0-1 (S1)
Wetness (w)										
Flooding	no (S1)	no (S1)	no (S1)	no (S1)	no (S1)	no (S1)	no (S1)	no (S1)	no (S1)	no (S1)
Drainage	Gd (S1)	Gd (S1)	Gd (S1)	Gd (S1)	Imp. (S2)	Gd (S1)	Gd (S1)	Gd (S1)	Pr. (S3)	Pr. (S3)
Physical soil characteristics (s)										
Texture/Structure	C-L (S1)	C-SCL(S1)	C-SCL(S1)	C-CL (S1)	C-L (S1)	L-SL (S1)	SCL-SL(S1)	CL-L(S1)	CL-L (S1)	L-LS (S1)
Coarse fragments (%) s	54.28 (N2)	21.32 (S3)	26.87 (S3)	38.86 (N2)	42.02 (N2)	59.03 (N2)	58.16 (N2)	28.65 (S3)	19.40 (S3)	44.71 (N2)
d	45.80 (S3)	44.19 (S3)	69.08 (N2)	48.21 (S3)	51.51 (S3)	59.25 (N2)	34.28 (S2)	21.88 (S2)	39.58 (S3)	33.73 (S2)
Soil depth (cm)	200 (S1)	196 (S1)	200 (S1)	200 (S1)	196 (S1)	110 (S1)	165 (S1)	185 (S1)	175 (S1)	172 (S1)
Fertility characteristics (f)										
Apparent CEC (meq/100g clay)	10.76 (S3)	16.85 (S1)	14.26 (S2)	17.19 (S1)	12.82 (S2)	16.96 (S1)	18.69 (S1)	14.72 (S2)	16.20 (S1)	15.43 (S2)
Base saturation (%)	76.15 (S1)	66.86 (S1)	64.64 (S1)	74.16 (S1)	85.85 (S1)	49.93 (S1)	46.28 (S1)	56.34 (S1)	63.48 (S1)	55.44 (S1)
Organic matter (%C, 0 - 15 cm)	2.92 (S1)	2.98 (S1)	3.19 (S1)	4.82 (S1)	1.78 (S1)	2.25 (S1)	2.13 (S1)	1.82 (S1)	2.29 (S1)	1.65 (S1)
Suitability class										
Actual	N2s	S3s	N2s	N2s	N2s	N2s	N2s	S3s	S3ws	N2s
Potential	N2s	S3s	N2s	N2s	N2s	N2s	N2s	S3s	S3s	N2s

Table 4.19: Land suitability classification (Non-parametric) for Irish potato, under soils derived from Unconsolidated deposits

Land Qualities		Soil Profiles									
		JP-UDP1-1	JP-UDP1-2	JP-UDP1-3	JP-UDP1-4	JP-UDP1-5	JP-UDP2-1	JP-UDP2-2	JP-UDP2-3	JP-UDP2-4	JP-UDP2-5
Climate (C)											
Monthly rainfall (mm)											
- 1st Month		94.70 (S1)	94.70 (S1)	94.70 (S1)	94.70 (S1)	94.70 (S1)	94.70 (S1)	94.70 (S1)	94.70 (S1)	94.70 (S1)	94.70 (S1)
- 2nd Month		190.80 (S1)	190.80 (S1)	190.80 (S1)	190.80 (S1)	190.80 (S1)	190.80(S1)	190.80 (S1)	190.80 (S1)	190.80(S1)	190.80 (S1)
- 3rd Month		228.10 (S1)	228.10 (S1)	228.10 (S1)	228.10 (S1)	228.10 (S1)	228.10(S1)	228.10 (S1)	228.10 (S1)	228.10 (S1)	228.10 (S1)
- 4th Month		323.90 (S2)	323.90 (S2)	323.90 (S2)	323.90 (S2)	323.90 (S2)	323.90(S2)	323.90 (S2)	323.90 (S2)	323.90 (S2)	323.90 (S2)
Mean temperature growing season (°C)		23.40 (S1)	23.40 (S1)	23.40 (S1)	23.40 (S1)	23.40 (S1)	23.40 (S1)	23.40 (S1)	23.40 (S1)	23.40 (S1)	23.40 (S1)
Topography (t)											
Slope (%)		3-5 (S2)	2-3 (S1)	2-3 (S1)	2 (S1)	1-2 (S1)	4-5 (S2)	3-4 (S2)	2-3 (S1)	1-2 (S1)	0-1 (S1)
Wetness (w)											
Flooding		no (S1)	no (S1)	no (S1)	no (S1)	no (S1)	no (S1)	no (S1)	no (S1)	no (S1)	no (S1)
Drainage		Gd. (S1)	Gd. (S1)	Gd. (S1)	Imp. (S2)	Imp. (S2)	Gd. (S1)	Gd. (S1)	Gd. (S1)	Imp. (S2)	Imp. (S2)
Physical soil characteristics (s)											
Texture/Structure		CL-LS (S1)	CL-SL (S1)	CL-L (S1)	CL-SL (S1)	CL-L (S1)	SiL-SL (S1)	CL-L (S1)	SCL-SL (S1)	CL-L (S1)	CL-SL (S1)
Coarse fragments (%)	s	4.51 (S2)	29.55 (S3)	14.32 (S2)	37.01 (N2)	13.58 (S2)	60.43 (N2)	23.14 (S3)	13.75 (S2)	34.79 (S3)	14.86 (S2)
	d	15.65 (S2)	33.12 (S2)	21.69 (S2)	38.90 (S3)	38.90 (S3)	25.81 (S2)	23.36 (S2)	29.82 (S2)	36.34 (S3)	46.66 (S3)
Soil depth (cm)		190 (S1)	195 (S1)	200 (S1)	166 (S1)	180 (S1)	170 (S1)	196 (S1)	198 (S1)	192 (S1)	185 (S1)
Fertility characteristics (f)											
Apparent CEC (meq/100g clay)		14.37 (S2)	14.48 (S2)	14.26 (S2)	15.50 (S2)	14.43 (S2)	16.89 (S1)	16.82 (S1)	16.43 (S1)	15.25 (S2)	16.30 (S1)
Base saturation (%)		92.65 (S1)	93.84 (S1)	87.49 (S1)	92.66 (S1)	85.09 (S1)	48.46 (S1)	55.68 (S1)	55.06 (S1)	59.03 (S1)	51.72 (S1)
Organic matter (%C, 0 - 15 cm)		1.30 (S1)	1.14 (S1)	1.66 (S1)	1.26 (S1)	0.85 (S1)	0.64 (S2)	2.25 (S1)	2.83 (S1)	0.06 (S2)	1.24 (S1)
Suitability class											
	Actual	S2ctsf	S3s	S3s	S3s	S3s	N2s	S3s	S3s	S3s	S3s
	Potential	S2cts	S3s	S3s	S3s	S3s	N2s	S3s	S3s	S3s	S3s

Table 4.20: Land suitability classification (Non-parametric) for citrus, under soils derived from Basalt

Land Qualities	Soil Profiles									
	JP-BST1-1	JP-BST1-2	JP-BST1-3	JP-BST1-4	JP-BST1-5	JP-BST2-1	JP-BST2-2	JP-BST2-3	JP-BST2-4	JP-BST2-5
Climate (C)										
Annual rainfall (mm)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)
Relative Humidity (%)	47 (S1)	47 (S1)	47 (S1)	47 (S1)	47 (S1)	47 (S1)	47 (S1)	47 (S1)	47 (S1)	47 (S1)
Minimum temperature (°C)	19.6-22.8 (S1)	19.6-22.8 (S1)	19.6-22.8 (S1)	19.6-22.8 (S1)	19.6-22.8 (S1)	19.6-22.8 (S1)	19.6-22.8 (S1)	19.6-22.8 (S1)	19.6-22.8 (S1)	19.6-22.8 (S1)
Maximum temperature (°C)	23.5-30.9 (S2)	23.5-30.9 (S2)	23.5-30.9 (S2)	23.5-30.9 (S2)	23.5-30.9 (S2)	23.5-30.9 (S2)	23.5-30.9 (S2)	23.5-30.9 (S2)	23.5-30.9 (S2)	23.5-30.9 (S2)
Soils (s)										
Clay (g/kg)	120 (S2)	166 (S1)	147.6 (S2)	190.8 (S1)	66.8 (S3)	357.8 (S3)	435 (N1)	152.8 (S1)	134.2 (S2)	132.8 (S2)
Texture	L-LS (S2)	SCL-SL(S2)	SCL-LS(S2)	SCL-LS(S2)	SL-LS (S3)	SCL-SL(S2)	C-CL (S1)	L-SL (S2)	L-SL (S2)	SCL-SL (S2)
Effective soil depth (cm)	82 (S2)	180 (S1)	137 (S1)	63 (S3)	132 (S1)	170 (S1)	168 (S1)	105 (S1)	120 (S1)	123 (S1)
Depth to water table (cm)	142 (S1)	180 (S1)	137 (S1)	190 (S1)	190 (S1)	170 (S1)	168 (S1)	180 (S1)	179 (S1)	180 (S1)
Drainage	Wd. (S1)	Wd. (S1)	Wd. (S1)	Wd. (S1)	Wd. (S1)	Wd. (S1)	Wd. (S1)	Wd. (S1)	Id. (S2)	Id. (S2)
Gravel (%) 0-40 (cm)	32.70 (S2)	41.45 (N1)	20.84 (S1)	33.44 (S2)	60.38 (N2)	13.44 (S1)	9.14 (S1)	18.24 (S1)	41.39 (N1)	46.42 (N1)
Topography (t)										
Slope (%)	3-5 (S1)	2-3 (S1)	2 (S1)	2-3 (S1)	2 (S1)	3-5 (S1)	2-4 (S1)	2-3 (S1)	1-2 (S1)	0-1 (S1)
Fertility (f)										
pH	5.3 (S1)	5.4 (S1)	5.2 (S1)	5.1 (S1)	5.7 (S1)	5.3 (S1)	4.4 (S3)	5.5 (S1)	5.2 (S1)	5.0 (S1)
Organic matter (g/kg)	13.44 (S3)	12.81 (S3)	12.93 (S3)	13.69 (S3)	8.38 (N1)	15.38 (S3)	16.19 (S1)	12.98 (S3)	11.31 (S3)	10.39 (N1)
EECEC (cmol/kg)	4.39 (S3)	4.46 (S3)	4.96 (S3)	6.34 (S3)	4.30 (S3)	16.57 (S2)	15.82 (S2)	15.59 (S2)	16.54 (S2)	16.67 (S2)
Base saturation (g/kg)	773.85 (S2)	762.80 (S2)	679.56 (S3)	571.54 (S3)	789.48 (S2)	629.14(S3)	685.56 (S3)	671.77 (S3)	673.38 (S3)	687.00 (S3)
Suitability class:										
Actual	S3f	N1	S3f	S3sf	N1sf	S3sf	N1s	S3f	N1s	N1sf
Potential	S2cs	N1	S2cs	S3s	N1s	S3s	N1s	S3cs	N1s	N1s

Table 4.21: Land suitability classification (Non-parametric) for citrus, under soils derived from Granite

Land Qualities	Soil Profiles									
	JP-GNT1-1	JP-GNT1-2	JP-GNT1-3	JP-GNT1-4	JP-GNT1-5	JP-GNT2-1	JP-GNT2-2	JP-GNT2-3	JP-GNT2-4	JP-GNT2-5
Climate (C)										
Annual rainfall (mm)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)
Relative Humidity (%)	47 (S1)	47 (S1)	47 (S1)	47 (S1)	47 (S1)	47 (S1)	47 (S1)	47 (S1)	47 (S1)	47 (S1)
Minimum temperature (°C)	19.6-22.8 (S1)	19.6-22.8 (S1)	19.6-22.8 (S1)	19.6-22.8 (S1)	19.6-22.8 (S1)	19.6-22.8 (S1)	19.6-22.8 (S1)	19.6-22.8 (S1)	19.6-22.8 (S1)	19.6-22.8 (S1)
Maximum temperature (°C)	23.5-30.9 (S2)	23.5-30.9 (S2)	23.5-30.9 (S2)	23.5-30.9 (S2)	23.5-30.9 (S2)	23.5-30.9 (S2)	23.5-30.9 (S2)	23.5-30.9 (S2)	23.5-30.9 (S2)	23.5-30.9 (S2)
Soils (s)										
Clay (g/kg)	378 (S3)	422 (S3)	394 (S3)	378 (S3)	349 (S3)	146 (S2)	188 (S1)	230 (S1)	287.6 (S1)	10.4 (N1)
Texture	C-L (S1)	C-SCL(S1)	C-SCL(S1)	C-CL(S1)	C-L (S1)	L-SL(S2)	SCL-SL (S2)	SCL-SL (S2)	CL-L (S2)	L-LS (S2)
Effective soil depth (cm)	100 (S1)	196 (S1)	170 (S1)	200 (S1)	196 (S1)	110 (S1)	82 (S2)	185 (S1)	140 (S1)	172 (S1)
Depth to water table (cm)	200 (S1)	196 (S1)	170 (S1)	200 (S1)	196 (S1)	110 (S1)	165 (S1)	185 (S1)	175 (S1)	172 (S1)
Drainage	Wd. (S1)	Wd. (S1)	Wd. (S1)	Wd. (S1)	Mi. (S2)	Wd. (S1)	Wd. (S1)	Wd. (S1)	Pd. (S3)	Pd. (S3)
Gravel (%) 0-40 (cm)	54.28 (N1)	21.32 (S1)	26.87 (S2)	33.65 (S2)	42.02 (N1)	62.38 (N1)	58.16 (N1)	28.65 (S2)	19.4 (S1)	44.71 (N1)
Topography (t)										
Slope (%)	3-6 (S1)	2-4 (S1)	3 (S1)	1-2 (S1)	1-2 (S1)	3-4 (S1)	2-3 (S1)	1-2 (S1)	0-1 (S1)	0-1 (S1)
Fertility (f)										
pH	5.4 (S1)	5.5 (S1)	5.4 (S1)	5.4 (S1)	5.3 (S1)	4.6 (S3)	5.1 (S1)	5.1 (S1)	4.9 (S3)	4.9 (S3)
Organic matter (g/kg)	18.43 (S1)	21.54 (S1)	21.17 (S1)	20.36 (S1)	13.73 (S3)	13.20 (S3)	12.46 (S3)	12.54 (S3)	9.87 (N1)	9.58 (N1)
EECEC (cmol/kg)	10.76 (S2)	16.85 (S1)	14.26 (S2)	17.19 (S2)	12.82 (S2)	16.96 (S2)	18.69 (S2)	14.72 (S2)	16.20 (S2)	15.43 (S2)
Base saturation (g/kg)	761.56 (S2)	668.62 (S3)	646.42 (S3)	741.68 (S2)	858.55 (S1)	499.33(N1)	462.82(N1)	563.42 (S3)	634.80 (S3)	554.48 (S3)
Suitability class:										
Actual	N1s	S3sf	S3sf	S3s	N1s	N1sf	N1sf	S3sf	N1f	N1sf
Potential	N1s	S3s	S3sf	S3s	N1s	N1s	N1s	S2cs	S3s	N1s

Table 4.22: Land suitability classification (Non-parametric) for citrus, under soils derived from Unconsolidated deposits

Land Qualities	Soil Profiles									
	JP-UDP1-1	JP-UDP1-2	JP-UDP1-3	JP-UDP1-4	JP-UDP1-5	JP-UDP2-1	JP-UDP2-2	JP-UDP2-3	JP-UDP2-4	JP-UDP2-5
Climate (C)										
Annual rainfall (mm)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)	1403 (S1)
Relative Humidity (%)	47 (S1)	47 (S1)	47 (S1)	47 (S1)	47 (S1)	47 (S1)	47 (S1)	47 (S1)	47 (S1)	47 (S1)
Minimum temperature (°C)	19.6-22.8 (S1)	19.6-22.8 (S1)	19.6-22.8 (S1)	19.6-22.8 (S1)	19.6-22.8 (S1)	19.6-22.8 (S1)	19.6-22.8 (S1)	19.6-22.8 (S1)	19.6-22.8 (S1)	19.6-22.8 (S1)
Maximum temperature (°C)	23.5-30.9 (S2)	23.5-30.9 (S2)	23.5-30.9 (S2)	23.5-30.9 (S2)	23.5-30.9 (S2)	23.5-30.9 (S2)	23.5-30.9 (S2)	23.5-30.9 (S2)	23.5-30.9 (S2)	23.5-30.9 (S2)
Soils (s)										
Clay (g/kg)	210 (S3)	322 (S3)	310 (S3)	261.50 (S1)	343 (S3)	159.40 (S1)	253 (S1)	184.80 (S1)	226 (S1)	219.50 (S1)
Texture	CL-LS (S2)	CL-SL(S1)	CL-L(S1)	CL-SL(S1)	CL-L (S1)	SiL-SL(S2)	CL-L (S1)	SCL-SL (S2)	CL-L (S1)	CL-SL (S2)
Effective soil depth (cm)	90 (S2)	195 (S1)	160 (S1)	166 (S1)	115 (S1)	170 (S1)	116 (S1)	198 (S1)	192 (S1)	185 (S1)
Depth to water table (cm)	>190 (S1)	>195 (S1)	>200 (S1)	>166 (S1)	>180 (S1)	>170 (S1)	>196 (S1)	>198 (S1)	>192 (S1)	>185 (S1)
Drainage	Wd. (S1)	Wd. (S1)	Wd. (S1)	Wi. (S2)	Wi. (S2)	Wd. (S1)	Wd. (S1)	Wd. (S1)	Wi. (S2)	Id. (S2)
Gravel (%) 0-40 (cm)	4.51 (S1)	29.55 (S2)	14.32 (S1)	37.01 (S3)	13.58 (S1)	60.43 (N1)	23.14 (S1)	13.75 (S1)	34.79 (S2)	14.86 (S1)
Topography (t)										
Slope (%)	3-5 (S1)	2-3 (S1)	2-3 (S1)	2 (S1)	2 (S1)	4-5 (S1)	3-4 (S1)	2-3 (S1)	1-2 (S1)	0-1 (S1)
Fertility (f)										
pH	5.5 (S1)	5.4 (S1)	5.7 (S1)	6.0 (S1)	6.2 (S1)	4.6 (S3)	4.7 (S3)	4.7 (S3)	4.8 (S3)	4.9 (S3)
Organic matter (g/kg)	13.90 (S3)	10.30 (S3)	15.90 (S2)	10.00 (S3)	6.1 (N1)	7.8 (N1)	11.10 (S3)	13.00 (S3)	9.20 (N1)	9.58 (N1)
EECEC (cmol/kg)	14.38 (S2)	14.49 (S2)	14.27 (S2)	15.50 (S2)	14.44 (S2)	16.89 (S2)	16.82 (S2)	16.43 (S2)	15.25 (S2)	16.30 (S2)
Base saturation (g/kg)	926.54 (S1)	938.40 (S1)	874.98 (S1)	926.65 (S1)	850.92 (S1)	484.62 (N1)	556.85 (S3)	550.68 (S3)	590.32 (S3)	517.20 (S3)
Suitability class:										
Actual	S3sf	S3sf	S3s	S3sf	N1f	N1sf	S3f	S3f	N1f	N1f
Potential	S3s	S3s	S3s	S3s	S3s	N1s	S2c	S2c	S2cs	S2cs

C = climate, t = topography, w = wetness, s = soil characteristics, N1 = temporarily not suitable, N2 = permanently not suitable, f = fertility characteristics, S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, LS = loamy sand, L = loam, SL = sandy loam, SCL = sandy clay loam, C = clay, CL = clay loam.

Four of the soils formed on Granite (Soil profiles JP-GNT1-2, JP-GNT1-3, JP-GNT1-4 and JP-GNT2-3) were marginally suitable for the production of citrus while the remaining six soils (Soil profiles JP-GNT1-1, JP-GNT1-5, JP-GNT2-1, JP-GNT2-2, JP-GNT2-4 and JP-GNT2-5) are not suitable for citrus production.

Six of the soils formed on Unconsolidated deposits (Soil profiles JP-UDP1-1, JP-UDP1-2, JP-UDP1-3, JP-UDP1-4, JP-UDP2-2 and JP-UDP2-3) were marginally suitable for citrus production while the other four (Soil profiles JP-UDP1-5, JP-UDP2-1, JP-UDP2-4 and JP-UDP2-5) are not suitable for citrus production.

Again, the soils formed on Unconsolidated deposits were relatively more suitable for the production of citrus, than both the soils formed on Basalt and on Granite while the soils formed on Basalt were relatively more suitable for the production of citrus than the soils formed on Granite. The actual and potential suitability classes are same for each of the soils.

4.8 Fertility capability classification

Table 4.23 presents the fertility capability classes of the soils investigated. The soil fertility constraints common to most of the soils formed on Basalt include soil moisture stress (s), low nutrient reserves (f), gravel and high phosphorus fixation (s, f). Other constraints peculiar to some of the soils apart from the common ones include high erosion risk, vertic properties and high leaching potential. High erosion risk was common with soils of the crest and upper slope positions while imperfect drainage was common to soils of the lower and valley bottom positions. Most of the soils had four or five soil fertility constraints.

The soils formed on Granite shared both common and peculiar soil fertility constraints in common with the soils formed on Basalt. Most of them however had five or six soil fertility constraints. Waterlogging which was not observed in the soils formed on Basalt, was common in soils formed on Granite, also vertic properties were more pronounced in the soils formed on Granite than in the soils formed on Basalt.

