Characterisation, classification and suitability evaluation of agricultural soils of selected communities located along various river systems in Bayelsa State, Southern Nigeria

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ABSTRACT

The alluvial soils of Bayelsa State have high agricultural potentials but current information and knowledge on their characteristics, capabilities and suitability are inadequate and obsolete. Hence, efficient management of the soils for increased and sustainable crop production is constrained. Therefore, this study was conducted to characterize, classify and evaluate the suitability of agricultural soils of selected communities along different river systems in Bayelsa State, Nigeria. Detailed soil survey was conducted in six locations: Elemebiri (ELM), Odoni (ODN), Trofani (TFN), Odi (ODI), Koroama (KRM) and Niger Delta University (NDU), representing a total of 18 soil mapping units (SMUs). Three profile pits were dug per location, soils were morphologically described, samples collected at different horizons for physico-chemical, mineralogical analyses, and classified according to USDA Soil Taxonomy and FAO World Reference Base. Land and fertility capability classification (LCC and FCC) were assessed and suitability of soils for maize, upland rice, cassava, oil palm, plantain, rubber and coconut cultivation evaluated. Fertility and site quality were evaluated using Soil Fertility Index (SFI) and Soil Evaluation Factor (SEF) techniques. Principal Component Analysis (PCA) was used to detect important soil parameters that influence fertility while soil physical and chemical characteristics were correlated using Pearson correlation.

Soils were of alluvial origin, stratified, with redoximorphic features occurring at different depths; sometimes reaching A-horizon with subsurface grayization. Soils with annual alluvial enrichment were structurally very weak. Textural classification was predominantly silt loam except sandy loam and loamy sand observed in ELM3 and TFN3. Soils were strongly acid to neutral [pH(H_2O), 4.94-7.00], very low to medium organic C (0.01-5.25%) and total N (0.01-0.45%) contents, low to moderate available P (0.6-22 mg/kg), and low in ECEC (1.49-8.06 cmol/kg) with exchange sites dominated by Ca^{2+}. Quartz dominated the identified mineral phases followed by kaolinite while ferromagnesian minerals contents were low. Soils in ELM1, TFN1, KRM2, ODI2 and NDU2 were classified as Aquic Dystrudepts; ELM2, TFN2, KRM3 and ODN2, (Typic Epiaquepts); ODN1 and ODI1, (Humic Dystrudepts); KRM1 and NDU1 (Udic Dystropepts); ELM3 (Eutic Udifluvents); ODN3 (Fluvaquentic Epiaquepts); TFN3 (Aquic Udifluvents), ODI3 (Aeric Epiaquepts) and NDU3 (Fluvaquentic Endoaquepts), respectively. The ELM3 and TFN3 soils were Haplic-Fluvic Fluvisol and Haplic Fluvisol, respectively while all remaining MUs were Fluvic Cambisol. The LCC grouped all the soils into class II except

NDU3 but land capability index added classes I, III and IV. The FCC classed all the soils as acidic, 78% as low in nutrient reserve, 50% as deficient in K$^+$ and 39% hydromorphic. The PCA revealed the eight most important components with factor loading contributions, acidity dominating PC1. Clay and silt correlated positively ($r = 0.40^{***}$) while sand correlated negatively with clay ($r = -0.68^{***}$) and silt ($r = -0.94^{***}$). The soils were fertile, not currently suitable but potentially suitable for maize and plantain, marginally suitable for upland rice and oil palm, moderately suitable for cassava and moderately to highly suitable for coconut. The major limitations were wetness, flooding, and soil chemical and physical fertility. Improved drainage, liming and adequate fertilization practices are recommended to enhance increased and sustainable crop production on the soils.

Keywords: Capability Index, Soil Fertility Index, Clay Mineralogy, Redoximorphic Characteristictics, Floodplain Soils.

DECLARATION

I declare that this research project titled “Characterisation. Classification and Suitability Evaluation of Agricultural Soils of Selected Communities Located Along Various River Systems in Bayelsa State. Southern Nigeria” is my own work and all the sources I have used or quoted are indicated and acknowledged by means of complete referencing and that this work has not been submitted for any other degree in another institution.

Achimota A. Dickson

DEDICATION

This thesis is dedicated to the living memory of my late mother, Mrs Pamowari B. Saiyou, who passed to glory on the 2nd of March, 2016 while I was at Abuja, Nigeria, to collect my study permit from the South African Embassy. May her gentle soul find rest in the bosom of our Lord, Jesus Christ, Amen.