Table 4.23: Fertility capability classes of the soils investigated

Soils and parent materials	Soil profiles and their fertility capability classes									
Soils deroved from Basalt	JP-BST1-1	JP-BST1-2	JP-BST1-3	JP-BST1-4	JP-BST1-5	JP-BST2-1	JP-BST2-2	JP-BST2-3	JP-BST2-4	JP-BST2-5
	LLdkeierx	LSdkeierx	LLdkierx	LSdkierx	Ldkerx	Lcdkeivrx	Lcdkeivx	Ldkerx	Ldkierx	LLdkierx
Soils derived from Granite	JP-GNT1-1	JP-GNT1-2	JP-GNT1-3	JP-GNT1-4	JP-GNT1-5	JP-GNT2-1	JP-GNT2-2	JP-GNT2-3	JP-GNT2-4	JP-GNT2-5
	LLdkeievr	LLdkeevr	Lckeigevr	Ldkigevr	Lcdkigevr	LLdkeier	LLdkeier	LLdkeir	LLdkeigr	SLdkeigr
Soils derived from Unconsolidated deposits	JP-UDP1-1	JP-UDP1-2	JP-UDP1-3	JP-UDP1-4	JP-UDP1-5	JP-UDP2-1	JP-UDP2-2	JP-UDP2-3	JP-UDP2-4	JP-UDP2-5
	LLdkeex	LLdkeirx	LLdkrx	LLdkrx	Ldkgrx	LLdkeirx	LLdkirx	Ldkirx	Ldkirx	LLdkir

Key: LL = Loamy top soil and loamy subsoil, d = Soil moisture stress, k = Low nutrient reserves, e = High erosion risk, i = No major chemical limitation, v = Cracking clays, r = Gravel, g = Waterlogging, x = Amorphous, volcanic, e = High leaching potential, c = Sulpdic (cat clays).

The soils formed on Unconsolidated deposits had notably less soil fertility constraints (three of four) for most of the soils, as compared to four or five and five or six, for the soils formed on Basalt and Granite respectively. Waterlogging was negligible, no cracking clays, high leaching potential was rare and the soils were less gravelly. The soils formed on Unconsolidated deposits had the highest agricultural potentials, followed by the soils formed on Basalt while the soils formed on Granite had the lowest agricultural potentials.

4.9 Results of statistical analysis

Some key statistical values from the analysis of variance done for selected properties of the soils investigated, using a Randomized Complete Block Design (RCBD) and employing Genstat Statistical Package (8th Edition), at 5% level of significance; are as presented in Table 4.24 while Table 4.25 shows the statistical values and results, for selected properties, of the toposequences of soils derived from each of the parent materials involved in the study on the Jos Plateau. Considering the effects of physiographic positions in the toposequences on organic carbon, soils in the different positions of the toposequences had significantly higher organic carbon than the valley bottom soils, for the three categories of soils (soils formed on Basalt, Granite and Unconsolidated deposits) Table 4.24 refers. In terms of the interactions between parent materials and the toposequences in relation to organic carbon, the trend was same for both the soils formed on Basalt and Granite but for the soils formed on Unconsolidated deposits, soils in the middle slope positions had significantly higher organic carbon than the soils of the valley bottoms, Table 4.24 refers.

No significant difference in the organic carbon levels of soils of toposequence BST1 and BST2, formed on Basalt (S.E.D not significant) Table 4.25 refers. Soils of toposequence GNT1 had significantly higher organic carbon than soils of toposequence GNT2, all formed on Granite; S.E.D = 2.358, Table 4.25 refers. No significant differences in the organic carbon contents of soils of toposequence UDP1 and UDP2 formed on Unconsolidated deposits; (S.E.D not significant). The soils formed on Granite had significantly more organic carbon than the soils formed on Basalt and Unconsolidated deposits ($P < 0.001$; l.s.d = 2.268). There were no significant differences in the organic carbon levels of the soils formed on Basalt and those of the soils formed on Unconsolidated deposits.

Table 4.24: Some key statistical values from the Analysis of variance done for selected properties of the soils investigated

Variate	Source of variation	F pr	e.s.e	s.e.d	l.s.d	Mean variates for sources of variation					
OC	Parent Material	< .001	0.813	1.150	2.268	Basalt	Granite	Unconsolidated deposits			
						12.19	15.18	10.33			
	Toposequence	0.014	1.050	1.485	2.927	Toposequence	1	2	3	4	5
							12.80	13.60	14.35	12.66	9.43
	Parent material/ Toposequence	0.719	1.819	2.572	5.070	Parent material/ Toposequence	1	2	3	4	5
						Basalt	13.53	13.77	11.74	12.51	9.39
						Granite	14.02	16.84	16.82	15.70	12.53
						Unconsolidated deposits	10.86	10.18	14.48	9.76	6.37
TN	Parent Material	0.007	0.0791	1.1119	0.2206	Basalt	Granite	Unconsolidated deposits			
						1.277	1.403	1.053			
	Toposequence	0.009	0.1022	0.1445	0.2848	Toposequence	1	2	3	4	5
							1.305	1.354	1.417	1.219	0.928
	Parent material/ Toposequence	0.646	0.1770	0.2503	0.4934	Parent material x Toposequence	1	2	3	4	5
						Basalt	1.401	1.513	1.218	1.281	0.974
						Granite	1.356	1.618	1.639	1.333	1.069
						Unconsolidated deposits	1.157	0.930	1.394	1.043	0.740

Table 4.24: Some key statistical values from the Analysis of variance done for selected properties of the soils investigated

Variate	Source of variation	F pr	e.s.e	s.e.d	l.s.d	Mean variates for sources of variation					
Avail. P	Parent Material	< .001	0.524	0.741	1.461	Basalt	Granite	Unconsolidated deposits			
						1.74	3.30	5.95			
	Toposequence	0.243	0.676	0.956	1.886	Toposequence	1	2	3	4	5
							4.64	2.94	3.00	3.35	4.38
	Parent material/ Toposequence	0.138	1.171	1.657	3.266	Parent material x Toposequence	1	2	3	4	5
						Basalt	1.00	0.80	2.26	1.98	2.65
						Granite	3.29	3.81	2.48	3.09	3.80
						Unconsolidated deposits	9.63	4.21	4.26	4.97	6.69
Exch. K	Parent Material	< .001	0.0341	0.0483	0.0952	Basalt	Granite	Unconsolidated deposits			
						0.409	0.641	0.387			
	Toposequence	< .001	0.0441	0.0623	0.1228	Toposequence	1	2	3	4	5
							0.366	0.597	0.416	0.607	0.410
	Parent material/ Toposequence	< .001	0.0763	0.1079	0.2128	Parent material x Toposequence	1	2	3	4	5
						Basalt	0.437	0.385	0.467	0.392	0.363
						Granite	0.381	0.949	0.316	0.948	0.613
						Unconsolidated deposits	0.281	0.457	0.465	0.481	0.254

Table 4.24: Some key statistical values from the Analysis of variance done for selected properties of the soil investigated cont'd

Variate	Source of variation	F pr	e.s.e	s.e.d	l.s.d	Mean variates for sources of variation					
	Parent Material	< .001	0.431	0.610	1.202	Basalt	Granite	Unconsolidated deposits			
						10.64	15.55	15.48			
	Toposequence	0.395	0.557	0.787	1.552	Toposequence	1	2	3	4	5
							13.59	14.49	13.53	14.51	13.33
ECEC	Parent material/ Toposequence	0.421	0.964	1.364	2.689	Parent material x Toposequence	1	2	3	4	5
						Basalt	1.401	1.513	1.218	1.281	0.974
						Granite	1.356	1.618	1.639	1.333	1.069
						Unconsolidated deposits	1.157	0.930	1.394	1.043	0.740

e.s.e: estimated standard error; s.e.d: standard error of difference; l.s.d: least significant difference; ECEC: Effective cation exchange capacity: OC: organic carbon, TN: Total nitrogen; Avail. P: Available phosphorus; Exch. K: Exchangeable potassium

Table 4.25: Statistical values and results, for selected properties, of the toposequences of soils derived from each of the parent materials involved in the study on the Jos Plateau

Parent material/ Toposequence	Means of selected properties for the toposequences			
	OC	Total N	Avail. P	Exch. K
BST1	11.6	1.2	1.4	0.13c
BST2	12.8	1.4	2.2	0.68a
S.E.D	Ns	ns	ns	0.065
GNT1	18.9a	1.7a	5.0a	0.57
GNT2	10.8b	1.1b	1.6c	0.71
S.E.D	2.358	0.211	0.837	Ns
UDP1	10.9	1.1	9.9a	0.15c
UDP2	9.7	0.9	2.0c	0.63a
S.E.D	Ns	ns	1.872	0.66

s.e.d: standard error of differences of means; ns: not significantly different at 5% probability level; BST: Basalt; GNT: Granite; UDP: Unconsolidated deposits

Soils in all the other physiographic positions of the toposequences had significantly higher Total Nitrogen than the valley bottom soils, for all the three categories of soils investigated.

In terms of interactions between the parent materials and the toposequences with respect to Total Nitrogen, upper slope position soils had significantly more Total Nitrogen than soils of valley bottom, for the soils formed on Basalt; upper slope position soils had significantly more Total Nitrogen than the valley bottom soils, for the soils formed on Granite while for the soils formed on unconsolidated deposits, middle slope position soils had significantly more Total Nitrogn than the valley bottom soils, Table 4.24 refers.

No significant differences in the Total Nitrogen of soils of both toposequences BST1 and BST2, formed on Basalt, (S.E.D not significant). Soils of toposequences GNT1 had significantly higher Total Nitrogen than soils of toposequence GNT2, all formed on Granite; S.E.D = 0.211, Table 4.25 refers. No significant differences in the Total Nitrogen of soils of both toposequences UDP1 and UDP2, formed on Unconsolidated deposits, Table 4.24 refers.

The soils formed on Basalt and Granite had significantly higher Total Nitrogen than the soils formed on Unconsolidated deposits (P = 0.007; l.s.d = 0.2206). No significant difference between the levels of Total Nitrogen of the soils formed on Basalt and those formed on Granite.

No significant difference in the available phosphorus of the soils in the different physiographic positions of the toposequences, for all the three categories of soils, Table 4.24 refers. The interactions between the parent materials and toposequences with respect to available phosphorus, indicated that the trend was same for both the soils formed on Basalt and Granite while for the soils formed on Unconsolidated deposits, soils at the crest positions had significantly higher available phosphorus than the upper slope, middle slope and lower slope position soils but not significantly higher than soils of the valley bottoms. No significant differences in the available phosphorus of soils of both toposequences BST1 and BST2, formed on Basalt.

Soils of toposequences GNT1 had significantly higher available phosphorus than soils of GNT2; all formed on Granite, S.E.D = 0.837, the Table 4.25 refers. Similarly, soils of toposequence UDP1 had significantly higher available phosphorus than soils of toposequence UDP2, S.E.D = 1.872, both sets of soils were formed on Unconsolidated deposits.

The soils formed on Unconsolidated deposits as well as the soils formed on Granite, had significantly more available phosphorus than the soils formed on Basalt ($P< 0.001$; l.s.d = 1.461). Similarly, the soils formed on Unconsolidated deposits, had significantly more available phosphorus than the soils formed on Granite.

The soils at the lower slope positions in the toposequences, had significantly higher exchangeable potassium than the soils at the crest, middle slope and valley bottom positions but not significantly different from soils of the upper slope positions in exchangeable potassium. The interactions between parent materials and toposequences in relation to exchangeable potassium, indicated that the trends were same for the soils formed on Basalt and Unconsolidated deposits while for the soils formed on Granite, soils of the upper slope positions had significantly higher exchangeable potassium than soils of the crest, middle slope and valley bottom positions.

Soils of toposequence BST2 had significantly higher exchangeable potassium than soils of toposequence BST1, S.E.D = 0.065; no significant differences in the exchangeable potassium of soils of toposequence GNT1 and GNT2, all formed on Granite, Table 4.25 refers. Soils of toposequence UDP2 had significantly higher exchangeable potassium than soils of toposequence UDP1, S.E.D = 0.066, both sets of soils formed on Unconsolidated deposits.

The soils formed on Granite had significantly more exchangeable potassium than those formed on Basalt and the soils formed on Unconsolidated deposits ($P< 0.001$; l.s.d = 0.0952). No significant difference in exchangeable potassium of soils formed on Basalt and those formed on Unconsolidated deposits. Table 4.24 refers.

Considering the physiographic positions of the soils formed on the three different parent materials and the ECEC, there were no significant differnces in the ECEC of the soils in the different positions. With respect to the interactions between the parent materials and physiography in relation to ECEC, the trends were same for the soils formed on Basalt and

Unconsolidated deposits but for the soils formed on Granite, soils of the upper slope positions had significantly higher ECEC than soils of the crest, middle slope and valley bottom positions.

The soils formed on Granite and the soils formed on Unconsolidated deposits had significantly higher Effective Cation Exchange Capacity than the soils formed on Basalt ($P < 0.001$; l.s.d = 1.202). There was no significant difference in the Effective Cation Exchange Capacity of the soils formed on Granite and that of the soils formed on Unconsolidated deposits.

Data were analysed using one-way Anova of randomized complete block design with level of significance set at 5% probability level.

CHAPTER 5

DISCUSSION

5.1 Observations on the natural settings of the parent materials, the soils derived from them, the features and possible reasons

The three major parent materials (Basalt, Granite and Unconsolidated deposits); from which the soils investigated were formed, usually occur close to one another within the landscapes of the Jos Plateau. In some cases, however, they occur relatively far apart. Granite parent rocks stand conspicuously within the landscapes as high hills often surrounded by low lying granitic outcrops. The large crystals are visible to the naked eyes. Thin section preparation of Granite revealed the presence of Quartz, Biotite, Muscovite, and Plagioclase. Granite is acidic in reaction; this could be a contributory factor to the acidic nature of the soils formed on Granite.

Basalt rocks occur at relatively lower heights within the landscapes and often as Boulders or rock fragments; this may be explained by the fact that Basalt weather readily owing to its tiny crystals and the unstable nature of its mineral components. A thin section preparation of Basalt revealed the presence of Hornblend, Biotite, Muscovite, Plagioclase and Quartz.

The Unconsolidated deposits have after many years weathered intricately into soils which now occupy extensive valleys bounded by far away hills; only tiny pieces of some of the initial resistant rock components of the Unconsolidated deposits now remain in the soils, especially granite. The thin section preparation of a tiny piece of Granite picked from a profile of one of the soils formed on Unconsolidated deposits (Profile pit JP-UDP1-4), revealed the presence of Feldspar, Kaolinite and Quartz, an indication of progressive weathering.

The more gradual slope of the soils formed on Basalt as compared to the steeper slopes of the soils formed on Granite and Unconsolidated deposits, may be due to the parent materials effects. Basalt weathers readily owing to its unstable nature and fine crystals. Accordingly, the soils formed on Basalt assume the lower position of the parent material from which they were formed and upon which they rest. Granite consists of large crystals and it is relatively stable and weathers slowly. The soils formed on Granite also assume the higher elevation of the parent material upon which they were formed. The soils formed on Unconsolidated deposits have assorted parent materials some of which weather slowly while others weather readily, they therefore occupy a slope that is intermediate in elevation between that of soils formed on Basalt and that of soils formed on Granite.

5.2 Contrasting properties of the soils of the different parent materials, physiographic positions and reasons

Soils of the valley bottom positions having the highest mean percentage gravel amongst the soils of the different physiographic positions, for the soils formed on Basalt, could possibly be due to transportation of gravel by water, from the preceeding positions and deposition in the valley bottom physiographic positions. The lowest mean percentage gravel recorded in the soils of the upper slope positions might possibly be due to removal to lower physiographic positions by water and gravity. Soils of the crest positions having the highest mean percentage gravel amongst soils of all physiographic positions, for the soils formed on Granite, could possibly be due to removal by water, of large amounts of fine soil materials to the down slope physiographic positions. Furthermore, it could be due to early stage of weathering whereby the products were relatively bigger rock piecies. Finer products would result with progressive weathering. Soils of the middle slope positions, having the lowest mean gravel, could possibly be due to receipts of large amounts of fine soil materials (colluvial) from the upslope physiographic positions and possibly, more intense and advanced weathering, resulting in the breaking down of coarse rock materials.

Soils of the lower slope positions having the highest mean percentage gravel while soils of the middle slope positions, had the lowest mean percentage gravel, for the soils formed on Unconsolidated deposits, could possibly be due to removal of some gravel from the middle slope positions and subsequent deposition in the lower slope positions by water and gravity; furthermore, soils of the middle slope positions, could receive ample supplies of fine soil materials from upslope physiographic positions.

In the soils of those physiographic positions of the three categories of soils investigated, where coefficients of variation for percentage gravel were high, it implies that percentage gravel varies greatly from one point to the other, in the affected soils. Such great variations may possibly be due to the removal of gravel from some points in the soils to others by water and gravity; likewise, soils in those positions where coefficients of variation for percentage gravel were low, implies that changes in amounts of gravel in the soils from one point to another, are minimal and this might probably be due to relative uniformity in environmental forces at work, at different points in the soils, as well as relative uniformity in the compositions of the different parent materials of the soils.

The differences in the amounts of gravel amongst the soils may be due to the nature of the parent materials, rate of weathering, the extent of weathering and erosional processes. Granite is more resistant to weathering than Basalt which consists of minerals that weather readily. Unconsolidated deposits could consist largely of finer materials with less coarse fragments, depending on the materials deposited. The B and C horizons of the soils formed on Unconsolidated deposits were constantly high in gravel. This observation is in consonance with that of Ojanuga and Awujoola (1981), who reported many or abundant coarse fragments in the B and C horizons of some soils of the Jos Plateau. The high concentration of coarse fragments in the B horizons has been attributed to erosional processes whereby the coarse fragments have been deposited partly by moving water. The washing away of the fine soil materials by moving water, leaving behind the coarse fragments, is another contributory factor. The concentration of coarse fragments in the C horizons has been attributed to decreasing intensity of weathering processes with depth.

The highest mean sand recorded in soils of the lower slope positions, for the soils formed on Basalt, could possibly be due to sand deposition from upslope physiographic positions, by water. Similarly, soils of the upper slope positions that recorded the lowest mean sand, could possibly have lost some of their sand contents to soils in the downslope physiographic positions through removal by running water. The highest mean sand occurring in soils of the crest positions for the soils formed on Granite, could possibly be due to sand deposition by wind, a phenomenon reported to have occurred on the Jos Plateau a long time ago. The high level of sand recorded for soils of the crest positions could also be an indication that the soils are relatively young, developing soils, which are often high in sand; deposition by wind, is another possible reason.

The lowest mean sand recorded for soils of the lower slope positions, for the soils formed on Unconsolidated deposits, could possibly be due to advanced weathering whereby progressive weathering has resulted in a more developed soil, with less sand. The highest coefficient of variation for sand, recorded in soils of the lower slope positions, tends to suggest that the soils are mixed up with soil materials deposited from soils of the upslope positions. The lowest coefficient of variation for sand, recorded in soils of the upper slope positions, suggests that the soils are generally more uniform in their sand contents as compared to the soils of the other physiographic positions; relative uniformity in the weathering of the parent material, may be responsible for the observed trend.

The dominance of the fine earth fraction of most of the soils by sand, conforms with the findings of Ugwu (1983), Akinwa (1989) and Olowolafe (2009) who reported the dominance of sand in the fine earth fraction of most soils of the Jos Plateau. Notably, higher sand contents in the soils formed on Basalt over those formed on Granite may possibly be due to the fact that a number of the soils formed on Basalt, are Inceptisols while most of the soils formed on Granites are Alfisols. Inceptisols are slightly developed soils, they have no contrasting horizons; Alfisols and Ultisols are more developed soils with an argillic/kandic B horizon. Alfisols do not have less than 35% Base Saturation at a depth of 125 cm below the upper boundary of a kandic horizon, the contrast is the case with Ultisols. Deposition of sand by wind and run-off water could be another possible reason. Similarly, the higher contents of sand in the soils formed on Unconsolidated deposits over those formed on Granite, may be due to the parent material effects of the soils formed on Unconsolidated deposits. The Unconsolidated deposits were products of moving water and could have significant amounts of sand. The complex nature of the parent materials could be another contributory factor.

The concentration of sand in the surface horizons of most of the soils may be due to the deposition by wind and run-off water. The surface horizons of the soils of the Jos Plateau have been influenced by aeolian fine loamy material (Macleod *et al*., 1971; Akinwa, 1989; Olowolafe, 2009). Esu (1982), attributed the relatively higher fine sand in the upper horizons of some of the soils in Kaduna area of Nigeria, to the aeolian source of the soil parent material of the upper layers of the soils.

Soils of the valley bottom positions had the highest mean silt for both the soils formed on Basalt and Granite; the accumulation of silt in the valley bottom soils may possibly be due to removal of silt by running water, from soils of the upslope physiographic positions and subsequent deposition in the valley bottom soils. Same explanation holds for the accumulation of silt in the soils of the lower slope positions, for the soils formed on Unconsolidated deposits. Soils of the upper slope positions, having the lowest mean silt for both the soils formed on Basalt and Granite, may possibly be due to less Intense weathering of the parent rocks, resulting in less production of silt. Removal of silt to the downslope positions by water could be another reason.

Silt having the highest coefficients of variation in soils of the crest positions for both the soils formed on Granite and Unconsolidated deposits, could possibly be due to the little amounts of silt in the soils of the crest positions in relation to the sand and clay components of the soils. Similarly, the least coefficients of variation for silt being in the soils of the lower slopes and valley bottom positions for the soils formed on Granite and Unconsolidated deposits respectively, could possibly be due to the high amounts of silt in the affected soils in relation to sand and clay.

The high silt content of the soils differentiates them from the soils of the humid tropical lowlands of South-West Nigeria (Ojanuga, 1981). This makes them similar to those of Kaduna area however, Esu, (1982) reported high silt contents of some soils of kaduna area. The constantly high levels of silt in the uppermost horizons of most of the soils may possibly be due to deposition both by wind and water. The relatively higher silt contents of the soils formed on Basalt over those on Granite and Unconsolidated deposits, may be due to the parent material effects. Basalt consists of fine crystals which weather readily while Granite consists of large crystals resistant to weathering. The Unconsolidated deposits contains some coarse materials (Rock fragments, Quartz, etc.)

The highest mean clay recorded in soils of the upper slope positions, for the soils formed on Basalt, could possibly be due to more development of the soils; developed soils are associated with clay accumulation, all the soils of the upper slope positions have accumulation of clay in their B horizons. The accumulated clay might have been eluviated from the overlying horizons. The least mean clay recorded in soils of the valley bottom positions could be due to the fact that one of the soils (JP-BST1-5), is an Inceptisol. Inceptisols are relatively young soils, they don't have an accumulation of clay. Clay having the highest coefficient of variation in soils of the valley bottom positions may possibly be due to the relatively unstable nature of the soils as they are seasonally affected by flooding. The lowest coefficient of variation for clay recorded in soils of the lower slope positions, could possibly be due to relatively uniform accumulation of clay in the B horizons of the soils. All the soils of the lower slope positions are Alfisols.

Similar observations were made for the soils formed on Granite and Unconsolidated deposits in terms of soils of physiographic positions with highest or lowest mean clay and highest or lowest coefficients of variation for clay; the explanations made with respect to the soils formed on Basalt, also apply to the soils formed on Granite and Unconsolidated deposits. However, clay having the highest coefficient of variation in soils of the crest positions for the soils formed on Unconsolidated deposits rather than in the soils of the valley bottom physiographic positions as it was the case for the soils formed on Granite and Basalt, could possibly be due to the fact that the soils formed on Unconsolidated deposits had parent materials made up of assorted materials which weather at different rates and giving rise to products that may vary.

The markedly higher clay contents of the soils formed on Granite over the clay contents of the soils formed on Basalt and Unconsolidated deposits may be due to differences in the stages of soil development. The soils formed on Granite may probably be at a more advanced stage of development than the soils formed on Basalt and Unconsolidated deposits. The fact that a number of the soils formed on Basalt are Inceptisols, tend to lend support to this viewpoint. Also, for the soils formed on Unconsolidated deposits, the nature of the materials deposited would ultimately influence the type and characteristics of the resultant soil.

Soils of the upper slope and lower slope positions having the highest mean Bulk density, for the soils formed on Unconsolidated deposits, might possibly be due to compaction of the soils by heavy machines as tractor hiring services are now being embraced by farmers, while the least mean Bulk density recorded for the valley bottom soils could possibly be due to good tillage during land preparation. Those physiographic positions in the different categories of soils investigated that recorded the highest coefficient of variation for Bulk density, imply that Bulk density varies more from one point to the other there, as compared to those physiographic positions with less coefficients of variation for Bulk density. Differences in the coefficients of variation for Bulk density, could possibly be due to differences in tillage, compaction, texture and organic matter, all of which influence Bulk density in one way or the other. Good tillage and high level of organic matter, reduce Bulk density while compaction and clay texture increase Bulk density.

The relatively lower bulk density of the soils formed on Basalt compared to that of those formed on Granite or Unconsolidated deposits, is in conformity with the findings of Olowolafe (2003), who observed that soils formed on Basalt and Volcanic ash on the Jos Plateau, have low bulk density in contrast to that of those formed on Granite which have rather high bulk density, getting up to 1.75 g cm^{-3} in many horizons. The low bulk density of soils formed on Basalt has been attributed to high humus content and low particle density resulting from their high porosity (Meada *et al*., 1977). A number of the soils formed on Basalt in this study, had moderate levels of organic carbon. Vapraskas (1977), has noted that bulk density above 1.46 g cm^{-3} to 1.63 g cm^{-3} for loam and clays result in hindrance to root penetration and insufficient aeration due to compaction.

The very strongly acidic nature of soils of the upper slope positions as compared to the strongly acidic nature of soils of the other physiographic positions, for the soils formed on Basalt, could possibly be due to more leaching of basic ions from the soils of the upper slope positions. Again, the upper slope soils could have received more acid forming fertilizers such as urea and muriate of potash, than the soils of the other physiographic positions. The application of the fertilizers mentioned, is popular on the Jos Plateau. Soils of the valley bottom positions being moderately acidic while soils of the other physiographic positions were strongly acidic, for the soils formed on Unconsolidated deposits, might possibly be due to deposition of basic ions washed from soils of the upslope positions into the soils of the valley bottom positions. Ogeh and Ukodo (2012), reported higher pH values for middle slope and valley bottom than the upper slope.

The highest coefficients of variation for pH recorded in soils of the crest positions, for both the soils formed on Basalt and Granite, could possibly be due to differences in leaching from one point to the other in the soils; differences in the use of acid forming fertilizers in the soils, could be another possible reason. The lowest coefficients of variation for pH recorded in soils of the lower slope or valley bottom positions for the soils formed on Basalt and Granite respectively, could possibly be due to relative uniformities in the management of the soils and the impact of environmental factors. The highest coefficient of variation for pH recorded in soils of the valley bottom positions, could possibly be due to the unstable environment of the soils occasioned by seasonal flooding which deposits or removes different materials into or from the soils.

The acidic nature of the soils can partly be attributed to regular heavy orographic (relief) rainfall experienced on the Jos plateau during the rainy seasons, leading to leaching. Fawole *et al*. (2016) partly attributed the acid nature of the soils in their study to high rate of leaching of bases, prevalent in the humid tropics. The common use of acid forming fertilizers such as Urea, Ammonium sulphate and Muriate of Potash, could also be a contributory factor. Also, the parent material effect may be another contributory factor, Granite for example is acidic. Even though there are no notable differences in the pH values of the soils formed on the different parent materials, the soils formed on Basalt had values that were a bit higher than those of the soils formed on Granite and Unconsolidated deposits. This may be due to the parent material effect, as Basalt is Basic in reaction.

The constantly higher pH of some of the soils formed on Basalt and Granite in the lower horizons than those of the overlying, upper horizons may be due to the leaching of basic ions from the upper horizons and deposition in the lower horizons. Under the acidic conditions of the soils, phosphates are expected to react with Fe and Al, thereby becoming unavailable. Mizota and van Reeuwijk (1989), have noted that apart from the nature of soil parent materials, moisture regime and vegetation are other factors affecting soil pH. Most soils of volcanic origin in the tropics are acidic and under strong leaching by tropical rains, the pH values can drop from 5 - 4 range (Bornemisza, 1988). Under such conditions, Phosphorus becomes less available to plants; bacterial nitrification decreases and Al toxicity could possibly increase. Such acid related problems constitute limitation to crop production (Wiechmann, 1987).

The soils generally should benefit from liming, for better crop production. Under the strongly acidic nature of the soils, leguminous plants in particular, may not do well, because they may not be able to nodulate (Alva, 1986).

Differences in the physiographic positions of the three soils groups where exchange acidity attained the highest or lowest levels, depend on the amounts of Aluminium and Hydrogen ions in the soils in such locations, and such amounts in turn depend on Aluminium released from weathering of the parent materials or transported from one point and deposited in another. Leaching of basic ions leaving behind hydrogen ions has to be taken into account too.

The physiographic positions of the soils where coefficients of variation for exchangeable acidity attained the highest values imply that exchange acidity differ much from one point to the other in the soils of such slope positions.

Likewise, soils of the physiographic positions where the coefficients of variation attained the lowest values, don't differ much in exchangeable acidity from one point to the other, in other words, exchangeable acidity is relatively more uniform across the soils.

The highest mean exchangeable Hydrogen recorded in soils of the crest positions for the soils formed on Basalt could possibly be due to washing down slope, of basic ions, another possible reason could be due to the relatively young age of soils of the crest positions, one of which was an Inceptisol. Weathering of the parent material to release into the soils, the basic ions it carries, is just at the inception. The lowest mean exchangeable Hydrogen recorded in soils of the valley bottom physiographic positions, might possibly be due to the enrichment of the soils with basic ions washed down from the upslope positions. The highest coefficient of variation for exchangeable Hydrogen recorded in soils of the crest physiographic positions, could possibly be due to differences in the extent of weathering of the parent material fragments across the soils, differences in the organic matter contents of the soils and differences in amounts of basic ions washed downslope, from one point to another in the soils.

Exchangeable Aluminium accounting for a relatively higher portion of the exchange acidity of the soils formed on Basalt, could be due to the presence of Aluminium in Basalt; weathering of the rock released the Aluminium it carried. The very high coefficients of variation recorded in soils of all positions, could possibly be due to differences in the fixation of Aluminium by forming complexes with some soil materials like organic matter as well as differences in the weathering of fragments of the parent material across the soils. Differences in levels of organic matter from one point to another in the soils, could be another reason.

Trends observed in the soils formed on granite were quite similar to those as observed in the soils formed on Basalt and the explanations made for the observed trends in the soils formed on Basalt adequately address the trends observed for the soils formed on Granite. However, for the soils formed on Unconsolidated deposits, there were some notable differences owing to the assorted nature of the parent materials. The contributions of exchangeable Hydrogen and exchangeable Aluminium to exchange acidity in the soils formed on Unconsolidated deposits, were even (fifty-fifty) but for the soils formed on Basalt and Granite, Aluminium contributed relatively more than exchangeable Hydrogen. Again, in both the soils formed on Basalt and Granite, exchangeable Hydrogen was highest in soils of the crest physiographic positions but for the soils formed on Unconsolidated deposits, soils of the valley bottom physiographic positions had the highest levels of exchangeable Hydrogen.

The notably high values of exchangeable acidity of soils formed on Granite over those formed on Basalt and Unconsolidated deposits may be attributed to the acidic nature of Granite. Aluminium ions accounting for a relatively greater proportion of the exchange acidity of the soils formed on Basalt, may probably be due to more Aluminium ions on the exchange sites than Hydrogen ions. Similarly, Hydrogen and Aluminum ions accounting for about same proportions of the exchange acidity of the soils formed on Unconsolidated deposits, could be due to the presence of about same levels of Hydrogen and Aluminium ions on the exchange sites of the soil colloids.

Differences in the physiographic positions of the three categories of soils investigated, where the soils had the highest levels of organic carbon, could possibly be due to differences in management. Soils of the physiographic positions with the highest levels of organic carbon could possibly have received some farmyard manure in a previous cropping season. Again, the affected soils might have had plants and crop residues incorporated into them during land preparation or crop and plants residues might have been allowed to decay on the soils in a previous cropping season.

The lowest levels of organic carbon recorded in the valley bottom soils of all the soils investigated, might possibly be due to impeded decomposition of plant and animal residues owing to water logging which is often associated with valley bottom soils during the rains. Loss of organic carbon to flowing water could be another reason for the observed trend.

The highest coefficients of variation for organic carbon recorded in the valley bottom or lower slope positions of the soils, could possibly be due to assorted materials deposited on the soils annually, during the rains. The least coefficients of variation for organic carbon recorded for soils of the crest, upper slope or middle slope positions, could probably be due to the relative uniformity of the soils of the affected physiographic positions, in their organic carbon contents. Again, loss of fine particles to flowing water at the valley bottoms, could be another reason.

The very low or low levels of organic carbon in some of the soils may partly be attributed to the rapid decomposition of organic matter, characteristic of tropical climates, bush burning and the non-incorporation of crops residues into the soils after harvesting. Again, the degradative effect of cultivation and other land use and management practices could be another contributory reason (Fawole *et al*., 2016). The soils with very low or low levels of organic carbon are expected to have only little reserves of nutrient elements for crop use, except where they are rich in minerals, such as feldspars and micas, otherwise they may not be able to sustain good crop yields without the application of fertilizers.

The soils with moderate levels or high organic carbon may possibly have had crops and other plant residues incorporated into them during land preparations; they could also possibly have received the application of farm yard manure during the cropping season. The practices mentioned are common on the Jos Plateau as many farmers cannot afford the high costs of chemical fertilizers. Furthermore, literature has it that soils formed on basalt are usually high in organic matter; some of the soils with moderate to high levels of organic carbon in this study were formed on Basalt. Olowolafe (2002), reported organic matter of more than 2% and sometimes up to 3% for most of the soils derived from Basalt and volcanic ash, on the Jos Plateau especially in the surface layers. The generally higher organic carbon contents in the surface horizons of the soils may be attributed to higher levels of organic materials (crops/plants residues, farm yard manure, roots) in the surface horizons than in the sub-surface horizons.

The significantly higher organic carbon contents of the soils formed on Granite over those formed on Basalt and on Unconsolidated deposits, may probably be due to receipts of more farm yard manure and crop residues by the soils than those formed on Basalt and Unconsolidated deposits. Again, during land preparation, crop residues as well as residues of other plants, might have been burnt off, in the case of both the soils formed on Basalt and on Unconsolidated deposits. The practices mentioned are popular on the Jos Plateau. Again, the soils formed on Basalt and Unconsolidated deposits were more intensively farmed than the soils formed on Granite resulting in their low levels of organic carbon.

The significantly higher organic carbon contents of soils of toposequence GNT1 ($p = 0.014$; l.s.d = 2.927) formed on Granite in Vom over the organic carbon contents of soils of toposequence GNT2 formed on Granite at Kasen, may be due to differences in amounts of organic materials (crop residues, manure, etc.) received by the soils. Soils where crop residues were burnt during land preparation for example, would have less organic matter than soils into which crop residues were incorporated during land preparation, even in the same locality and on same parent material. Again, soils that received large quantities of manure during the immediate past cropping season, would have more organic matter than other soils on same parent material and in the same locality but which received less or no manure.

Ladon (1991), has noted that organic carbon contents below 2% in tropical soils are very low, due to high temperature in most period of the year, leading to high rates of decomposition, mineralization and disappearance of organic materials, thereby preventing appreciable accumulation of organic carbon in the soils. Considering the important roles of organic matter in the sustainability of tropical agriculture (Olowolafe, 2002), the very low or low contents of organic carbon in some of the soils constitute a serious constraint to sustainable crop production.

Soils of the valley bottom positions all had the lowest levels of total nitrogen for all the soils investigated as it was precisely the case with organic carbon. The observed trend could possibly be due to the linkage between organic matter and Total Nitrogen. Soils high in organic matter are expected to have adequate levels of Total Nitrogen since organic matter is a reservoir of Total Nitrogen and other nutrients. the impeded decomposition and mineralisation of organic materials of the valley bottom soils due to water logging during the rains, might have partly accounted for the low Total Nitrogen of the valley bottom soils. Leaching and washing away of Nitrogen from the soil by water, could be another reasons for the observed low Total Nitrogen of the affected soils.

The highest levels of Total Nitrogen recorded in soils of the upper and middle slopes positions, could possibly be due to improved decomposition of organic materials and good mineralisation of organic matter due to good aeration in the affected soils. Again, the soils could possibly have received farmyard manure or nitrogen fertilizers during a previous cropping season.

The inadequate levels of Total Nitrogen in most of the soils may be attributed to rapid mineralization of organic matter due to high temperature of the tropics, leaching and erosion, as a result of heavy rainfall. Steep slopes within the landscapes also aggravate soil erosion. Furthermore, the soils especially those derived from Basalt have been intensively cultivated for long without adequate organic return.

The soils will require the application of Nitrogen fertilizers for sustainable crop production. Adepetu *et al*. (2002), have observed high response of upland rice to N-fertilizers on the Jos Plateau.

The high total Nitrogen in some of the soils may be due partly to organic matter contents of the soils and partly due to the application of some Nitrogen fertilizers during the cropping season. In this study, soils high in organic matter were also high in Total Nitrogen and vice versa. The higher Total Nitrogen in the surface horizons of the soils than the sub-surface horizons may be attributed to higher levels of organic materials in the surface horizons than in the sub-surface horizons. The application of Nitrogen fertilizers too, can be a contributory factor to the noted difference.

The significantly higher Total Nitrogen of both the soils formed on Basalt and Granite, over those formed on Unconsolidated deposits, might partly be due to the influence of organic matter. Both the soils formed on Basalt and on Granite, are of volcanic origin. Olowolafe (2002), has observed that volcanic soils have much higher contents of organic matter than non-volcanic ones under similar conditions and has attributed this to the hindrance of organic matter decomposition in volcanic soils by amorphous Al hydroxide and the effect of vegetation. Active aluminium can form complexes with humus and such Al-humus complex is relatively a stable compound particularly at low pH (Parfitt, 1990).

The significantly higher Total Nitrogen of the soils of Toposequence GNT1 formed on Granite in Vom over that of the toposequence GNT2 formed on Granite in Kasen, may be due to differences in organic matter contents of the soils of the two toposequences. The soils of toposequence GNT1, were significantly higher in organic carbon than the soils of toposequence GNT2. Organic matter is a reservoir of Nitrogen and other nutrients.

The highest or lowest levels of available phosphorus did not follow any particular trend with respect to the positions of the soils. Similarly, the highest or lowest coefficients of variations did not follow a specific trend in relation to the physiographic positions of the soils. The observations tend to suggest that the availability of phosphorus in soils, is a function of many factors such as fixation of phosphorus, amounts in the parent materials, weathering, levels of organic matter and management practices, such as fertilizer application.

The very low or low available phosphorus of most of the soils may be partly due to the strongly acidic or moderately acidic conditions of most of the soils, resulting in the fixation of phosphorus. Again, some of the soils studied were very low or low in organic carbon, this partly explains the very low or low available phosphorus of some of the soils, since organic matter is a reservoir of many nutrient elements including phosphorus. Furthermore, the soils are cropped on a continuous basis with little or no time of fallow and often with inadequate application of phosphorus fertilizers, resulting in the depletion of available phosphorus in the soils.

The higher levels of available phosphorus in the surface horizons of the soils over the sub-surface horizons, may partly be due to the influence of organic matter and also the effect of phosphorus fertilizers that might have been applied to the soils during the cropping season.

The very low or low available phosphorus of most of the soils suggests that sustainable crop production may not be possible without the application of phosphorus fertilizers. Again, the acidic conditions of most of the soils suggests that liming could be beneficial to crop production on the Jos Plateau as the phosphorus fixed will become available to the crop.

The significantly higher available phosphorus of the soils formed on Unconsolidated deposits over those formed on Basalt and Granite may be due to the parent material effects. Olowolafe (2002), has observed that volcanic soils are characterized by their capability to react rapidly with large amounts of phosphorus due to their allophane contents. This explains perhaps, why the available phosphorus is lower in soils formed on Basalt and on Granite, than in soils formed on Unconsolidated deposits; some of the available phosphorus of the volcanic soils might have formed compounds with the allophane in the soils. Again, Unconsolidated deposits may contain some materials such as bones and shells of fossils rich in phosphorus, and the phosphorus is inherited by the soils formed from the deposits.

The significantly higher available phosphorus of soils formed on Granite over those formed on Basalt, may probably be due to receipts of more organic materials (manure, crops residue, etc.), in the past cropping season than the soils formed on Basalt. Organic matter contains phosphorus and other nutrient elements.

The significantly higher available phosphorus of soils of toposequence GNT1 over that of soils of toposequence GNT2 may be explained by the significantly higher organic carbon of soils of toposequence GNT1 over that of soils of toposequence GNT2. The same explanation holds for the significantly higher available phosphorus of soils of toposequence UDP1, the soils of toposequence UDP1, are higher in organic carbon than the soils of toposequence UDP2. Higher organic carbon implies higher organic matter. Organic matter contains phosphorus and other nutrients that are released to the soil when the organic matter is broken down by microbes.

The lack of any regular trend in the levels of exchangeable calcium, magnesium and potassium, from the crest to the valley bottom positions, for all the soils investigated, could possibly be due to differences in the amount of the elements inherent in the parent materials, differences in the extent of weathering of the parent materials, differences in levels of organic matter, differences in soil management practices and removal of the nutrient elements from one place and deposition in another, by water. Orimoloye *et al*. (2018), observed a lack of uniformity in the distribution of basic cations (Ca, Mg, K, Na) down the slope, in their study.

The relative uniformity in levels of exchangeable sodium in the soils of all the physiographic positions, for the soils formed on Basalt and Granite, might possibly be due to uniformity of the element, in the parent materials and relative uniformity in the rate of weathering of the respective parent materials. Again, the management practices for soils of all the positions, could be relatively uniform. The differences in the levels of exchangeable sodium in soils of the various positions, for the soils formed on Unconsolidated deposits, might possibly be due to the assorted nature of the parent material which could result in differences in levels of exchangeable sodium in the soils formed from them.

The markedly higher exchangeable calcium of soils formed on Unconsolidated deposit over the levels in soils formed on Basalt and Granite, may be due to the parent material effect. The Unconsolidated deposits may contain some materials that are rich in calcium especially calcareous materials. The higher exchangeable calcium of the soils formed on Granite over the levels for soils formed on Basalt may be due to the higher clay contents of the soils formed on Granite; the clay fraction of soils are higher in minerals than the sand or silt fraction. The low to moderate levels of calcium in most of the soils suggest that some calcium need to be applied to the soils as fertilizers, for sustainable crop production.

The three soil groupings did not differ much in their levels of magnesium. The low to moderate levels of magnesium in most of the soils also suggest that some magnesium has to be applied to the soils as fertilizers for sustainable crop production.

The significantly higher levels of potassium in the soils formed on Granite than those formed on Basalt and Unconsolidated deposits may be due to the parent material effect; Granite may contain more feldspars that are rich in potassium. The very low or moderate levels of potassium in most of the soils imply that some potassium needs to be applied to the soils as fertilizers, for good crop yields.

The significantly higher exchangeable potassium of soils of toposequence BST2 formed on Basalt over that of soils of toposequence BST1 also formed on Basalt, may be attributed partly to the higher clay contents of soils of toposequence BST2; the clay fraction of soils is usually rich in minerals. Again, soils of toposequence BST2, were significantly higher in organic carbon, than the soils of toposequence BST1; organic matter contains nutrient elements including potassium, which are released into the soil as the organic matter is mineralized.

The significantly higher exchangeable potassium of soils of toposequence UDP2 over that of soils of toposequence UDP1 may possibly be due to receipts of larger amounts of potassium fertilizers in the past cropping season over the amount received by soils of toposequence UDP1. Soils of toposequence UDP2 are not higher in either clay or organic carbon than the soils of toposequence UDP1. Again, the parent materials of the soils of toposequence UDP2, may be rich in potassium.

The relatively higher exchangeable sodium of the soils formed on Unconsolidated deposit and Granite over the soils formed on Basalt, may be due to the parent material effects.

Unconsolidated deposits as a type of parent material could have some sodium salts dissolved in the water transporting them; the salts remain with the deposited materials when the water evaporates and the soils formed from such deposits, inherit the salts.