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CHAPTER ONE
INTRODUCTION

1.1 Background to the Study

The effective take-off of the economic, industrial and technological development of any nation hinges on a sound agricultural base. Agricultural development is dependent on the soil around which all investments revolve (Blum, 2013; Usman and Kundiri, 2016). Soils in any ecosystem, play five key roles (Brady and Weil, 2005) which are namely: (a) support the growth of higher plants, by providing a medium for plant roots and supplying nutrient elements essential for plant growth; (b) influence water movement in the hydrologic system; (c) function as nature's recycling system for nutrients; (d) provide habitats for a myriad of living organisms; and (e) play an important role as an engineering medium. Therefore, planning for improved agricultural productivity, should in fact, involve planning for sustainable soil use (Blum, 2013; Usman and Kundiri, 2016). Past and present failures of agricultural development in many Sub-Saharan Africa (SSA) countries have been traced to inadequate consideration given to soil. Hence, the widespread abuses of soils in the SSA which include improper land clearing and development practices for agriculture, road, infrastructural development, housing and industrial estates construction, quarrying and mining, over-grazing (Blum, 2013; Tully et al., 2015), improper use of chemicals and blanket fertilizer application without soil testing (Seitzinger et al., 2010; Abdi et al., 2013) resulting in land degradation. The situation is further exacerbated by smallholder farmers' poor management practice of low to sub-optimal use of fertilizer inputs (Lal, 2001; Kutu and Asiwe, 2010; Kutu and Diko, 2011) that neither mitigate the nutrient mining process nor adequately guarantee the restoration of the fertility status (Shisanya et al., 2009). The resultant effect of land degradation encompasses desertification, erosion, siltation and flooding, soil acidity, salinity and alkalinity, leading to low crop yields and crop failures.

Greenland (1981) and more recently, UNEP (2012), revealed that a combination of proper management with necessary inputs can produce high yields of many crops in the humid tropical soils and those of Sub-Saharan Africa, respectively. However, the cost of the inputs required and measures needed for proper management of soils differ considerably in different regions of the humid tropics and for different soils within a region. Therefore, if soils of the humid tropics are to continue to produce sufficient crops to sustain the increasing population, it is essential that the soils be properly and fully characterized, classified, and their suitability evaluated (Kefas et al., 2016). In Nigeria, the commonly used soil classification systems are the USDA Soil Taxonomy and the World Reference Base systems.

According to Esu (2005), soil characterization study is a major building block for understanding the soil, classifying it and getting the best understanding of the environment. Ogunkunle (2005), reported that soil characterization provides information for the understanding of the physical, chemical, mineralogical and microbiological properties of soils we depend on to grow crops, sustain forests and grasslands as well as support homes and society structure. Soil characterization provides the basic information necessary to create functional soil classification schemes, and assess soil fertility in order to unravel unique soil problems in any ecosystem (Lekwa et al., 2004). On the other hand, soil classification organizes knowledge, facilitates transfer of experience and technology from one place to another and compares soil properties (Sharu et al., 2013). Atkinson (1993) defined classification of soil as a scheme for separating soils into broad groups, each with broadly similar characteristics. The basic goal of soil classification is to organize knowledge so that the soil properties are remembered and their relationships understood more easily for specific objectives (Esu, 2010; Zata et al., 2013). Soil classification like any other system of classifying objects, ideas or concepts provides a framework for the storage and retrieval of soil information. It also gives room for the retention of useful soil information collected in the past for the acquisition of new ones. When soil classification is properly carried out, it can help organize knowledge of extremely complex landscape features into units that can be readily understood and manipulated by man (Esu, 2010). Ukut et al. (2014) emphasized that soil characterization and classification contribute to the alleviation of the adverse effect of soil diversity and aid precision agriculture.

Modern agriculture requires that farmers have direct or indirect knowledge of the soil nutrient status and other chemical and physical characteristics as well as the capability of the soils for the intended use (Dickson et al., 2002). Such knowledge enables farmers to make informed choices of crops and/or livestock to be raised that are economically and technically feasible (Harrison, 1987). Therefore the need to incorporate land suitability evaluation into soil characterization and classification studies prior to crop cultivation and other agricultural land uses, cannot be over-emphasized.

Suitability evaluation of land is an inventory that makes data relevant and applicable to an existing land the problem (Esu, 2010). Furthermore, several authors (Olaleye et al., 2002;

Fasina and Adeyanju, 2006), opined that in addition to the technical feasibility of land for any particular use, the land use to the farmer must be socially acceptable and economically feasible and viable. Otherwise recommendations from soil characterization, classification and land suitability evaluation would not be perceived as worthwhile innovations by the recipient farmer (Dickson et al., 2002).