The lack of any uniformity in the levels of effective cation exchange capacity of the soils, from the crest to the valley bottom positions, might possibly be due to differences in levels of organic matter, nutrient elements inherent in the parent materials of the soils, weathering, soil management practices and removal or deposition of nutrient elements, in the soils of the different positions.

The relative uniformity in the effective cation exchange capacity of the soils of all the physiographic positions, for the soils formed on Unconsolidated deposits, tends to suggest a relative uniformity in the composition of the parent material, weathering, and soil management practices across the soils of all the positions.

The highest coefficient of variation for effective cation exchange capacity recorded in soils of the crest positions, for the soils formed on Granite, could possibly be due to differences in rates of weathering, levels of organic matter and soil management, across the soils. Higher rates of weathering lead to release of more nutrient elements from the parent rock, higher levels of organic matter result in release of more nutrient elements into the soils, from the mineralisation of the organic matter. Again, application of fertilizers into the soil for crop use, improve the levels of the nutrient elements contained in the fertilizers in the soil.

The significantly higher effective cation exchange capacity of soils formed on Granite and Unconsolidated deposits over that for the soils formed on Basalt, may be attributed to the clay and organic matter contents of the soils. The soils formed on Granite and Unconsolidated deposits had notably higher clay than those formed on Basalt. Also, the soils formed on Granite were significantly higher in organic carbon than the soils formed on Basalt or Unconsolidated deposits. Clay and organic matter improve significantly, the Effective Cation Exchange Capacity of soils because they are rich in exchangeable cations.

The less clay contents recorded in the soils formed on Basalt as compared to the higher clay contents of the soils formed on Granite and Unconsolidated deposits, may be attributed partly to differences in stages of development of the soils, whereas the soils formed on Granite and Unconsolidated deposits, were at an advanced stage of development with significant accumulation of clay in some of their horizons (B horizons), some of the soils formed on Basalt especially in the Riyom area, were at a relatively younger stage of development with no significant accumulation of clay. A number of soils formed on Basalt in Riyom area, were Inceptisols.

Soils of the valley bottom or lower slope positions having the highest base saturation percentages might possibly be due to deposition of basic ions washed down from the upslope physiographic positions. Again, soils of the valley bottom or lower slope positions were generally high in clay which is usually rich in basic ions.

The highest coefficients of variation for base saturation percentages recorded in different physiographic positions of the soils investigated, could possibly be due to differences in the weathering of the parent materials, clay contents of the soils, levels of organic matter and soil management practices. Advanced weathering releases more clay minerals into soils, higher clay content implies more basic ions in the soils; higher levels of organic matter give rise to more basic ions from the mineralisation of the organic matter. Application of fertilizers carrying basic ions, improves the level of basic ions in the soil.

The notably higher base saturation percentages of the soils formed on Basalt and Unconsolidated deposits, than the soils formed on Granite, may be due to the parent material effects; the parent materials may be rich in clay minerals which weathered to release the basic cations they carry. Moreover, Granite is acidic in reaction. Thin section preparation of Basalt done in this study showed the presence of Biotite, Muscovite, Quartz, Plagioclase and Hornblend. Biotite and Muscovite carry Potassium and Calcium

The constantly higher base saturation percentages of surface horizons and the B horizons of the soils generally, may be attributed to the influence of organic matter and clay respectively. Organic matter is a reservoir of nutrient elements including basic cations. Similarly, the clay fraction of soils is rich in minerals which weather and release the basic cations they carry.

The highest levels of extractable manganese and iron, in soils of the valley bottom or lower slope positions for the soils formed on Basalt and Granite, could possibly be due to deposition of the two elements in the affected soils, from soils of the upslope positions, by water. The highest levels of extractable manganese and iron, recorded in soils of the middle or upper slope positions, for the soils formed on Unconsolidated deposits, could possibly be due to higher levels of the elements in the assorted materials that constituted the parent material of the soils, in the affected positions.

The markedly higher level of manganese in the soils formed on Basalt over the levels of the element in the soils formed on Granite and Unconsolidated deposits, may possibly be due to the parent material effects; Basalt perhaps may contain some manganese. Similarly, the notably higher levels of manganese in the soils formed on Granite than in the soils formed on Unconsolidated deposits, could be due to parent material effects, as Granite may contain some minerals rich in Manganese.

Parent material effect could possibly be responsible too, for the markedly higher levels of iron in both the soils formed on Unconsolidated deposits and Basalt as against the lesser level recorded in the soils formed on Granite. The red colour of the soils formed on Basalt may be due to presence of Haematite, a compound of iron. Similarly, the yellowish colour of some of the soils formed on Unconsolidated deposits may be due to the presence of Geotite, another compound of iron. The report of Hassan *et al*. (2015), that the basaltic soils of Plateau State Nigeria, were reddish in colour (2.5YR 3/3 – 5YR 3/4), acidic (pH 4.6 – 5.6), low to high CEC values (4.3 – 14.8 cmol kg^{-1}); generally low in organic matter (< 1.5% on the average) and exchangeable bases and were all well drained, is in agreement with the findings in this study.

The report by Sohotden *et al*. (2015), that organic matter, total nitrogen, soil pH and exchangeable Calcium and Magnesium, decline down the slope, for some soils of the Jos Plateau they investigated, is at variance with the findings in this study where the said characteristics follow no regular pattern down the slope. However, soils of the valley bottom positions, were least in organic matter, total nitrogen and pH. The report of Tijani and Hassan (2017), who investigated Variability of Some Soil Properties Along Toposequence on a

Basaltic Parent Material of Vom, Plateau State Nigeria and noted that no regular pattern was observed in the distribution of the studied characteristics (clay, silt, gravel, pH, Avail. P, Mg, K, Ca, Na, Exchangeable Acid), is in consonant with the findings in this study. The report by Olowolafe and Dung (2000), that soils derived from biotite – granite on the Jos Plateau are characterised by low to very low nitrogen, available phosphorus deficiency and low to very low exchangeable calcium and deficiencies of exchange potassium, magnesium, zinc and copper in some places, is in consonant with the findings in this study. The deficiencies may be partly attributed to erosion, leaching, crop removal and the acidic and lateritic nature of most of the soils.

The relative uniformity in levels of extractable copper for soils of all the physiographic positions except the middle slope positions, in the soils formed on Basalt, could possibly be due to uniformity in levels of copper in the parent material in the affected positions. Relative uniformity in weathering of the parent material in the affected positions, could be another reason. Lesser amounts of copper in the parent material at the middle slope position and lesser rate of weathering of the parent material, could possibly be responsible for the lesser amounts of extractable copper, in the soils of the middle slope positions.

The soils of the crest positions, having the highest levels of copper among soils of all the physiographic positions, for the soils formed on Unconsolidated deposits, could possibly be due to richness of the assorted materials that constitute the parent material, the weathering of which released the copper contained in them.

The lowest levels of extractable zinc recorded in all soils of the crest physiographic positions, for all the three groups of soils investigated, could possibly be due to the relatively low level of weathering of the parent materials, at the crest positions, resulting in low amount of zinc released from weathering. Again, the levels of zinc in the parent materials at the crest positions could possibly be low. Again, some of the zinc in the crest positions, could possibly be washed down by water.

The highest coefficients of variation for extractable zinc, recorded in the upper slope, lower slope and the crest positions for the soils formed on Basalt, Granite and Unconsolidated deposits respectively, imply that extractable zinc varies the most for the soils, in the affected physiographic positions. The variation could be due to variations in the amounts of zinc in the parent materials from one point to the other as well as differences in intensities of weathering of the parent materials from one point to the other.

The notably high levels of copper and zinc in the soils formed on Granite above the levels of the elements, in the soils formed on unconsolidated deposits and Basalt, could be due to the parent material effects; Granite may contain some minerals that carry copper and zinc. Similarly, the markedly higher levels of copper and zinc in the soils formed on Unconsolidated deposits over the levels of the two elements in the soils formed on Basalt, could also be due to parent material effects. The low to moderate levels of copper and zinc in all the soil groupings, suggest that some copper and zinc supplements may be added to the soils for sustainable crop production.

5.3 Linkage between soils identified in this study and those from previous studies, on the Jos Plateau

Most of the soils encountered in this study have been encountered by earlier workers on soils of the Jos Plateau. Ojanuga and Awujoola (1981) identified Typic Haplustalf (Orthic Luvisol), Udic Rhodustalf (Chromic Luvisol) and Typic Eutropept (Chromic Cambisol). Ugwu (1983), identified Ultic Haplustalf (Eutric Nitosol), Acquic Ustifluvent (Dysteric Fluvisol), Typic Paleustult (Ferric Acrisol) and Andic Ustic Humistropept (Dysteric Cambisol), Akinwa (1989), identified Typic Rhodustult (Orthic Acrisol), Plinthic Paleustalf (Plinthic Lixisol) and Plinthic Udic Paleustalf (Plinthic Lixisol). Olowolafe (2002), identified Oxic Dystrustept, Inceptic Haplustalf, Andic Haplustept, Typic Haplustult and Typic Dystrustept.

5.4 Agricultural potentials of the soils and the assessment of the land evaluation systems used

The observation that the soils formed on Unconsolidated deposits were more suitable for the productions of the crops considered (Maize, Irish potato and Citrus) as compared to the soils formed on Basalt or Granite, may be largely due to the less coarse fragment contents of the soils formed on Unconsolidated deposits, with a mean of 27.54% as against 42.16% for the soils formed on Granite and 33.24% for the soils formed on Basalt. Similarly, the observations that the soils formed on Basalt were more suitable for the crops considered than the soils formed on Granite may be largely due to the lower contents of coarse fragments in the soils formed on Basalt than the soils formed on Granite.

The emerging fact that the soils formed on Unconsolidated deposits as well as those formed on Basalt were more suitable for the cultivation of the three crops considered (maize, Irish potato and citrus) over the soils formed on Granite, suggests that a good management of the soil groups and putting same to judicious cultivation of the said crops, can greatly increase the production of the said crops on the Jos Plateau. This expectation may be true for other similar crops with similar requirements, on the Jos Plateau, because coarse fragments which were most limiting in the soils formed on Granite, will hinder the growth and yields of the crops. The soils formed on Unconsolidated deposits and on Basalt, cover vast areas on the Jos Plateau.

The highest content of coarse fragments 42.16% (Mean) in the soils formed on Granite, may be attributed to the resistance of Granite to weathering. Granite contains some minerals that do not weather easily notable among which is Quartz (Plate 4). Again, Granite consists of large crystals (Plate 4), which slows down its disintegration.

In this study, soil JP-BST2-3 was classified as IIe-1 whereas the same soil was classified as S3s for maize production. Similarly, soil GNT2-2 was classified as IIIe-2 but it was classified as unsuitable for maize cultivation in the land suitability classification. The reason for the noted differences is that while land capability is based on generalized qualities of the land, land suitability classification in addition takes due consideration of crop specific land qualities. Land suitability classification is therefore a better land evaluation system than land capability classification. Fertility capability classification too, is superior to land capability classification because it addresses more, fundamental requirments for crop production, than land capability classification. Fertility capability classification complements land suitability classification by presenting the fertility management requirments to achieve or produce optimal yields, for each suitability class. Again, fertility capability classification presents the fertility of the soil regardless of crop types.

CHAPTER 6

SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 Summary

The agricultural potential of a soil depends on both the physical and chemical properties of the soil. The properties of a soil are largely determined by its parent material. Parent material composition has direct impacts on soil chemistry and fertility. Parent material is one of the major factors of soil formation; the others are climate, organic matter, relief and time, parent material may be considered as predominantly comprising either primary in-situ bed-rock; or secondary transported materials such as alluvium, aeolian or glacial deposits.

Weathering forces such as heat, rain, ice, snow, wind, sunshine and other environmental forces, break down parent materials and affect how fast or slow soil formation processes go; the resulting weathering products that form the soils, and their unique nature and properties are important for soil scientists to establish the proper management and utilization of soils. Only very few of the soil studies of the Jos Plateau have attempted to establish any link between the soils and the parent materials and such information has been inadequate.

Available comprehensive soil data on the Jos Plateau is relatively scanty as compared to what obtains for soils of the other parts of Nigeria. The high potential the Plateau holds for agricultural production including the cultivation of some temperate climate crops such as Irish potato, Wheat and cucumber, cannot be fully realized without reliable and sufficient soil formation.

This study was carried out to identify, characterise and classify soils derived from three major parent materials on the Jos Plateau, examine the level of association between soils and the parent materials; evaluate the potentials of the soil for agricultural production and assess land degradation and its mitigation strategy through good land use and management.

Field works were carried out to identify and confirm three major parent materials on the Jos Plateau (Basalt, Granite, Unconsolidated deposits) and the soils formed from them. A total of thirty soil profile pits were sunk and sampled in the project area which covered parts of Riyom, Jos South and Barakin-Ladi Local Government Areas. Ten profile pits were sunk in soils formed from each of the three major parent materials and routine laboratory analyses were done on the soil samples. Some tests were also carried out on some of the rock samples collected, to give insight into their nature.

Tests concluded on some of the rock samples showed that granite was milky grey, light grey or milk brown in color while basalt was dark grey in color; granite was made up of large crystals which were visible to the naked eyes but the crystals of basalt were very small and cannot be seen with the naked eyes. A thin section preparation of Granite revealed that it contained Biotite, Muscovite, Quartz, Pyroclase and it was made up of large crystals while a thin section preparation of Basalt showed that it contained Hornblende, Biotite, Muscovite, Quartz and it was made up of very small crystals. A thin section preparation of a piece of Granite picked from the profile pit of a soil formed on Unconsolidated deposits revealed the presence of Feldspar, Kaolinite, Quartz and the features observed in the rock parent materials often influence the properties of the soils formed from them significantly.

The soils occured on undulating, gently undulating or relatively flat land. The surface horizons were dark reddish brown (5YR3/3), reddish brown (5YR4/4), strong brown (75YR5/6); yellow red (5YR4/8) or yellowish brown (10YR5/6). The sub surface horizons were Yellowish red (5YR4/6), red (2.5YR5/6), strong brown (7.5YR5/8), grey (5YR6/1) or light grey (10YR7/1)

The surface horizons had weak, medium sub angular blocky, moderate, medium sub angular blocky, moderate, medium angular blocky or strong, medium angular blocky structure. The subsurface horizons reflected most of the structural classes encountered in the surface horizons but in addition, had moderate, coarse angular blocky and strong, coarse angular blocky structure.

The surface horizons ranged from loamy sand, sandy loam, loam and clay loam, to sandy clay loam or clay in texture while the subsurface horizons reflected virtually all the textural classes observed in the surface horizons but the subsurface horizons were generally more clayey than the surface horizons.

The soils formed on Basalt were conspicuously reddish in outlook while those formed on Granite and Unconsolidated deposits were brownish in outlook. Mottles were not many in the soils formed on Basalt whereas the soils formed on Granite or Unconsolidated deposits had many mottles.

Though the physical properties of the soil did not follow any regular trend down the slope positions, soils of the valley bottom or lower slope positions often had the highest bulk density and the highest amounts of silt, soils of the upper slope positions, the highest amounts of clay and soils of the crest positions, the highest amounts of sand.

Percentage gravel content ranged from 1.58% to 92.37% for the soils; the soils formed on Granite had the highest contents of gravel (mean = 42.16%) while the soils formed on Unconsolidated deposits had the lowest contents of gravel (mean = 27.54%). Sand accounted for between 192 and 772 g/kgof the fine earth fraction (< 2mm) of the soils, and dominated the fine earth fraction of most of the soils. Silt ranged from 34 g/kgto 594 g/kgof the fine earth fraction of the soils, the soils were generally high in silt. Clay accounted for between 14 and 666 g/kgof the fine earth fraction of the soils, the soils formed on Granite had notably higher clay than those formed on Basalt or Unconsolidated deposits. The soils formed on Basalt had relatively lower bulk density as compared to those formed on Granite or Unconsolidated deposits.

Although the chemical properties of the soils followed no uniform trend down the slope positions, soils of the valley bottom or lower slope positions often had the highest levels of exchangeable calcium and magnesium, base saturation, extractable manganese, iron and zinc and pH. Soils of the upper slope positions often had the highest levels of total nitrogen, extractable aluminium and effective cation exchange capacity.

The soils were generally acidic in reaction, the pH values ranging from 4.3 (Extremely acidic) to 7.4 (slightly alkaline), with most of the soils being in the strongly acidic to moderately acidic (5.0 - 6.0), pH range. Exchange acidity ranged from 0.4 cmol kg^{-1} to 13.9 cmol kg^{-1} for the soils; Exchangeable Aluminum accounted for the greater proportion of the exchangeable acidity of majority of the soils.

The levels of organic carbon of the soils ranged from very low (0.32 g kg^{-1}) to very high (48.26 g kg^{-1}), with most of the soils being in the moderate to high (10 g kg^{-1}-20 g kg^{-1}) range. The soils formed on Granite were significantly higher in organic carbon than those formed on Basalt and Unconsolidated deposits. The Total Nitrogen contents of the soils were in the range 0.03-3.74 g/kg (very low-very high) with most of the soils being in the low to medium range (0.6 g kg^{-1}-2.0 g kg^{-1}). The soils formed on Basalt and Granite were significantly higher in Total Nitrogen than the soils formed on Unconsolidated deposits. Available phosphorus for the soils ranged from very low (0.01 mg kg^{-1}) to high (50.14 mg kg^{-1}), with most of the soils being in the very low to low (< 3 mg kg^{-1}-7 mg kg^{-1}) range. The soils formed on Unconsolidated deposits were significantly higher in Available phosphorus than the soils formed on Basalt and Granite.

Exchangeable cations for the soils ranged from very low to very high, with most of the soils being in the very low to moderate range. The soils formed on Unconsolidated deposits were notably higher in exchangeable calcium than the soils formed on Basalt and Granite; the soils formed on Granite were significantly higher in exchangeable potassium than the soils formed on Basalt or Unconsolidated deposits.

The range in the Effective Cation Exchange Capacity of the soils was, very low to high (3.40–28.60 cmol kg^{-1}) with most of the soils being in the low to moderate (6-25 cmol kg^{-1}). Both the soils formed on Granite and those formed on Unconsolidated deposits, had significantly higher Effective Cation Exchange Capacity than the soils formed on Basalt. The base saturation percentages of the soils ranged from 35.75% (low) to 96.11% (very high), with most of the soils being in the moderate to high (40% - 80%) range. The soils formed on Unconsolidated deposits and Basalt, had notably higher base saturation percentages than the soils formed on Granite.

The soils had extractable manganese in the 0.4 g/kgto 42 g/kgrange, extractable iron in the 1.42 g/kgto 506.1 g/kgrange, extractable copper, 0.10 kg^{-1} to 85.0 g/kgrange and extractable zinc, in the 0.02 g/kgto 42 g/kgrange. The soils formed on Granite were notably higher in Zinc and Copper than the soils formed on Basalt and Unconsolidated deposits; the soils formed on Basalt were markedly higher in Manganese than the soils formed on Granite and Unconsolidated deposits. The soils formed on Unconsolidated deposits were notably higher in Iron than the soils formed on Basalt or Granite.

The soils have been classified as Dystric Haplusept (Ferralic Cambisol, Dystric), Typic Natrustalf (Ferric Lixisol, Dystric), Plinthic Kandiustalf (Plinthic Lixisol, Vitrandic), Aquic Natrustalf (Gleyic Lixisol, Dystric), Aquic Kandiustalf (Gleyic Lixisol, Vitrandic) and Oxyaquic Haplustept (Gleyic Cambisol, Fluventic) amongst others.

The soils were classified into land capability classes II to IV, their suitability diminishing from class II to IV. The soils in the crest positions in the landscape were only marginally suitable for the cultivation of arable crops. Soils in classes II to III, fall into good and moderate arable land respectively. A major limitation of the soils for arable use, is the hazard of erosion which in turn depends on the slope of the land.

Some of the soils were moderately suitable for the cultivation of maize, Irish potato and citrus, others marginally suitable, while some others were not suitable. The soils formed on Unconsolidated deposits and those formed on Basalt, were more suitable than the soils formed on Granite, for the cultivation of maize, Irish potato and citrus. Similarly, the two soil groups had less soil fertility constraints than the soils formed on Granite and were of higher agricultural potentials.

The major limitations of the soils studied to crop production include (i) leaching of nutrient elements and acidification, resulting from heavy relief or orographic rainfall, (ii) the undulating nature of the land which promotes soil erosion and washing away of the fertile topsoil, (iii) the sandy nature of most of the soils which facilitates leaching and soil acidification; (iv) increased pressure on the land which allows little or no time of fallow during which the soils could build up again, nutrients lost; (v) the use of acid forming fertilizers which further acidify the soils. Management of the soils for sustainable crop production should therefore be directed at minimizing the impacts of unfavorable environmental factors as well as correcting whatever negative imprints the factors have left or leave on the soils.

6.2 Conclusion

Parent materials influence both the physical and chemical properties of the soils formed from them in many ways and accordingly, their agricultural potentials. The soils derived from Basalt were conspicuously red, well drained with low bulk density and were rich in extractable manganese; the soils derived from Granite were rich in potassium, significantly high in organic carbon, Total Nitrogen and Effective Cation Exchange Capacity, while the soils derived from Unconsolidated deposits were significantly high in extractable iron, available phosphorus, exchangeable calcium, and had relatively less coarse fragments.

The soils were classified as Inceptisols (Cambisols) and Alfisols (Lixisols and Nitisols). The soils derived from Unconsolidated deposits had the highest agricultural potentials, followed by those from Basalt while those from Granite had the lowest agricultural potentials. The soils derived from Unconsolidated deposits and those from Basalt would support sustainable agricultural production with good management.

6.3 Recommendations

Agricultural production on the Jos Plateau should be restricted to the soils formed on Unconsolidated deposits and Basalts. Soils derived from Granite should only be used for subsistence croppoing and mild grazing. Efforts at managing the soils should be geared at preventing or minimizing unfavourable impacts as well as correcting the degradation brought about by the unfavourable environmental impacts. such as leaching occasioned by heavy relief rainfall, soil erosion due to the undulating topography, over grazing, wrong cultivation methods, etc.

6.4 Contributions to knowledge

More, elaborate and reliable information have been provided on the soils of the Jos Plateau which will facilitate the use and management of the soils for agricultural and non-agricultural purposes.

(i) Relationships between major parent materials on the Jos Plateau and the soils formed from them, have been adequately established. This will facilitate the transfer of knowledge to other places with similar settings, as well as enhance good use of the soils for agriculture.

(ii) A major group of soils on the Jos Plateau, the soils derived from Unconsolidated deposits, which hitherto have received little or no attention of previous researchers, have been adequately captured in this study, thereby promoting their uses and management for agriculture and other purposes.

(iii) Two major soil groups that were adequately suitable for the cultivation of maize, Irish potato and citrus on the Jos Plateau, namely the soils derived from Unconsolidated deposits and Basalt, were identified in this study.

(iv) The study revealed that the soils derived from Unconsolidated deposits and Basalt had higher agricultural potentials than those from Granite, on the Jos Plateau.

REFERENCES

Adepetu, A. A. (1985). Farmers and their farms on four fadamas in the Jos Plateau. Report No. 2, Jos Plateau Environmental Resources Development Programme.

Adepetu, A. A., Olowolafe, E. A. and Dung, J. E. (2002). Effects of application of different levels of nitrogen fertilizers on upland rice yields on the Jos Plateau, Nigeria. The report of a Senate Research Grant, (NO RGS/1999/027) University of Jos, Nigeria, pp. 39.

Adepetu, A. A., Olowolafe, E. A. and Dung, J. E. (2003). Effects of application of different levels of nitrogen and phosphorus fertilizers on upland rice yields on the Jos Plateau, Nigeria. Unpublished Project Report. pp 41.

Ahamed, S., Balk, D., Flor, R., Levy, M., Palm, C., Sanchez, P. A., Storeygard, A. and Wood, S. (2006). Soil functional capacity classification map of the world. World Soil Science Congress, Philadelphia Pennsylvania. July 10-14, 2006. Book of Abstract. 1.

Aiboni, V. (1989). Evaluation of soil management level and land use pattern in Ibadan area of South West Nigeria. In: Babalola, O. Ed. Proceedings of 17th Annual Conference of Soil Science Society of Nigeria. Nsukka: 70-76.

Akinbola, G. E. (2003). Characterization and classification of some valley bottom soils on basement complex of South Western Nigeria. Proceedings of 27th Annual Conference of Soil Science Society of Nigeria. Babalola, O., Ojeniyi, S. O., Ano, A. O., Asawalam, D. and Chukwu, G. O. Eds. Calabar: 100-111.

Akinbola, G. E. and Kutu, F. R. (1999). Productivity and suitability assessment of an Inland valley soils on basement complex of South Western Nigeria for dry season vegetable production. *Environmental Analar* 2: 135-146.

Akinbola, G. E. and Ojimadu, O. C. (2008). Variation in soil physical properties and land use types on a toposequence on Basement Complex of South western Nigeria. *Journal of Tropical Forest Resources* 18: 17-25.

Akinbola, G. E., Adeoye, G. O., Ndaeyo, N. U. and Agboola, A. A. (2002). Fertility status and sustainability of some soils from basement complex and sedimentary parent materials in South Western Nigeria. *Journal of Tropical Forest Resources*. 18: 17-25.

Akinbola, G. E., Ojetade, J. O. and Olaleye, A. O. (2006). Variability of soil properties along two toposequences of basement complex in South Western Nigeria. *Discovery and Innovation* 18.1: 44-52.

Akinbola, G. E., Umeokafor, T. O. and Obi, J. C. (2008). Land evaluation for sustainable urban and land use in the humid forest agroecological zone of south western Nigeria. *Nigerian Journal of Soil and Environmental Research*. 8: 86-92.

Akinwa, A. O. (1989). Characterization and classification of major Irish potato growing soils on the Jos Plateau. Unpublished M. SC. Project report, ABU, Zaria.

Akinwa, A. O and Akinbola, G. E. (2018). Characterisation, classification and management of selected soils on the Jos Plateau. Proceedings of the 42nd Annual Conference of the Soil Science Society of Nigeria; 12th-16th March, 2018, Ibadan, Nigeria.: 98-111.

Alford, J. M. and Tuley, P. (1974). The land resources of central Nigeria. Interim report on the landform, soils and vegetation of the Jos Plateau. Vol. II 1971. pp 138.

Alva, A. K. (1986). Importance of soil pH to nutrient availability in plant growth; being notes given to the P.G class in the Intermediate Soil Fertility course, on 15th of October, 1986 at the Ahmadu Bello University, Zaria.

Amusan, A. A., Shitu, A. K., Makinde, W. O. and Orewole, O. (2006). Assessment of changes in selected soil properties under different land use in Obafemi Awolowo University community, Ile-Ife, Nigeria. *Electronic Journal of Environment, Agriculture, Food Chemistry* 5.1: 1178-1184.

Anderson, J. M and Ingram J. S. I. (1993). Tropical soil biology and fertility: A handbook of methods. CAB International, Wallinford, U.K. pp. 95-99.

Abestian, M. C; Barreal, M. E and Macias, F. (1999). Parent Material Influence on Sulphate Sorption in Forest Soils from Northern Spain. *Soil Science Society of American Journal*. 63:1906-1914 (1999).

Aruleba, J. O and Fashina, A. S. (2003). Land quality evaluation and tree crop production in South Western Nigeria. 21st Annual Conference of Horticultural Society of Nigeria. Fashina, A. S., Olufolaji, A. O and Umeh, V. C. Eds. Lagos: 93-96.

Aruleba, J. O. and Ogunkunle, A. O. (2005). Land degradation assessment of South Western Nigeria. *Nigeria Journal of Soil Science*. 15.2: 36-57.

Attua, E. M. and Fisher, J. B. (2010). Land suitability assessment for pineapple production in the Akwapim South District, Ghana: A GIS multi criteria approach. *Ghana Journal of Geography*. 2: 47-83.

Babalola, O. and Lal, R. (1977). Subsoil gravel horizon and maize root growth II. Effects of gravel size, intergravel texture and natural gravel horizon. *Plant and Soil* 46: 347-357.

Babalola, T. S., Oso, T., Fashina, A. S. and Godonu, K. (2011). Land evaluation studies of two wetland soils in Nigeria. *International Research Journal of Soil Science*. 1.6: 193-204.

Beatty, M. T., Peterson, G. W. and Swindale, L. D. (eds). (1979). Planning the uses and management of land. Agronomy Monogragh 21. American Society of Agronomy, Madison, WI. 1028p

Benoit, P. (1976). A study of the variability of the growing season in northern Nigeria. Paper Nigerian Geographical Association Conference No. 65.

Bolte, P. B. J. (2010). Agricultural Land use. 2nd ed. Williamettte: River Basin Atlas. 103 pp.

Bornemisza, E. (1988). Management of tropical Andisols. In: Kinloch, D. I., Shoji, S., Beinroth, F. H. and Eswaran, H. (eds). Proceedings of the Ninth International Soil Classification Workshop. Japan. 1987. Soil Management Support Service Washington D. C., pp 319-329.

Brady, N. C. (1974). The Nature and properties of soils, 8th Edition; Land capability classification. 347-352 pp.

Brady, N. C. and Weil, R. R. (1999). Nature and properties of soil. 12th ed. New Jersey: Prentice Hall. 881 pp.

Bray, R. A. and Kurtz, C. L. (1945). Determination of total organic and available forms of phosphorus in soils. *Journal of Soil Science*. 59: 45-49.

Bzali, V., Shalbazi, F. and Hajrasouli, M. (2011). Quantitative and qualitative land suitability evaluation for maize cultivation in Ghobadloun region, Iran. *Ozean Journal of Applied Sciences*. 4.1 91-104.

Chukwu, G. O. (2007). Land suitability classification of South Eastern Nigeria wetlands for Azolla. *Scientific Research and Essays*. 2.12: 512-515.

CT ECO, (2010). Maps and Geospatial Data for Planning, Management, Education and Research. Connecticut Environmental Conditions Online (CT ECO) Complete Resource Guide. Document last revised April, 2010. www.cteco.uconn.edu

Dabi, D. D. (1990). Farming possibilities on soils of the heavily mined terrain Rayfield area of Jos Plateau. Unpublished M. Sc. Thesis, Department of Geography and Planning. University of Jos, Plateau State. 156pp.

Danlami, M. S. and Onimisi, A. H. (2016). An Analysis of Soil Physico-chemical Properties of Kerang Volcanic Landscape Catena, Jos Plateau, Nigeria. *Resources and Environment* 2016. 6(1): 9-15

Day, P. R. (1965). Particle fractionation and particle size analysis. In: C. A. Black (ed.), Methods of soil analysis. Agronomy Monogram No. 9, American Society of Agronomy, Madison, Wisconsin.

Dent, D. and Young, A. (1981). Soil Survey and Land Evaluation. 1st ed. London: George Allen and Unwin. 278pp.

Dobermann, A., Goovaerts, P. and George, T. (1995). Sources of soil variation in an Ultisol of the Philippines, *Geoderma*. 68.3: 173-191.

Doi, R. and Ranamukhaarachchi, (2007). Soil colour designation using adobe photoshopTM in estimating soil fertility restoration by Acacia auriculiformis plantation on degraded land. *Current Science*. 92.11: 1604-1609.

Edwards, C. (1970). An appraisal of storie index in terms of actual and potential productivity. FAO, Rome.

Egawa, T. (1977). Properties of soils derived from volcanic ash. In: Yoshiaka I. and Black C. A. (eds). Soils derived from volcanic ash in Japan. CIMMYT. Mexico. pp. 85-102.

Eriba, I. M. (2002): Application of geographical information systems (GIS) for land evaluation in selected wetland rice producing areas of Benue State Nigeria. A Ph. D research proposal submitted to the Department of Agronomy, University of Ibadan. 1-12.

Esu, I. E. (1982). Evaluation of soils for irrigation in the Kaduna area of Nigeria. Ph. D. Thesis, Ahmadu Bello University, Zaria, Nigeria.

Esu, I. E., Ojanuga, A. G. (1986). Soil characterization studies within natural levels of River Kaduna. *Nigerian Journal of Soil Science*. 1-13

Fagbami, A. A. (1980). Aerial photo interpretation of the Ibadan soils, South Western Nigeria. *Nigerian Journal of Soil Science*. 1: 99-109.

Fagbami, A. A. and Ogunkunle A. O. (2000). Soil survey, land evaluation and Agronomy: The Nigeria case study. Agronomy in Nigeria. M. O. Akoroda Ed. Ibadan: Polygraphic Ventures. 165-173.

FAO, (1976). Food and Agricultural Organization. A framework for land evaluation. Soil bulletin 32. FAO, Rome.

FAO, (1996). The state of food and agriculture. FAO, Rome (Italy) ISBN 92-5-103858-9

FAO, (2007). Land evaluation: towards a revised framework. Land and water discussion paper 6. FAO, Rome.

FAO, (2007). The state of food and agriculture: Paying farmers for environmental services. Agricultural Development Economics Division (ESA), FAO, Rome. www.fao.org/docrep/010/a1200e/a1200e00.htm

FAO/IUSS (2014). World Reference Base for Soil Resources (WRB) 2014. International soil classification system for naming soils and creating legends for soil maps. *World Soil Resources Report* No. 106 FAO. Rome.

Fashina, A. S., Aruleba, J. O., Omotoso, S. O., Omolayo, F. O. and Shittu, O. S. (2005). Evaluation of potentials of some soils for crop production at Ado Ekiti, South Western Nigeria. *Nigerian Journal of Soil Science*. 15.2: 16-20.

Fawole, O. A., Ojetade, J. O., Muda, S. A. and Amusan, A. A. (2016). Genesis and classification of soils on a toposequence underlain by mica schist in Ife area, Southwestern Nigeria. Global Journal of Science Frontier Research: D Agriculture and Veterinary 16(7): 31-42.

FDALR, (1990). The reconnaissance soil survey of Nigeria: Anambra, Akwa-Ibom, Benue, Cross Rivers, Imo and Rivers States. Federal Department of Agricultural Land Resources. Soils report 4: 74-76.

Gosden, P. N. (1980). Land resources of central Nigeria, farming systems. Land resource Report, Land Resources Development Centre, UK Ministry of Overseas Development, No. 17.

Gray, J. M. and Murphy, B. W. (1999). Parent materials and soils: a guide to influence of parent material on soil distribution in Eastern Australia. Technical report No. 45 122 pp.

Gribble, C. D. (1984). (Revised). Rutleys's elements of mineralogy, 27th Edition, Department of Geology, University of Glasgow. pp 479.

Grove, A. T. (1952). Land use and soil conservation on the Jos Plateau. Geological survey of Nigeria Bulletin. 22: 5.

Gupta, R. D., Arora S., Gupta, G. D. and Sumberia, N. M. (2010). Soil physical variability in relation to erodibility under different land uses in foot-hills of Siwaliks in North West India. *Tropical Ecology* 51.2: 183-197.

Hassan, A. M., Raji, B. A., Malgwi, W. B. and Agbenin, J. O. (2015). The basaltic soils of Plateau State, Nigeria: Properties, classification and management practices. *Journal of Soil Science and Environmental Management*, Vol. 6(1), pp 1-8, Jan. 2015.

Helms, D. (1992). Readings in the history of the soil conservation service. Soil Conservation Service, US Government Printing Office, Washinton D.

Hill, I. D. (1978). Land resources of central Nigeria, Agricultural development possibilities, Vol. 2B. The Jos Plateau. Land Resources Development Centre, Ministry of Overseas Development, Tolworth Tower, Surbition, Surrey, England KT 6 7 DY 1978, 113 p.

Hill, I. D. and Rackham, L. J. (1973). The land resources of central Nigeria. Interim report on the Land forms, soils and vegetation of the Jos Plateau Vol. 1. Land forms and soils. Land Resources Division Tolworth Tower, Surbition, England 220 p.

Hill, I. D. and Rackham, L. J. (1974). Interim report on the Land forms, soils and vegetation of the Bauchi Area Volumes 1 and 3. Miscellaneous Report 152. Land Resources Division, U.K. Ministry of Overseaa Development, No. 153.

Ibanga, I. J., Udoma, G. H., Edet, A. B., Akpan, A. F. (2005). Physic-chemical properties of some lime stone soils in South Eastern Nigeria. *Nigerian Journal of Soil Science* 15: 81-86.

Idoga, S., Azagaku, D. E. (2005). Characterization and classification of soils of Janta Area, Plateau State of Nigeria. *Nigerian Journal of Soil Science* 15: 116-122.

Igwe, C. A., Akamigbo, F. O. R. and Mbagwu, J. B. C. (1995). Physical properties of soils of South Eastern Nigeria and the role of some aggregation agents in their stability. *Soil Sccience* 160: 431-441.

International Union of Soil Sciences (2008). IUSS Bulletin No. 110. June 2008.

Jacobson, R. R. E., Macleod, W. N. and Black, R. (1958). Ring complexes in the younger granite provinces of Northern Nigeria. Memoir, Geological Society of London, No. 1.

Jaradat, A. A. (2005). Saline agriculture in the Arabian Peninsula: Management of marginal lands and saline water resources. *Journal of Food, Agriculture and Environment* 3.2: 302-306.

Jones, R. G. B. (1975). Central Nigeria Project report on a soil conservation consultancy to study soil erosion problems on the Jos Plateau. Land Resources Report, Land Resources Division UK Ministry of Overseas Development, No. 6.

Jothimani, S., Pandian, B. J., and Thiyagarajan, T. M, (2007). Nutrient use efficiency in crop plants: *Agrobios* Vol. 5, Issue No. 8, pp 28-29.

Jungerius, P. D. (1964). The soils of Eastern Nigeria. Publications services of Geologigue du Luxembourge 14: 185-198.

Juo. A. S. R. and Moorman, F. R. (1980). Characteristics of two soil toposequences in South Eastern Nigeria and their relation to potential agricultural land use. *Nigerian Journal of Soil Science* 1: 47-61.

Kassama, A. H., van Velthuizen, H. T., Fischer, G. W. and Shah, M. M. (1991). Agroecological land resources assessment for agricultural development planning: A case study of Kenya: Resource database and land productivity. FAO and IIASA, Rome and Vienna.

Keay, R. W. J. (1953). An outline of Nigerian vegetation. Government Printer. Nigeria.

Klingebiel, A. A. and Montgomery, P. H. 1961. Land Capability Classification. USDA Soil Conservation Service. Agricultural Handbook. pp 210.

Klinkenberg, K. and Higgins, G. M. (1968). An outline of Northern Nigerian Soils. *Nigerian Journal of Soil Science* 2.2: 91-115.

Kowal, J. M. and Knabe, D. T. (1972). An agroclimatological atlas of the Northern States of Nigeria. Ahmadu Bello University Press, Zaria. pp 111.

Landon, J. R. ed. (1991). Booker Tropical Soil Manual: A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Longman Scientific 8 Technical, Oxon, U.K. BAI, Antony Rowe Ltd., Chippenham, Wiltshire, pp.450.

Lawal, B. A., Tsado, P. A., Eze, P. C., Idefoh, K., Zaki., A. A. and Kolawole, S. (2014). Effect of slope positions on some properties of soils under a Tectona grandis Plantation in Minna, Southern Guinea Savannah of Nigeria. International Journal of Research in Agriculture and Forestry 1(2): 37-43.

Laya, D., Van Ranst, E. and Herrero, J. (1998). A modified parametric index to estimate yield potentials for irrigated alfafa on soils with gypsum in Quinto (Aragon, Spain). *Geoderma* 87: 111-122.

Lekwa, G. (1985). Properties, classification and site suitability of two soil mapping units in the Guinea Savanna, Nigeria. *Nigerian Journal of Soil Science* 5: 89-106.

Lin, C. (1989). Fertility capability classification of Taiwan soils. Proceedings of the 5th International Soil Management Workshop on rice growing soils. Peterson, J., Eswaran, H., and Juang, T. C. Eds. Taiwan. FFTC book series 39: 80-90.

Lobb, D. A. (2011). Understanding and managing the causes of soil variability. *Journal of Soil and Water Conservation* 66.6: 175-179.

Lobel, D. B., Ivan Ortiz-M. and Asner, G. P. 2004. Relative importance of soil and climate variability for nitrogen management for irrigated wheat. *Field Crops Research* 87: 155-165.

Long, H. L., Heilig, G. K., Wang, J., Li, X. B., Luo, M., Wu, X. Q., Zhang, M. (2006). Land use and soil erosion in the upper reaches of the Yangtze River: Some socio-economic considerations on China's grain-for-green programme. *Land Degradation and Development* 17: 589-603.

Loro, P. (2005). Detailed soil survey: The foundation of sustainable resource management. Manitoba agriculture, food and rural initiatives. Retrieved April 10, (2006) from http://www.gov.mb.ca/agriculture/environment.

Macleod, W. N., Turne, D. C. and Wright, E. P. (1971). The Geology of the Jos Plateau, Bulletin, Geology Survey of Nigeria, No. 32.

Manchanda, M. L., Kudrat, M. and Tiwari, A. K. (2002). Soil survey and mapping using remote sensing. *Tropical Ecology* 43.1: 61-74.

Mbagwu, J. S. C. (2008). Environmental sustainability: reversing the degradation trends in Sub-Saharan Africa. Sustainable agriculture in Sub-Saharan Africa: A critical look into the constraints and prospects. 13th Annual International IARSAF Workshop 72-83.

Maeda, T., Tanaka, H. and Warkentin. (1977). Physical properties of allophane soils. *Advance Agronomy* 29: 229-264.

Maeda, T. and Soma, K. (1987). Classification of Andisols in Japan based on physical properties. In: Schultz, L. G., Van Olphen, V. and Mumpton, F. A. (eds), Proceedings of International Clay Conference, Denver, 1985.

Mirabella, A., Egli, M., Carnicelli, S. and Sartori, G. (2002). Influence of parent material on clay mineral formation on Podzols of Trentino, Italy. *Clay Minerals* 37: 699-707.

Mizota, C. and Van Reeuwijk, L. P. (1989). Clay mineralogy and chemistry of soils formed in volcanic materials in diverse climatic regions. International Soil Reference and Information Centre's Soil Monograph 2.

Morgan, W. T. C. (Ed) (1979). The Jos Plateau. A Survey of Environment and Land Use. Occassional Publication (New Series) 14. Department of Geography. University of Durham, U.K.

Moss, R. P. (1957). Report on the classification of the soils formed over sedimentary rocks in South Western Nigeria. *Soil Survey Report* No. 67, Institute of Agricultural Research and Training, Ibadan, Nigeria.

Moss, R. P. (1968). The soil resources of Tropical Africa, Cambridge University Press, 226p.

Mulongoy, K. and Merckx, R. (1993). Soil organic matter dynamics and sustainability of tropical agriculture. Proceedings of International Symposium organized by Katholieke University Leuven and International Institute of Tropical Agriculture. Leuven, Belgium, November, 1991.

Murdoch, G., Ojo, Atere J., Colborne, G., Olomu, E. I. and Odugbesan, E. M. (1976). Soils of western state savanna in Nigeria. Description of basement complex soil series. Volume 2. *Land Resources Study* 23: 145-146.

Naga Bhushana, S. R., Shankaranarayana, H. S. and Shivaprasad, C. R. (1982). Classification requirement of red soils of India for transfer of technology. Proceedings of the consultant's workshop on the state of the art and management alternatives for optimizing the productivity of Semi Arid Tropics (SAT) alfisols and related soils, ICRISAT Centre, India. 3-9.

National Research Council (NRC). (2001). Basic research opportunities in Earth Science. National Academy Press, Washington DC.

NCSU, (2013). Soil morphology, genesis and classification. North Carolina State University courseware. Retrieved Nov. 13, 2013 from http//:ncsu.edu/ssc551.

NRCS, (2013). The twelve soil orders of the soil taxonomy. National Resource Conservation Service. Retrieved Feb. 23. http//:nrcs.usda.gov/wps/portal/nrcs/details/sois/edu.

Obi, J. C., Akinbola, G. E., Ogunkunle, A. O. and Umeojiakor, A. O. (2010). Profile description of clay, Ca, Mg and K in some soils of the savanna region of Nigeria. *Jorunal of Tropical Agriculture, Food, Environment and Extension* 9.2:76-83.

Ogbodo, E. N. and Chukwu, G. O. (2012). Soil fertility evaluation of selected Aquic Haplustalf in Ebonyi State, South Eastern Nigeria. *Nigeria Journal of Soil Science* 22.1: 97-102.

Ogeh, J. S. and Ukodo, E. (2012). Profile distribution of physical and chemical properties in soils of a toposequence in Benin, Rainforest of Nigeria. Nigerian Journal of Basic and Applied Science 20(1): 68-72.

Ogunkunle, A. O. (1986). Spatial variability of some chemical properties in two Ultisol mapping units in South-Western Nigeria. *Soil Survey and Land Evaluation.* 6.1: 26-33.

Ogunkunle, A. O., Ataga, D. O. and Omoti U. (1989). Variation within a taxonomic unit: The Ibadan series example in South West Nigeria. *Nigeria Journal of Soil Science* 9: 9-20.

Ogunsola, O. A. and Omueti, J. A. I. (1989). Some chemical and mineralogical characteristics of soils in Benue State. A case study of Gboko soils. Proceedings of 17th Annual Conference of Soil Science Society of Nigeria. Babalola O. Ed. Pp 88-91.

Ojanuga, A. G. (2006). Agroecological zones of Nigeria manual. Berding, F. and Chude, V. O. Eds. Food and Agricultural Organization and Special Progamme on Food Security. 1-54.

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

Okafor, B. N. (2016). Characterization, classification and evaluation of selected citrus (citrus spp) plantation soils in Nigeria. Unpublished Ph. D Thesis, University of Ibadan. XIX + 275.

Okoye, E. O. U. (1985). Ed. The Reconnaissance soil survey of Plateau State Nigeria (1:250,000). Soil Report, Federal Department of Agricultural Land Resources.

Okusami, T. A. (1988). Soil survey for soil conservation: Soil morphology and potential land use on selected soils in the humid rainforest of Nigeria. Proceedings of 16th Annual Conference of Soil Science Society of Nigeria. Babalola O. Ed. 103-113.

Ololade, I. A., Ajayi, I. R., Gbadamosi, A. E., Mohammed, O. Z. and Sunday, A. G. (2010). A Study on Effect of Soil Physico-chemical Properties on Cocoa Production in Ondo State. Journal of Modern Applied Science 4: 35-43.

Olowolafe, E. A. (1997). Distribution, characteristics and land use prediction of soils developed on the volcanic parent material on the Jos Plateau. *Nigeria Journal of Social and Management Studies* 4: 153-165.

Olowolafe, E. A. (1998). Soil constraints to sustainable crop production in the Biotite granite areas of Jos Plateau, Nigeria. Soil management for sustainable agriculture and environment harmony. Proceedings of 24th Annual Conference of Soil Science Society of Nigeria, Abubarkar Tarawa Balewa University, Bauchi, 7th-11th December, 1998, 30-35.

Olowolafe, E. A. (2002). Soil parent materials and soil properties in two separate catchment areas on the Jos Plateau, Nigeria. *Geological-Journal* 56:201-212, K/muser Academic Publishers. Printed in the Netherlands.

Olowolafe, E. A. (2008). Effects of corralling on the properties of an Inceptisol in Vom area, Jos Plateau, Nigeria. *Australian Journal of Soil Research* 11.2013 :34-40

Olowolafe, E. A. (2008). Effects of using municipal waste as fertilizer on soil properties in Jos area, Nigeria. *Resources Conservation and Recycling* 52.11: 1266-1270.

Olowolafe, E. A. (2008). Land use effects on the properties of an Alfisol on the Jos Plateau, Nigeria. *GeoJournal* (2008) 71: 83-91.

Olowolafe, E. A. and Dung, J. E. (2000). Soils derived from Biotite granite on the Jos Plateau, Nigeria: their nutrient status and management for sustainable agriculture; resources conservation and recycling. 213-244.

Oluwatosin, G. A. and Ogunkunle, A. O. (1991). Suitability ratings of some soils of the savanna zone of South Western Nigeria for rainfed maize. *Nigeria Journal of soil science* 10: 1-24.

Ontkean, G. and Serafinchon, A. (2000). Land classification for irrigation in Alberta. Retrived May 10th, 2007 from http://www.agric.gov.ab.ca

Onyekanne, C. F., Akamigbo, F. O. R. and Nnaji, G. U. (2012). Characterization and classification of soils of Ideato North Local Governmnet Area. *Nigerian Journal of Soil Science* 22.1: 11-17.

Onyike, J. A. (1983). Application of semi-detailed soil survey to rural and land use planning: A case study of part of Riyom Local Government Area of Plateau State. Unpublished M. Sc. Project report, Unijos, Nigeria.

Orimoloye, J. R. (2011). Characterization and evaluation of selected Southern Nigerian soils for rubber (*Havea brasilinensis*, Meull. Arg.) cultivation. Unpublished Ph. D Thesis, University of Ibadan. XV+216.

Orimoloye, J. R., Gheghere, E. J., Aliku, O. and Nkwocha, H. U. (2018). The effects of parent material and physiography on selected soil chemical properties in Ibadan, South

Western Nigeria. Proceedings of the 42nd Annual Conference of the Soil Science Society of Nigeria.

Osodeke, V. F., Ojeniyi, S. O. (2005). Evaluation of the soils of some forest zone of South Eastern Nigeria for soybean production. *Nigeria Journal of soil science* 15: 129-132.

Parfitt, R. L., (1990). Soils formed in Tephra in different climatic regions. Trans. 14th International Soil Science Society Congress. Kyoto. VII 134-139.

Phil-Eze, P. O. (2010). Variability of soil physical properties related to vegetation cover in a tropical rainforest landscape. *Journal of Geography and Regional Planning* 3.7: 177-184.

Ping, C. L., Shoji, S., Ito, T., Takahashi, T. and Moore, J. P. (1989). Characteristics and classification of volcanic ash-derived soils in Alaska. *Soil Science* 148: 8-12

Pugh, J. C. and King, L. C. (1952). Outline of the geomorphology of Nigeria. *Geographical Journal of South Africa*. 34: 30-36.

Raji, B. A., Malgwi, W. B., Berding, F. R., and Chude, V. O. (2011). Integrating indigenous knowledge and soil science. *Journal of Soil Science and Environmental Management*. 2.3: 66-73.

Ritter, M. E. (2006). The Physical Environment: An Introduction to Physical Geography. http://www.earthonlinemedia.com/ebooks/tpe-3e/title-page.html.

Rossiter, D. G. (2001). Principles of soil classification. Lecture notes. International Institute of Aerospace Survey and Earth Sciences (ITC), Enschede Netherlands. 1-10.

Sanchez, P. A. (1986). Edaphic parameters for characterizing IBSRAM'S acid tropical soils network sites. Proceedings of IBSRAM session on land development and management of acid soils in Africa. Douala Cameroun, January 21-27, 1986. IBSRAM 4: 113-123.

Sanchez, P. A., Couto, W. and Buol, S. W. (1982). The fertility capability soil classification system: Interpretation, applicability and modification. *Geoderma* 27.4: 283-309.

Sanchez, P. A., Palm, C. A. and Buol, S. W. (2003). Fertility capability soil classification: a tool to help assess soil quality in the tropics. *Geoderma* 114:157-185.

Shoji, S., Dahlgren, R. and Nanzyo, M. (1993). Classification of volcanic ash soils. Pp. 73-100 in: Volcanic Ash Soils – Genesis, properties and utilization (S. Shoji, M. Nanzyo and R. Dahlgren, editors). *Development in Soil Science*. 21. Elsevier, Amsterdam

Singer, A. (1966). The mineralogy of the clay fraction from basaltic soils in Galilee, Israel. *Journal of Soil Science* 17.1: 136-147.

Smyth, A. J. and Montgomery, R. F. (1962). Soils and land use in central western Nigeria. 1st ed. Government Western Nigeria Press, Ibadan, Nigeria. 264-265.

Sohotden. C. D., Vivian, E. L., Ali, A. Y. and Shehu, B. M (2015). An assessment of landscape segments suitable for agriculture in Kerang volcanic area of Jos Plateau, Nigeria. *Internation Journal of Scientific and Technology Research,* 4.4: 294-298.

Soil Survey Staff (1975). Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. 1st edition. USDA Handbook No. 436, US. Govt. Printing Office, Washington DC, pp. 754.

Soil Survey Staff. (2003). Keys to Soil Taxonomy. 19th Edition. United States Departement of Agriculture. Natural Resources Conservation Services, Washington, D. C.

Soil Survey Staff (2014). Keys to Soil Taxonomy. 12th Edition, USDA Natural Resources Conservation Service, Washington, D.C pp 332.

Sparks, D. L. (2000). Soils. *Geotimes* 45: 49-40.

Stavi, I. and Lal, R. (2011). Variability of soil physical quality and erodibility in a water eroded cropland. *Catena* 84: 148-155.

Suton, P. M. and Loganathan, P. (1989). Characterization and classificatrion of representative upland soils of Rivers State. *Nigeria Journal of soil science* 14-35.

Sys, C. (1985). Land evaluation part I, International Training Centre for Post-Graduate Soil Scientists, State University of Ghent, Belgium.

Sys, C., Van Ranst, E. and Debaveye, J. (1991). Land evaluation part I: Principles in land evaluation and crop production calculations. International Training Centre for Post-Graduate Soil Scientists, University Ghent, Belgium, General administration for development cooperation, Brussels, pp. 40-80. pp: 265.

Thorp, M. B. (1967). Closed basins in younger Granite massifs, Northern Nigeria. 2. Geomorphology. 11: 459-480.

Tijjani, M. A. and Hassan, I. M. (2017). Variability of Some Soil Properties Along Toposequence on a Basaltic Parent Material of Vom, Plateau State, Nigeria. *International Journal of Scientific and Technology Research* 6.2. February, 2017.

Tijjani, M. A. and David, A. A (2017). Forms and distribution of potassium along a toposequence on Basaltic soils of Vom, Jos, Plateau State of Nigeria. *International Journal of Environment, Agriculture and Biotechnology* (IJEAB), 2.1: 213-218.

Tomlison, P. R. (1965). Soils of Northern Nigeria, Samaru Miscellaneous Paper No. 11, I.A.R, A.B.U. Samaru, Zaria, Nigeria.

Udo, E. J., Ibia, T. O., Ogunwale, J. A., Ano, A. O. and Esu, I. E. (2009). Manual of soil, plant and water analyses, published by Sibon Books Limited, Flat 15, Block 6, Fourth Avenue, Festac, Lagos. Pp.183.

Ugwu, T. O. (1983). The properties, classification and geomorphic relationship of some soils of the Jos Plateau. Unpublished M. Sc. Project report, ABU, Zaria.

USBR, (2005). Reclamation, managing water in the West; technical guidelines for irrigation suitability and land classification. United States Department of Interior Bureau Reclamation. Retrieved March 19, 2015, from http://www.usbr.gov

Vapraskas, M. J. (1988). Bulk density values diagnostic of restricted root growth in coarse textured soils. *Soil Science Society of American Journal* 52: 1117-1121.

Wiechmann, H. (1987). Some factors affecting sustained crop production in the tropics. In: International Board for Soil Research and Management Inc. Proceedings of the 2nd Regional Workshop on Land Development and Management of Acid Soils in Africa. Lusaka and Kasama. 9th -16th April. pp. 187-194.

Wilding, L. P. (1994). Surficial studies: soil science. *Geotimes* 39: 13-14.

Wooldridge, D. D. (1964). Effects of Parent Material and Vegetation on Properties Related to Soil Erosion in Central Washington. *Soil Science Society of American Journal* 28: 430-432.

Wu, J. (2008). Land use changes: economic, social and environmental impacts. Choices 23.4: 6-10.

Yusuf, A. A.., Amapu, I. Y., Eben-Johnson, A. F. and Chude, V. O. (2004). The characteristics and fertility status of Tin Mine Spoils of the Jos Plateau, *Nigeria. Nigerian Journal of Soil Resources* (2004) 5: 44-52.

APPENDIX

APPENDIX 1: Detailed description of sites, morphology and physical properties of the soils derived from Basalts.

Profile JP-BST 1-1 (Vitrandic Haplustept – USDA; Ferralic Cambisol (Vitrandic) – WRB)

Location: Riyom, Lat. 9° 37' 41.8", Lon. 8° 44' 40.66"
Parent material: Basalt
Physiography: Undulating land
Topography: 3-5% slope
Slope Position: Crest
Drainage: Well drained
Erosion: Moderate
Surface characteristics: Many Basalt boulders nearby and common Basalt boulders on the soil surface.
Vegetation/Land use: Northern Guinea Savanna (Montane vegetation), cultivated to Irish Potato, Maize, Acha, etc.
Depth to water table: Not encountered, but parent material (Basalt) encountered at the depth of 82cm.
Date described: 04/02/2015
Author: Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-11	RB (5YR4/4) l; mod., med. sbks; slightly hard (dry) firm (moist), slightly stc. and npstc. (wet); com. coarse pores and many med. and fn. pores; many med. and fn. roots; pH5.1, diffuse smt. bdr.
A2	11-40	RB (5YR4/4) ls; mod. med. Sbks; slightly hard (dry), firm (moist), nstc., npstc. (wet); com. coarse pores and many med. and fn. pores; many fn. roots; pH 5.3, clear irregular bdr.
B	40-82	RB (5YR4/4) gravelly sl; mod., med. sbks; slightly hard (dry), firm (moist), stc. and npstc. (wet); com. coarse pores and many med. and fn. pores; com. fn. roots; pH 5.5, clear irregular bdr.
C	82-142^{+}	Parent material (Unconsolidated, decaying basaltic rocks with some soil material in between the pieces of rocks).

Note: The key to the abbreviated words is as contained on pages 217 and 218.

Profile JP-BST 1-2 (Plinthic Kandiustalf – USDA; Plinthic Lixisol (Vitrandic) – WRB)

Location:	Riyom, Lat. 9° 37' 37.29", Lon. 8° 44' 12.35"
Parent material:	Basalt
Physiography:	Undulating land
Topography:	2-3% slope
Slope Position:	Upper slope
Drainage:	Well drained
Erosion:	Moderate
Surface characteristics:	Com. Basalts boulders on the soil surface.
Vegetation/Land use:	Northern Guinea Savanna (Montane vegetation), cultivated to Irish Potato, Maize, Acha, etc.
Depth to water table:	Below profile pit depth.
Date described:	04/02/2015
Author:	Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-20	RB (5YR4/4) slightly gravelly scl; mod., med. abks; hard (dry), firm (moist), stc. and pstc. (wet), many med. and fn. pores; many med. and fn. roots; pH 5.3, diffuse wavy bdr.
B	20-47	RB (5YR4/4) slightly gravelly sl; mod., med. sbks; hard (dry), firm (moist), slightly stc. and npstc. (wet), many med. and fn. pores; many med. and fn. roots; pH 5.2, diffuse smt. bdr.
Bt	47-98	YR (5YR4/6) slightly gravelly scl; mod., med. abks; slightly hard (dry), firm (moist), stc. and pstc. (wet), com. med. and fn. pores; com. med. and fn. roots; pH 5.5, diffuse smt. bdr.
C	98-180	YR (5YR4/6) gravelly sl; mod., med. sbks; hard (dry), firm (moist), stc. and npstc. (wet), com. med. and fn. pores; com. med. and fn. roots; pH 5.5.

Profile JP-BST 1-3 (Oxyaquic Haplustalf – USDA; Ferric Lixisol (Dystric) – WRB)

Location: Riyom, Lat. 9° 37' 33.83", Lon. 8° 44' 48.83"
Parent material: Basalt
Physiography: Gently undulating land
Topography: About 2% slope
Slope Position: Mid slope
Drainage: Well drained
Erosion: Moderate
Surface characteristics: Com. basalt boulders on the soil surface.
Vegetation/Land use: Northern Guinea Savanna (Montane vegetation), cultivated to Irish Potato, Maize, Acha, etc.
Depth to water table: Below profile pit depth.
Date described: 04/02/2015
Author: Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-20	RB (5YR4/3) scl; mod., med. sbks; hard (dry) firm (moist), stc. and pstc. (wet); many coarse med. and fn. pores; many coarse med. and fn. roots; pH5.3, diffuse smt. bdr.
A2	20-45	RB (5YR4/4) ls; mod., med. Sbks; hard (dry), firm, (moist), slightly stc. and npstc. (wet); many med. and fn. pores; com. fn. roots; PH 5.4 diffuse smt. bdr.
BA	45-80	RB (5YR4/4) slightly gravelly ls; mod., med. sbks; hard (dry), firm (moist), slightly stc. and npstc. (wet); many med. and fn. pores; com. fn. roots; pH 5.0, diffuse smt. bdr.
Bt	80-137	RB (5YR4/4) ly; mod., med. sbks; hard (dry), firm (moist), stc. and npstc. (wet); com. med. and many fn. pores; few med. and com. fn. roots; pH 5.1, distinct smt. bdr.
C	137^+	Parent material (Unconsolidated, Decaying basaltic rocks with some soil materials in between some of the rock fragments)

Profile JP-BST 1-4 (Oxyaquic Haplustalf – USDA; Ferric Lixisol (Dystric)– WRB)

Location:	Riyom, Lat. 9° 37' 27.94", Lon. 8° 44' 55.3"
Parent material:	Basalt
Physiography:	Undulating land
Topography:	2-3% slope
Slope Position:	Foot slope
Drainage:	Well drained
Erosion:	Slight
Surface characteristics:	Few noticeable basalt pieces on the soil surface.
Vegetation/Land use:	Northern Guinea Savanna (Montane vegetation), cultivated to Irish Potato, Maize, Acha, etc.
Depth to water table:	Not encounteR
Date described:	05/02/2015
Author:	Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-15	RB (5YR4/4) slightly gravelly l; mod., med. sbks; slightly hard (dry) firm (moist), slightly stc. and npstc. (wet); many med. and fn. pores; many med. and fn. roots; pH5.0, diffuse smt. bdr.
A2	15-39	RB (5YR4/3) ls; mod., med. Sbks; slightly hard (dry), firm (moist), nstc., npstc. (wet); com. coarse pores and many med. and fn. pores; many med. and fn. roots; pH5.2, diffuse smt. bdr.
Bt	39-63	YR (5YR4/6) gravelly cl; mod., med. abks; hard (dry), firm (moist), stc. and pstc. (wet); many med. and fn. pores; com. med. and fn. roots; pH 5.2, diffuse smt. bdr.
C1	63-108	YR (5YR4/6) sl; mod., med. sbks; slightly hard (dry), firm (moist), slightly stc. and npstc. (wet); many med. and fn. pores; few fn. roots; pH 5.0, diffuse smt. bdr.
C2	108-190	YR (5YR4/6) scl; mod., med. abks; hard (dry), firm (moist), slightly stc. and pstc. (wet); many med. and fn. pores; few fn. roots; pH 5.2.

Profile JP-BST 1-5 (Oxyaquic Haplustept – USDA; Gleyic Cambisol (Fluventic) – WRB)

Location:	Riyom, Lat. 9° 37' 13.99", Lon. 8° 45' 13.77"
Parent material:	Basalt
Physiography:	Relatively flat land
Topography:	2% slope
Slope Position:	Valley bottom
Drainage:	Well drained
Erosion:	Slight
Surface characteristics:	Very few noticeable basalt pieces on the soil surface.
Vegetation/Land use:	Northern Guinea Savanna (Montane vegetation), cultivated to Irish Potato, Maize, Acha, etc.
Depth to water table:	Not encounteR.
Date described:	05/02/2015
Author:	Akinwa, A.

Horizon	**Depth (cm)**	**Description**
Ap	0-22	DRG (5YR4/2) gravelly sl; mod., med. sbks; hard (dry) firm (moist), stc. and npstc. (wet); few coarse pores; many med. and fn. pores; few coarse roots; many med. and fn. roots; pH5.4, distinct smt. bdr.
A2	22-56	B (7.5YR5/4) gravelly sl; mod., med. sbks; hard (dry) firm (moist), stc. and npstc. (wet); many med. and fn. pores; few med. roots; pH 5.5, diffuse smt. bdr.
E	56-109	DR (2.5YR3/6) gravelly sl; mod., med. sbks; hard (dry) firm (moist), stc. and npstc. (wet); many fn. pores; pH 5.7, diffuse smt. bdr.
C1	109-132	DR (2.5YR3/6) slightly gravelly ls; weak, med. sbks; hard (dry) firm (moist), nstc. and npstc. (wet); many fn. pores; pH 5.6, diffuse smt. bdr.
C2	132-190	DR (2.5YR3/6) gravelly ls; weak, med. sbks; hard (dry) firm (moist), nstc. and npstc. (wet); many fn. pores; pH 6.1.

Profile JP-BST 2-1 (Typic Natrustalf – USDA; Ferric Lixisol (Dystric) – WRB)

Location:	National Veterinary Research Institute farmland, Vom, Lat. 9° 43' 30", Lon. 8° 46' 53"
Parent material:	Basalt
Physiography:	Undulating land
Topography:	3-5% slope
Slope Position:	Crest
Drainage:	Well drained
Erosion:	Moderate
Surface characteristics:	Non stony.
Vegetation/Land use:	Northern Guinea Savanna (Montane vegetation), cultivated to Irish Potato, Maize, Acha, etc.
Depth to water table:	Below profile pit depth.
Date described:	09/06/2016
Author:	Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-22	DuR (10R3/4) scl; mod., med. sbks; hard (dry) firm (moist), stc. and pstc. (wet); com. coarse pores and many med. and fn. pores; com. coarse roots and many med. and fn. roots; pH 5.9, diffuse wavy bdr.
BA	22-38	DuR (10R3/4) c; mod., med. abks; hard (dry) firm (moist), stc. and pstc. (wet); few coarse pores and many med. and fn. pores; few coarse roots and many med. and fn. roots; pH 4.7, diffuse smt. bdr.
B1	38-73	DR (2.5YR3/6) sl; strong, med. abks; hard (dry) firm (moist), stc. and pstc. (wet); com. med. pores and many fn. pores; com. med. and fn. roots; pH 4.8, diffuse smt. bdr.
B2	73-120	DR (2.5YR3/6) scl; strong, med. abks; very hard (dry) very firm (moist), very stc. and very pstc. (wet); few med. pores and many fn. pores; few med. and fn. roots pH 6.7, diffuse smt. bdr.
Bt	120-170	DR (2.5YR3/6) c; strong, med. abks; very hard (dry) very firm (moist), very stc. and very pstc. (wet); many fn. pores; pH 4.5.

Profile JP-BST 2-2 (Plinthic Kandiustalf - USDA; Plinthic Lixisol (Vitrandic) – WRB)

Location:	National Veterinary Research Institute farmland, Vom, Lat. 9° 43' 28", Lon. 8° 46' 50"
Parent material:	Basalt
Physiography:	Undulating land
Topography:	2-4% slope
Slope Position:	Upper slope
Drainage:	Well drained
Erosion:	Moderate
Surface characteristics:	Non stony.
Vegetation/Land use:	Northern Guinea Savanna (Montane vegetation), cultivated to Irish Potato, Maize, Acha, etc.
Depth to water table:	Below profile pit depth.
Date described:	09/06/2016
Author:	Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-22	DRB (5YR3/3) cl; mod., med. abks; hard (dry) firm (moist), stc. and pstc. (wet); com. coarse pores and many med. and fn. pores; com. coarse roots and many med. and fn. roots; PH 4.3, diffuse wavy bdr.
Bt1	22-49	YR (5YR4/6) c; mod., med. abks; hard (dry) firm (moist), stc. and pstc. (wet); few coarse pores and many med. and fn. pores; few coarse roots and com. med. and fn. roots; pH 4.4, diffuse smt. bdr.
Bt2	49-100	YR (5YR4/6) cl; with com., fn., distinct RY (5YR6/8) mottles; mod., med. abks; hard (dry) firm (moist), stc. and pstc. (wet); many med. and fn. pores; few med. and fn. roots; PH 4.6, diffuse wavy bdr.
Bt3	100-168	YR (5YR4/6) gravelly cl; mod., med. abks; hard (dry) firm (moist), stc. and pstc. (wet); com. coarse pores and many med. and fn. pores PH 4.6.

Profile JP-BST 2-3 (Oxyaquic Haplustalf – USDA; Ferric Lixisol (Vitrandic) - WRB)

Location:	National Veterinary Research Institute farmland, Vom, Lat. 9° 43' 27", Lon. 8° 46' 48"
Parent material:	Basalt
Physiography:	Gently undulating land
Topography:	2-3% slope
Slope Position:	Mid slope
Drainage:	Well drained
Erosion:	Slight
Surface characteristics:	Non stony.
Vegetation/Land use:	Northern Guinea Savanna (Montane vegetation), cultivated to Irish Potato, Maize, Acha, etc.
Depth to water table:	Below profile pit depth.
Date described:	09/06/2016
Author:	Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-24	DR (5YR3/4) l; mod., med. abks; hard (dry) firm (moist), stc. and pstc. (wet); com. coarse pores and many med. and fn. pores; com. coarse roots and many med. and fn. roots; pH 4.5, clear irregular bdr.
AB	24-42	YR (5YR4/6) l; mod., med. abks; hard (dry) firm (moist), stc. and pstc. (wet); many med. and fn. pores; com. med. and fn. roots; pH 6.0, diffuse wavy bdr.
Bt	42-57	RB (5YR4/3) gravelly cl; with com., fn., distinct YR (5YR4/8) mottles, mod., med. abks; hard (dry) firm (moist), stc. and pstc. (wet); many med. and fn. pores; com. fn. roots; pH 5.9, diffuse irregular bdr.
CB	57-105	RB (5YR4/3) very gravelly sl; with many, med., distinct YR (5YR5/8) mottles; strong, med. abks; hard (dry) firm (moist), stc. and pstc. (wet); few coarse pores and many med. and fn. pores; com. fn. roots pH 5.6, diffuse wavy bdr.
C	105-180	RB (5YR4/3) very gravelly sl; with many, med., distinct YR (5YR4/6) mottles; strong, med. abks; hard (dry) firm (moist), stc. and pstc. (wet); mod. c skins on peds; few coarse pores and many med. and fn. pores; few fn. roots pH 5.2.

Profile JP-BST 2-4 (Oxyaquic Haplustalf – USDA; Ferric Lixisol (Fluventic) – WRB)

Location:	National Veterinary Research Institute farmland, Vom, Lat. 9° 43' 25", Lon. 8° 46' 44"
Parent material:	Basalt
Physiography:	Relatively flat land
Topography:	1-2% slope
Slope Position:	Foot slope
Drainage:	Well to imperfectly drained
Erosion:	Slight
Surface characteristics:	Non stony.
Vegetation/Land use:	Northern Guinea Savanna (Montane vegetation), cultivated to Irish Potato, Maize, Acha, etc.
Depth to water table:	Below profile pit depth.
Date described:	09/06/2016
Author:	Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-25	DRB (5YR3/3) l; mod., med. abks; hard (dry) firm (moist), stc. and pstc. (wet); com. coarse pores and many med. and fn. pores; com. coarse roots and many med. and fn. roots; pH 4.7, clear irregular bdr.
Bt	25-46	RB (5YR4/3) l; mod., med. abks; hard (dry) firm (moist), stc. and pstc. (wet); com. coarse pores and many med. and fn. pores; few coarse roots and many med. and fn. roots; pH 5.4, diffuse smt. bdr.
BC1	46-72	RB (5YR4/3) gravelly l; mod., med. abks; hard (dry) firm (moist), very stc. and very pstc. (wet); com. coarse pores and many med. and fn. pores; com. fn. roots; pH 5.7, diffuse wavy bdr.
BC2	72-120	RB (5YR4/3) gravelly l; with com., fn., distinct YR (5YR5/8) mottles; strong, med. abks; hard (dry) firm (moist), stc. and pstc. (wet); many med. and fn. pores; few fn. roots pH 5.2, diffuse wavy bdr.
C	120-179	RB (5YR4/3) gravelly sl; with many, med., distinct YR (5YR5/8) mottles; strong, med. abks; very hard (dry) very firm (moist), stc. and pstc. (wet); many med. and fn. pores; pH 5.2.

Profile JP-BST 2-5 (Aquic Natrustalf – USDA; Gleyic Lixisol (Fluventic) – WRB)

Location:	National Veterinary Research Institute farmland, Vom, Lat. 9° 43' 19", Lon. 8° 46' 33"
Parent material:	Basalt
Physiography:	Almost flat land
Topography:	0-1% slope
Slope Position:	Valley bottom
Drainage:	imperfectly drained
Erosion:	Very slight
Surface characteristics:	Non stony.
Vegetation/Land use:	Northern Guinea Savanna (Montane vegetation), cultivated to Irish Potato, Maize, Acha, etc.
Depth to water table:	Below profile pit depth.
Date described:	09/06/2016
Author:	Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-23	DB (10YR3/3) slightly gravelly sl; mod., med. sbks; slightly hard (dry) slightly firm (moist), nstc., npstc. (wet); com. coarse pores and many med. and fn. pores; many med. and fn. roots; pH 4.8, clear smt. bdr.
A2	23-42	DYB (10YR4/4) gravelly l; mod., med. sbks; hard (dry) firm (moist), nstc. npstc.. (wet); com. coarse pores; and many med. and fn. pores, many med. and fn. roots; pH 4.8, distinct smt. bdr.
B	42-78	SB (7.5YR5/6) sl; with com., fn., distinct YR (5YR5/8) mottles, strong, med. abks; very hard (dry) very firm (moist), very stc. and very pstc. (wet); many med. and fn. pores; com. fn. roots; pH 5.5, diffuse wavy bdr.
Bt	78-123	R (2.5YR5/6) scl; with many, med., distinct YR (5YR5/8) mottles; strong, med. abks; very hard (dry) very firm (moist), very stc. and very pstc. (wet); many med. and fn. pores; few fn. roots pH 4.7, clear wavy bdr.
C	123-180	PG (5YR6/2) sl; with many, med., distinct YR (5YR5/8) mottles; strong, med. abks; very hard (dry) very firm (moist), very stc. and very pstc. (wet); many med. and fn. pores; pH 5.1.

APPENDIX 2: Detailed description of sites, morphology and physical properties of the soils derived from Granites.

Profile JP-GNT 1-1 (Plinthic Kandiustalf – USDA; Humic Nitisol (Dystric) - WRB)

Location:	Vom, near Vom Christian Hospital, Lat. 9° 39' 19.3", Lon. 8° 46' 1.66"
Parent material:	Granite
Physiography:	Undulating land
Topography:	3-6% slope
Slope Position:	Crest
Drainage:	Well drained
Erosion:	Moderate
Surface characteristics:	Granitic rock out crops nearby.
Vegetation/Land use:	Grasses, shrubs, baobab tree, cactus, millet, etc.
Depth to water table:	Not encounteR.
Date described:	18/12/2014
Author:	Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-19	DB (7.5YR4/4) scl; mod., med. sbks; hard (dry) firm (moist), stc. and pstc. (wet); com. coarse pores and many med. and fn. pores; many large, med. and fn. roots; pH 5.4, sharp irregular bdr.
BA	19-34	SB (7.5YR5/6) slightly gravelly cl; mod., med. abks; hard (dry) firm (moist), stc., and pstc. (wet); many med. and fn. pores; many med. and fn. roots; pH 5.1, sharp smt. bdr.
Bt1	34-64	SB (7.5YR5/6) gravelly c; strong, med. abks; hard (dry) firm (moist), stc. and pstc. (wet); many med. and fn. pores; com. coarse roots, many med. and fn. roots; pH5.3, diffuse smt. bdr.
Bt2	64-100	SB (7.5YR5/8) gravelly c; strong, med. abks; hard (dry) firm (moist), stc. and pstc. (wet); many med. and fn. pores; many med. and fn. roots pH 5.5, diffuse smt. bdr.
C	100-200	YR (5YR4/8) gravelly l; mod., med., sbks; hard (dry), firm (moist), slightly stc. and npstc. (wet); many med. and fn. pores; many fn. roots; pH 5.9.

Profile JP-GNT 1-2 (Plinthic Kandiustalf – USDA; Humic Nitisol (Dystric) - WRB)

Location:	Vom, Lat. 9° 39' 24.5", Lon. 8° 45' 57.34"
Parent material:	Granite
Physiography:	Undulating land
Topography:	2-4% slope
Slope Position:	Upper slope
Drainage:	Well drained
Erosion:	Mod.
Surface characteristics:	Nearby granite hills.
Vegetation/Land use:	Grasses, fan palms, scatteR tress, millet, Irish potato, etc.
Depth to water table:	Not encounteR.
Date described:	18/12/2014
Author:	Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-20	DB (7.5YR4/4) cl; mod., med. sbks; slightly hard (dry) slightly firm (moist), slightly stc. and npstc. (wet); com. coarse pores and many med. and fn. pores; many large, med. and fn. roots; pH 5.0, clear irregular bdr.
BA	20-63	SB (7.5YR5/6) slightly gravelly scl; mod., med. abks; hard (dry) firm (moist), stc., and pstc. (wet); many med. and fn. pores; many med. and fn. roots; pH 5.8, diffused wavy bdr.
Bt1	63-98	SB (7.5YR5/8) slightly gravelly c; strong, med. abks; hard (dry) firm (moist), stc. and pstc. (wet); few coarse pores and many med. and fn. roots; pH 5.5, diffuse irregular bdr.
Bt2	98-117	YR (5YR5/8) gravelly c; strong, med. abks; hard (dry) firm (moist), stc. and pstc. (wet); c skins, many med. and fn. pores; com. med. and many fn. roots pH 5.5, diffuse wavy bdr.
Bt3	117-196	YR (5YR5/8) gravelly c; mod., med., sbkss; hard (dry), firm (moist), stc. and pstc. (wet); many med. and fn. pores; com. fn. roots; pH 5.8.

Profile JP-GNT 1-3 (Plinthic Kandiustalf – USDA; Humic Nitisol (Vitrandic) - WRB)

Location:	Vom, Lat. 9° 39' 31", Lon. 8° 45' 51.94"
Parent material:	Granite
Physiography:	Undulating land
Topography:	3% slope
Slope Position:	Mid slope
Drainage:	Well drained
Erosion:	Moderate
Surface characteristics:	Non stony.
Vegetation/Land use:	Grasses, maize, millet, Irish potato, carrot, etc.
Depth to water table:	Not encounteR.
Date described:	18/12/2014
Author:	Akinwa, A. O

Horizon	**Depth (cm)**	Description
Ap	0-19	DB (7.5YR4/4) scl; mod., med. sbks; slightly hard (dry) slightly firm (moist), nstc., npstc. (wet); many coarse med. and fn. pores; many coarse med. and fn. roots; pH 5.2, clear wavy bdr.
Bt1	19-65	RY (7.5YR6/8) slightly gravelly c; mod., med. abks; hard (dry) firm (moist), stc., and pstc. (wet); many med. and fn. pores; many med. and fn. roots; pH 5.5, diffused wavy bdr.
Bt2	65-110	SB (7.5YR5/6) gravelly c; strong, med. abks; hard (dry) firm (moist), stc. and pstc. (wet); c skins, many med. and fn. pores; many med. and fn. roots; pH5.5, diffuse irregular bdr.
Bt3	110-170	YR (7.5YR5/8) gravelly cl; strong, med. abks; hard (dry) firm (moist), stc. and pstc. (wet); c skins, many med. and fn. pores; com. med. and fn. roots pH 5.5, diffuse smt. bdr.
C	170-200	R (2.5YR4/6) gravelly cl; strong, med., abkss; very hard (dry), very firm (moist), stc. and pstc. (wet); c skins, many med. and fn. pores; few fn. roots; pH 5.5.

Profile JP-GNT 1-4 (Aquic Kandiustalf – USDA; Humic Nitisol (Dystric) - WRB)

Location:	Vom, Lat. 9° 39' 36.2", Lon. 8° 45' 47.62"
Parent material:	Granite
Physiography:	Gently undulating land
Topography:	1-2% slope
Slope Position:	Foot slope
Drainage:	Well drained
Erosion:	Mild
Surface characteristics:	Non stony.
Vegetation/Land use:	Eucalyptus trees, cactus.
Depth to water table:	Not encounteR
Date described:	19/12/2014
Author:	Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-6	DYB (10YR4/4) cl; mod., med. sbks; hard (dry) firm (moist), stc. and pstc. (wet); partially decomposed organic materials, many coarse med. and fn. pores; few coarse roots and many med. and fn. roots; pH 5.4, smt. bdr.
BA	6-15	YB (10YR5/6) cl; mod., med. sbks; hard (dry) firm (moist), stc., and pstc. (wet); com. coarse pores and many med. and fn. pores; com. coarse roots and many med. and fn. roots; pH 5.1, clear smt. bdr.
Bt1	15-68	RY (7.5YR6/6) c; strong, med. abks; hard (dry) firm (moist), stc. and pstc. (wet); many coarse med. and fn. pores; many coarse, med. and fn. roots; pH5.4, gradual wavy bdr.
Bt2	68-113	SB (7.5YR5/6) gravelly c; strong, med. abks; hard (dry) firm (moist), stc. and pstc. (wet); c skins, many med. and fn. pores; com. fn. roots PH 5.6, diffuse wavy bdr.
Bt3	113-200	YR (5YR4/8) cl; strong, med., abkss; hard (dry), firm (moist), slightly stc. and pstc. (wet); many med. and fn. pores; pH 5.5.

Profile JP-GNT 1-5 (Aquic Kandiustalf – USDA; Humic Nitisol (Vitrandic) - WRB)

Location:	Vom, Lat. 9° 39' 40.75", Lon. 8° 45' 43.84"
Parent material:	Granite
Physiography:	Gently undulating land
Topography:	1-2% slope
Slope Position:	Valley bottom
Drainage:	Well to imperfectly drained
Erosion:	Mild
Surface characteristics:	Non stony.
Vegetation/Land use:	Grasses, scatteR trees, cactus, millet, etc.
Depth to water table:	Not encounteR.
Date described:	19/12/2014
Author:	Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-14	DB (10YR4/4) l; mod., med. sbks; slightly hard (dry) slightly firm (moist), nstc. and npstc. (wet); many med. and fn. pores; many med. and fn. roots; pH 5.5, clear smt. bdr.
Bt1	14-75	YB (10YR5/6) gravelly c; Strong, med. abks; hard (dry) firm (moist), stc., and pstc. (wet); many med. and fn. pores; com. fn. roots; pH 5.3, smt. diffused bdr.
Bt2	75-112	YB (10YR5/8) gravelly cl; strong, med. abks; hard (dry) firm (moist), stc. and pstc. (wet); c skins, many med. and fn. pores; com. fn. roots; pH5.3, diffused irregular bdr.
Bt3	112-196	YR (5YR4/8) gravelly cl; strong, med. abks; hard (dry) firm (moist), stc. and pstc. (wet); c skins, many med. and fn. pores; pH 5.2.

Profile JP-GNT 2-1 (Plinthic Natrustalf – USDA; Ferric Lixisol (Dystric) - WRB)

Location: Gasen, near Kuru, Lat. 9° 44' 59", Lon. 8° 49' 43"
Parent material: Granite
Physiography: Undulating land
Topography: 3-4% slope
Slope Position: Crest
Drainage: Well drained
Erosion: Mod.
Surface characteristics: Nearby granitic rocks.
Vegetation/Land use: Northern Guinea Savanna (Montane vegetation), cultivated to Irish potato, maize, Acha, etc.
Depth to water table: Below profile pit depth.
Date described: 17/06/2016
Author: Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-25	DB (10YR3/3) very gravelly sl; weak, med. sbks; slightly hard (dry) slightly firm (moist), nstc. and npstc. (wet); many med. and fn. pores; many med. and fn. roots; pH 4.4, distinct wavy bdr.
A2	25-66	R (10R5/8) very gravelly sl; weak, med. sbks; slightly hard (dry), slightly firm (moist), nstc., and npstc. (wet); many med. and fn. pores; com. fn. roots; pH 4.7, diffused smt. bdr.
Bt	66-110	R (10R5/8) gravelly l; Mod., med. sbks; slightly hard (dry) firm (moist), nstc. and npstc. (wet); many med. and fn. pores; few fn. roots; pH 4.6, diffused smt. bdr.

Profile JP-GNT 2-2 (Plinthic Natrustalf – USDA; Ferric Lixisol (Dystric) – WRB)

Location:	Gasen, near Kuru, Lat. 9° 45' 5", Lon. 8° 49' 48"
Parent material:	Granite
Physiography:	Undulating land
Topography:	2-3% slope
Slope Position:	Upper slope
Drainage:	Well drained
Erosion:	Moderate
Surface characteristics:	Non-stony.
Vegetation/Land use:	Northern Guinea Savanna (Montane vegetation), cultivated to Irish potato, maize, Acha, etc.
Depth to water table:	Below profile pit depth.
Date described:	07/06/2016
Author:	Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-13	YB (10YR5/8) slightly gravelly scl; mod., med. sbks; slightly hard (dry) slightly firm (moist), slightly stc., npstc. (wet); many med. and fn. pores; many fn. roots; pH 5.3, clear smt. bdr.
Bt	13-55	YB (10R5/8) slightly gravelly l; with com., med., distinct R (2.5YR4/8) mottles; mod., med., abks; hard (dry), firm (moist), stc., and pstc. (wet); com. coarse pores many med. and fn. pores; many fn. roots; pH 4.9, diffuse smt. bdr.
BC	55-82	YB (10R5/6) very gravelly scl; with many, coarse, distinct R (2.5YR4/8) mottles; mod., med., abks; hard (dry) firm (moist), stc. and pstc. (wet); many coarse med. and fn. pores; com. fn. roots; pH 4.6 diffuse smt. bdr.
C	82-165	YB (10R5/6) slightly gravelly sl; with many, coarse, distinct R (2.5YR4/8) mottles; strong, med., abks; very hard (dry) firm (moist), stc. and pstc. (wet); many coarse, med. and fn. pores; few fn. roots; pH 5.7.

Profile JP-GNT 2-3 (Oxyaquic Haplustalf – USDA; Ferric Lixisol (Dystric) – WRB)

Location:	Gasen, near Kuru, Lat. 9° 45' 6", Lon. 8° 49' 50"
Parent material:	Granite
Physiography:	Gently undulating land
Topography:	1-2% slope
Slope Position:	Mid slope
Drainage:	Well drained
Erosion:	Moderate
Surface characteristics:	Non-stony.
Vegetation/Land use:	Northern Guinea Savanna (Montane vegetation), cultivated to Irish potato, maize, Acha, etc.
Depth to water table:	Below profile pit depth.
Date described:	07/06/2016
Author:	Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-14	DYB (10YR4/4) sl; weak, med. sbks; slightly hard (dry) slightly firm (moist), nstc. npstc. (wet); many med. and fn. pores; many med. and fn. roots; pH 4.9, clear smt. bdr.
AB	14-43	YB (10R5/4) slightly gravelly scl; with com., med., distinct R (2.5YR4/6) mottles; mod., med., abks; hard (dry), firm (moist), stc., and pstc. (wet); com. coarse pores and many med. and fn. pores; com. fn. roots; pH 5.7, diffuse smt. bdr.
Bt1	43-87	LYB (10YR6/4) gravelly cl; with many, med., distinct R (2.5YR4/6) mottles; strong, med., abks; hard (dry), firm (moist), stc., and pstc. (wet); com. coarse pores and many med. and fn. pores; com. fn. roots; pH 4.8, clear smt. bdr.
Bt2	87-110	R (10R4/8) scl; mod., coarse abks; hard (dry) firm (moist), stc. and pstc. (wet); c skins on peds, many med. and fn. pores; few fn. roots; pH 5.0, diffuse smt. bdr.
Bt3	110-185	R (10R4/8) slightly gravelly scl; with many med., distinct RY (7.5YR7/8) mottles, strong, coarse abks; hard (dry) firm (moist), stc. and pstc. (wet); c skins on peds, many med. and fn. pores; pH 5.2.

Profile JP-GNT 2-4 (Oxyaquic Haplustalf – USDA; Ferric Lixisol (Dystric) – WRB)

Location:	Gasen, near Kuru, Lat. 9° 45' 7", Lon. 8° 49' 52"
Parent material:	Granite
Physiography:	Gently undulating land
Topography:	0-1% slope
Slope Position:	Foot slope
Drainage:	Poorly drained
Erosion:	Slight
Surface characteristics:	Non-stony.
Vegetation/Land use:	Northern Guinea Savanna (Montane vegetation), cultivated to Irish potato, maize, Acha, etc.
Depth to water table:	Below profile pit depth.
Date described:	07/06/2016
Author:	Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-20	LYB (10YR6/4) cl; with many, med., distinct SB (7.5YR5/8) mottles; mod., med. abks; hard (dry) firm (moist), stc. and pstc. (wet); many med. and fn. pores; com. med. roots and many fn. roots; pH 4.8, clear smt. bdr.
AB	20-55	G (5YR6/1) l; with many, med., distinct SB (7.5YR5/8) mottles; strong, med., abks; hard (dry), firm (moist), stc., and pstc. (wet); many med. and fn. pores; com. med. and fn. roots; pH 4.8, diffuse smt. bdr.
Bt1	55-67	G (5YR6/1) gravelly cl; strong, med., abks; hard (dry) firm (moist), stc. and pstc. (wet); coarse pores and many med. and fn. pores; few med. and fn. roots; pH 5.8, clear smt. bdr.
Bt2	67-140	G (5YR6/1) cl; with many med., distinct SB (7.5YR5/8) mottles, strong, med. abks; hard (dry) firm (moist), stc. and pstc. (wet); many med. and fn. pores; pH 4.7, diffuse smt. bdr.
C	140-175	LG (5YR7/1) l; with many, med., distinct SB (7.5YR5/8) mottles, strong, med. abks; hard (dry) firm (moist), stc. and pstc. (wet); many med. and fn. pores; pH 4.6.

Profile JP-GNT 2-5 (Aquic Haplustept – USDA; Gleyic Cambisol (Dystric) – WRB)

Location:	Gasen, near Kuru, Lat. 9° 45' 8", Lon. 8° 49' 54"
Parent material:	Granite
Physiography:	Almost flat land
Topography:	0-1% slope
Slope Position:	Valley bottom
Drainage:	Poorly drained
Erosion:	Slight
Surface characteristics:	Non-stony.
Vegetation/Land use:	Northern Guinea Savanna (Montane vegetation), cultivated to Irish potato, maize, Acha, etc.
Depth to water table:	Below profile pit depth
Date described:	07/06/2016
Author:	Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-12	YB (10YR5/4) gravelly ls; weak, med., sbks; slightly hard (dry) slightly firm (moist), nstc. and npstc. (wet); com. coarse pores and many med. and fn. pores; many med. and fn. roots; pH 4.9, clear smt. bdr.
A2	12-35	OY (2.5Y6/8) gravelly sl; mod., med., sbks; hard (dry), firm (moist), stc., and pstc. (wet); com. coarse pores and many med. and fn. pores; many med. and fn. roots; pH 4.8, diffuse smt. bdr.
AB	35-76	LYB (2.5Y6/4) gravelly sl; with many, med., distinct R (2.5YR4/8) mottles; mod., med., abks; hard (dry) firm (moist), stc. and pstc. (wet); com. coarse pores and many med. and fn. pores; com. fn. roots; pH 4.8, wavy bdr.
B	76-110	R (10R4/8) gravelly sl; strong, med. abks; hard (dry) firm (moist), stc. and pstc. (wet); thin c skins on peds, com. coarse pores and many med. and fn. pores; few fn. roots; pH 5.0, diffuse wavy bdr.
C	110-172	R (10R4/8) gravelly l; strong, med. abks; hard (dry) firm (moist), stc. and pstc. (wet); thin c skins on peds, com. coarse pores and many med. and fn. pores; pH 5.0.

APPENDIX 3: Detailed description of sites, morphology and physical properties of the soils derived from Unconsolidated Deposits.

Profile JP-UDP 1-1 (Typic Natrustalf – USDA; Ferric Lixisol (Fluventic) – WRB)

Location: Du, Lat. 9° 43' 54.92", Lon. 8° 54' 5.82"
Parent material: Unconsolidated deposits
Physiography: Undulating land
Topography: 3-5% slope
Slope Position: Crest
Drainage: Well drained
Erosion: Moderate
Surface characteristics: Non-stony.
Vegetation/Land use: Grasses, scatteR tress, maize, guinea corn, Irish potato, yam etc.
Depth to water table: Not encounteR.
Date described: 11/02/2015
Author: Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-17	YB (10YR5/6) sl; mod., med. sbks; slightly hard (dry) slightly firm (moist), nstc., npstc. (wet); many med. and fn. pores; com. med. and fn. roots; pH 5.7, gradual smt. bdr.
Bt1	17-46	BY (10YR6/8) cl; mod., med., sbks; hard (dry), firm (moist), stc., and pstc. (wet); many med. and fn. pores; com. med. and fn. roots; pH 5.5, clear smt. bdr.
Bt2	46-90	YB (10YR5/8) cl; mod., med., sbks; hard (dry) firm (moist), stc. and pstc. (wet); many med. and fn. pores; few fn. roots; pH 5.6, diffuse smt. bdr.
C1	90-133	RB (2.5YR5/4) ls; mod., med. sbks; hard (dry) firm (moist), nstc. and npstc. (wet); many med. and fn. pores; pH 5.5, diffuse smt. bdr.
C2	133-190	DYB (10R4/4) slightly gravelly sl; mod., med. sbks; hard (dry) firm (moist), nstc. and npstc. (wet); many med. and fn. pores; pH 5.4

Profile JP-UDP 1-2 (Plinthic Kandiustalf – USDA; Ferric Lixisol (Vitrandic) – WRB)

Location:	Lat. 9° 44' 2.77", Lon. 8° 54' 12.02"
Parent material:	Unconsolidated deposits
Physiography:	Undulating land
Topography:	2-3% slope
Slope Position:	Upper slope
Drainage:	Well drained
Erosion:	Moderate
Surface characteristics:	Non-stony.
Vegetation/Land use:	Grasses, scatteR tress, maize, guinea corn, mango etc.
Depth to water table:	Not encounteR
Date described:	11/02/2015
Author:	Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-19	SB (7.5YR5/6) slightly gravelly sl; weak, med. sbks; slightly hard (dry) slightly firm (moist), nstc., npstc. (wet); many med. and fn. pores; com. med. and fn. roots; pH 5.4 clear irregular bdr.
Bt1	19-80	SB (7.5YR5/6) gravelly cl; mod., med., sbks; hard (dry), firm (moist), stc., and pstc. (wet); many med. and fn. pores; com. fn. roots; pH 5.4, diffuse smt. bdr.
Bt2	80-115	SB (7.5YR5/6) gravelly cl; strong, med., sbks; hard (dry) firm (moist), stc. and pstc. (wet); com. coarse pores many med. and fn. pores; pH 5.5, diffuse irregular bdr.
Bt3	115-195	DYB (10YR4/4) gravelly cl; strong, med. sbks; hard (dry) firm (moist), stc. and pstc. (wet); com. coarse pores and many med. and fn. pores; pH 5.4.

Profile JP-UDP 1-3 (Typic Natrustalf – USDA; Ferric Lixisol (Fluventic) – WRB)

Location:	Du, Lat. 9° 44' 8.17", Lon. 8° 54' 15.82"
Parent material:	Unconsolidated deposits
Physiography:	Gently undulating land
Topography:	2-3% slope
Slope Position:	Mid slope
Drainage:	Well drained
Erosion:	Slight
Surface characteristics:	Non-stony.
Vegetation/Land use:	Grasses, scatteR tress, maize, guinea corn, Irish potato, cocoyam etc.
Depth to water table:	Not encounteR.
Date described:	12/02/2015
Author:	Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-11	YB (10YR5/8) gravelly scl; mod., med. sbks; hard (dry) firm (moist), stc., pstc. (wet); very many coarse med. and fn. pores; very many coarse med. and fn. roots; pH 5.7, clear wavy bdr.
Bt1	11-33	BY (10YR6/6) cl; mod., med., sbks; hard (dry), firm (moist), stc., and pstc. (wet); com. coarse pores and many med. and fn. pores; few coarse roots and many med. and fn. roots; pH 5.7, clear wavy bdr.
Bt2	33-62	R (2.5YR4/6) cl; strong, med., sub-angularblocky structure; hard (dry) firm (moist), stc. and pstc. (wet); com. med. and fn. pores; com. med. and fn. roots pH 5.5, diffuse smt. bdr.
Bt3	62-160	YR (10YR4/4) gravelly cl; strong, med. sbks; hard (dry) firm (moist), stc. and pstc. (wet); com. med. and fn. pores; few fn. roots; pH 5.8, diffuse smt. bdr.
C	160-200	B (7.5YR5/4) gravelly l; mod., med. sbks; hard (dry) firm (moist), stc. and npstc. (wet); com. med. pores and many fn. pores; very few fn. roots; pH 6.0.

Profile JP-UDP 1-4 (Aquic Kandiustalf – USDA; Gleyic Lixisol (Vitrandic) – WRB)

Location:	Du, Lat. 9° 44' 12.77", Lon. 8° 54' 19.56"
Parent material:	Unconsolidated deposits
Physiography:	Relatively flat land
Topography:	2% slope
Slope Position:	Foot slope
Drainage:	Well to imperfectly drained
Erosion:	Slight
Surface characteristics:	Non-stony.
Vegetation/Land use:	Grasses, scatteR tress, maize, guinea corn, etc.
Depth to water table:	Not encounteR
Date described:	12/02/2015
Author:	Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-33	YR (5YR5/8) gravelly l; weak, med. sbks; slightly hard (dry) firm (moist), slightly stc., npstc. (wet); com. coarse pores, many med. and fn. pores; com. coarse roots, many med. and fn. roots; pH 6.0, clear wavy bdr.
B1	33-74	YR (5YR4/8) gravelly cl; strong, med., abks; hard (dry), firm (moist), stc., and pstc. (wet); com. c skins, com. med. and fn. pores; com. fn. roots; pH 6.0, diffuse wavy bdr.
B2	74-123	RB (5YR5/3) gravelly sl; mod., med., sbks; hard (dry) firm (moist), stc. and npstc. (wet); many med. and fn. pores; few fn. roots pH 6.1, diffused smt. bdr.
Bt	123-166	RY (7.5YR6/6) gravelly cl; strong med. abks; hard (dry) firm (moist), stc. and pstc. (wet); com. c skins; many med. and fn. pores; pH 6.1.

Profile JP-UDP 1-5 (Aquic Kandiustalf – USDA; Gleyic Lixisol (Vitrandic) – WRB)

Location:	Du, Lat. 9° 44' 20.32", Lon. 8° 54' 25.53"
Parent material:	Unconsolidated deposits
Physiography:	Relatively flat land
Topography:	1-2% slope
Slope Position:	Valley bottom
Drainage:	Imperfectly drained
Erosion:	Slight
Surface characteristics:	Non-stony.
Vegetation/Land use:	Grasses, scatteR tress, maize, etc.
Depth to water table:	Not encounteR
Date described:	12/02/2015
Author:	Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-12	YR (5YR5/8) gravelly cl; strong, med. sbks; hard (dry), firm (moist), stc. and pstc. (wet); com. coarse pores; many med. and fn. pores; many med. and fn. roots; pH 7.04, gradual, wavy bdr.
Bt1	12-57	YR (5YR4/8) gravelly cl; strong, med., abks; hard (dry), firm (moist), stc. and pstc. (wet); com. c skins, com. med. and fn. pores; com. fn. roots; pH 6.05, clear, smoth bdr.
Bt2	57-115	RB (5YR5/3) gravelly cl; with many med., distinct, R (2.5YR 5/6) mottles; strong, med., abks; hard (dry) very firm (moist), stc. and pstc. (wet); com. c skins, com. med. and many fn. pores; few fn. roots; pH 5.88, diffused smt. bdr.
C2	115-180	RY (7.5YR6/8) gravelly l; with many fn., distinct, YB (10YR 5/8) mottles; mod. med. sbks; hard (dry), firm (moist), slightly stc. and slightly pstc. (wet); many fn. pores; pH 5.94.

Profile JP-UDP 2-1 (Psammentic Haplustalf – USDA; Ferric Lixisol (Dystric) -WRB)

Location: Bisichi, Lat. 9° 43' 41.27, Lon. 8° 53' 54.48"
Parent material: Unconsolidated deposits
Physiography: Undulating land
Topography: 4-5% slope
Slope Position: Crest
Drainage: Well drained
Erosion: Mod.
Surface characteristics: Non-stony.
Vegetation/Land use: Northern Guinea Savanna (Montane vegetation) cultivated to Irish potato, maize, Acha etc.
Depth to water table: Below profile pit depth.
Date described: 10/06/2016
Author: Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-23	YB (10YR5/4) gravelly sl; weak, med. sbks; slight hard (dry) firm (moist), nstc. and npstc. (wet); com. coarse pores and many med. and fn. pores; many med. and fn. roots; pH 4.8, diffuse smt. bdr.
A2	23-54	YB (10YR5/4) gravelly sl with com., fn. R (2.5YR4/6) mottles; mod., med., abks; slightly hard (dry), firm (moist), slightly stc. and npstc. (wet); many med. and fn. pores; com. fn. roots; pH 4.5, diffused smt. bdr.
Bt1	54-81	LYB (10YR6/4) gravelly sl with many med., R (2.5YR4/6) mottles; mod., med., sbks; slightly hard (dry) firm (moist), slightly stc. and npstc. (wet); many med. and fn. pores; few fn. roots pH 4.7, diffused smt. bdr.
Bt2	81-107	LYB (10YR6/4) sl with many med., R (2.5YR6/4) mottles; mod., med. sbks; hard (dry) firm (moist), stc. and npstc. (wet); many med. and fn. pores; pH 4.4, diffuse wavy bdr.
C	107-170	LG (10YR7/1) sl with many med., R (2.5YR4/6) mottles; strong, med. sbks; hard (dry) firm (moist), stc. and npstc. (wet); many med. and fn. pores; pH 4.8.

Profile JP-UDP 2-2 (Ultic Haplustalf – USDA; Ferric Lixisol (Dystric) – WRB)

Location:	Bisichi, Lat. 9° 43' 36.07", Lon. 8° 53' 50.06"
Parent material:	Unconsolidated deposits
Physiography:	Undulating land
Topography:	3-4% slope
Slope Position:	Upper slope
Drainage:	Well drained
Erosion:	Moderate
Surface characteristics:	Non-stony.
Vegetation/Land use:	Northern Guinea Savanna (Montane vegetation) cultivated to Irish potato, maize, Acha etc.
Depth to water table:	Below profile pit depth.
Date described:	10/06/2016
Author:	Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-18	SB (7.5YR5/4) gravelly scl; weak, med. sbks; slightly hard (dry), firm (moist), nstc., npstc. (wet); com. coarse pores and many med. and fn. pores; com. med. and fn. roots; pH 4.6, clear wavy bdr.
Bt1	18-80	SB (7.5YR5/6) gravelly cl; mod., med., sbks; hard (dry), firm (moist), stc. and pstc. (wet); many med. and fn. pores; com. fn. roots; pH 4.5, diffused smt. bdr.
Bt2	80-116	SB (7.5YR5/6) gravelly l; strong, med., abks; hard (dry) firm (moist), stc. and pstc. (wet); com. coarse pores and many med. and fn. pores; pH 4.9, diffused wavy bdr.
C	116-196	DYB (10YR4/4) gravelly l; strong, med. abks; hard (dry) firm (moist), stc. and pstc. (wet); com. coarse pores and many med. and fn. pores; pH 4.8.

Profile JP-UDP 2-3 (Ultic Haplustalf – USDA; Ferric Lixisol (Dystric) - WRB)

Location:	Bisichi, Lat. 9° 43' 31.19", Lon. 8° 53' 46.11"
Parent material:	Unconsolidated deposits
Physiography:	Gently undulating land
Topography:	2-3% slope
Slope Position:	Mid slope
Drainage:	Well drained
Erosion:	Slight
Surface characteristics:	Non-stony.
Vegetation/Land use:	Northern Guinea Savanna (Montane vegetation) cultivated to Irish potato, maize, Acha etc.
Depth to water table:	Below profile pit depth.
Date described:	10/06/2016
Author:	Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-12	YB (10YR5/4) gravelly sl; mod., med. sbks; hard (dry) firm (moist), stc. and pstc. (wet); many coarse med. and fn. pores; many coarse med. and fn. roots; pH 4.8, clear wavy bdr.
B	12-33	BY (10YR6/6) sl; strong, med., abks; hard (dry), firm (moist), stc. and pstc. (wet); many med. and fn. pores; few coarse roots and many med. and fn. roots; pH 4.7, diffuse wavy bdr.
Bt1	33-64	R (2.5YR4/6) scl; strong, med., abks; hard (dry) firm (moist), stc. and pstc. (wet); com. med. and fn. pores; com. med. and fn. roots; pH 4.8, diffuse smt. bdr.
Bt2	64-160	YR (5YR5/6) gravelly scl; strong, med., abks; hard (dry) firm (moist), stc. and pstc. (wet); com. med. and fn. pores; very few fn. roots; pH 4.6, diffuse smt. bdr.
C	160-198	B (7.5YR5/4) gravelly l; mod., med. sbks; hard (dry) firm (moist), stc. and npstc. (wet); many med. and fn. pores; few fn. roots pH 4.9.

Profile JP-UDP 2-4 (Aquultic Haplustalf – USDA; Ferric Lixisol (Dystric) – WRB)

Location:	Bisichi, Lat. 9° 43' 26.64", Lon. 8° 53' 42.33"
Parent material:	Unconsolidated deposits
Physiography:	Relatively flat land
Topography:	1-2% slope
Slope Position:	Foot slope
Drainage:	Well to imperfectly drained
Erosion:	Slight
Surface characteristics:	Non-stony.
Vegetation/Land use:	Northern Guinea Savanna (Montane vegetation) cultivated to Irish potato, maize, Acha etc.
Depth to water table:	Below profile pit depth.
Date described:	10/06/2016
Author:	Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-32	YR (5YR4/8) gravelly l; weak, med. sbks; hard (dry) firm (moist), slightly stc., and npstc. (wet); com. coarse pores, and many med. and fn. pores; com. coarse roots and many med. and fn. roots; pH 4.6, clear smt. bdr.
B	32-73	YR (5YR4/8) gravelly l; strong, med., abks; hard (dry), firm (moist), stc. and pstc. (wet); com. thin skins, com. med. and fn. pores; com. fn. roots; pH 5.1, diffuse wavy bdr.
Bt1	73-123	RB (5YR5/3) gravelly l; mod., med., sbks; hard (dry) firm (moist), slightly stc. and npstc. (wet); com. coarse pores and many med. and fn. pores; few fn. roots; pH 4.9, diffuse smt. bdr.
Bt2	123-192	RY (7.5YR6/8) gravelly cl; strong, med., abks; hard (dry) firm (moist), stc. and pstc. (wet); many med. and fn. pores; pH 4.8.

Profile JP-UDP 2-5 (Aquultic Haplustalf – USDA; Ferric Lixisol (Dystric) – WRB)

Location:	Bisichi, Lat. 9° 43' 22.09", Lon. 8° 53' 42.33"
Parent material:	Unconsolidated deposits
Physiography:	Relatively flat land
Topography:	0-1% slope
Slope Position:	Valley bottom
Drainage:	Imperfectly drained
Erosion:	Very slight
Surface characteristics:	Non-stony.
Vegetation/Land use:	Northern Guinea Savanna (Montane vegetation) cultivated to maize, Acha etc.
Depth to water table:	Below profile pit depth.
Date described:	10/06/2016
Author:	Akinwa, A. O

Horizon	**Depth (cm)**	**Description**
Ap	0-14	YR (5YR4/8) gravelly scl; mod., med. sbks; hard (dry); firm (moist), slightly stc., and npstc. (wet); many coarse med. and fn. pores; com. coarse roots and many med. and fn. roots; pH 4.8, clear smt. bdr.
Bt1	14-60	YR (5YR4/8) gravelly cl; mod. med., sbks; hard (dry), firm (moist), stc. and pstc. (wet); many med. and fn. pores; com. med. and fn. roots; pH 5.0, diffuse smt. bdr.
Bt2	60-115	YR (5YR4/8) gravelly l; strong, med., abks; hard (dry) firm (moist), stc. and pstc. (wet); many fn. R (10R5/8) mottles; many med. and fn. pores; com. fn. roots; pH 8.3, diffuse smt. bdr.
C	115-192	RY (7.5YR6/6) gravelly l; mod., med., sbks; hard (dry) firm (moist), slightly stc. pstc. (wet); many fn. YB (10YR5/8) mottles; many med. and fn. pores; pH 5.9.

Key:

Colour	**Texture/Structure**	**Consistency**
RB - Reddish brown	L – loam	Stc. – sticky
YR – Yellowish red	LS – loamy sand	Nstc. – non-sticky
DRG – Dark Reddish Gray	SCL – sandy clay loam	Pstc. – plastic
D – Dark	SL – sandy loam	Npstc. – non-plastic

DRB – Dark reddish brown
Y – Yellowish
RY – Reddish yellow
DR – Dark red
DB – Dark brown
SB – Strong brown
PG – Pinkish gray
DYB – Dark yellowish brown
YB – Yellowish brown
LYB – Light yellowish brown
G – Gray
LT – Light gray
OY – Olive yellow
BY – Brownish yellow
R – Red
DuR – Dusky red

CL – clay loam
C – clay
SiL – silty loam
Mod. – moderate
Med. – medium
Sbks – sub angular blocky structure
Absk – angular blocky structure
Smt. – smooth
Bdr. – boundary
Com. – common
Fn. – fine