1.2 Problem Statement

Given the nature of the materials from which soils in Bayelsa State are formed, the soils are expected to be among the most productive lands in the Niger Delta region. However, they present fertility challenges to the local farmers and this has prevented agriculture from being developed to a significant level. Consequently, the state cannot meet the food needs of the populace, resulting in dependence on the neighbouring Delta and other states for food supplies. Also, scarcity of land for agriculture remains a major constraint as the area is inherently lacking in relatively well-drained land for agriculture, due to the many rivers, rivulets and creeks criss-crossing the area (UNDP, 2006). Moreover, other development activities (urban expansion, oil exploration and exploitation activities) seriously compete with agriculture for land, coupled with the fact that these activities have caused colossal damage to the soils due to oil pollution and river bank erosion. Information and knowledge on the current nutrient status, capability and potential suitability of the land for various uses are inadequate and obsolete which makes the management of the soils difficult.

1.3 Significance of the Study

For decades, the Nigerian economy has been dependent on crude oil. With the dwindling oil resources, there is a drive to diversify the economy by both the federal and state governments with agriculture in focus. However, scarcity of land for agriculture remains a major constraint in the Niger Delta as the area is inherently lacking in dry and relatively well-drained land for agriculture. Also, urbanization and industrialization seriously competes with agriculture for land in Bayelsa State. Furthermore, increased agricultural production cannot be achieved without current information on the soils which can be achieved through soil characterization and classification. Therefore, there is need for soil characterization and classification to be augmented with suitability evaluation to provide the much needed current and complete soil information. Land suitability evaluation will not only provide information on the suitability of soils for alternative uses, but including cropping and other agricultural practices that are technically feasible on the land. It also provides clear information about the limitations of the land for various uses with management options to improve productivity which soil classification by itself cannot provide.

Furthermore, results of this study will provide the much needed current and complete technical soil information that will be useful not only to farming communities but agricultural stakeholders and land use planners, etc. It will also provide leads for future research in the areas of agronomy, crop science, forestry, etc.

1.4 Research Questions

The following research questions will be addressed in this study:

i. Do the morphological, physical and chemical characteristics of the commonly cultivated alluvial soils in Bayelsa State affect their productivity for sustainable agriculture?
ii. Using the standard procedures of USDA Soil Taxonomy and the World Reference Base system, which soil classes constitute the commonly cultivated alluvial soils of Bayelsa State?
iii. What are the mineralogical components of the soils?
iv. How suitable are the soils for rain-fed agriculture using LCC and FCC systems?
v. How suitable are the soils of the study area for the cultivation of cassava, maize, upland rice, banana, oil palm, coconut and rubber?
vi. What are the limitations of these soils for agricultural production?
vii. What are the appropriate management techniques that could be applied to enhance the sustainable productivity of these soils?

1.5 Research Aim and Objectives

The aim of the research was to characterize, classify and evaluate the suitability of agricultural soils of selected communities along different river systems in Bayelsa State, Nigeria.

1.5.1 Specific Objectives

The specific objectives of this study were to:

i. examine the morphological, physical and chemical characteristics of commonly cultivated alluvial soils along a north-south transect in Bayelsa State;
ii. classify the soils according to the standard procedures of USDA Soil Taxonomy and the World Reference Base system;

iii. examine the mineralogical composition of the soils;
iv. evaluate the suitability of the soils for rain-fed agriculture using LCC and FCC;
v. evaluate suitability of the soils (FAO, 1976) for the cultivation of cassava, maize, upland rice, banana, oil palm, coconut and rubber;
vi. determine the fertility limitations of the soils; and
vii. provide recommendation on appropriate management strategies that will enhance sustainable productivity of the soils.

1.6 Hypotheses

The study validated the following null hypotheses:

i. Ho= There are no differences in the morphological, physical and chemical characteristics of commonly cultivated alluvial soils in Bayelsa State.
ii. Ho= There are no differences in the soil classes of the commonly cultivated alluvial soils of Bayelsa State using the standard procedures of USDA Soil Taxonomy and the World Reference Base system.
iii. Ho= The mineralogical composition of the soils are not different.

iv. Ho= The suitability of the soils for rain-fed agriculture using LCC and FCC are not different.
v. Ho= There are no differences in suitability of the soils (FAO, 1976) for the cultivation of cassava, maize, upland rice, banana, oil palm, coconut and rubber.
vi. Ho= There are no limitations in the soils.
vii. Ho= There are no differences in management techniques that will enhance sustainable productivity of the soils.

CHAPTER TWO

LITERATURE REVIEW

2.1 Soil Characterization and Classification

One major limiting factor for agricultural development in Nigeria is the lack of information on soil and land characteristics (Atofarati et al., 2012). UNEP (2012) reported that Sub-Saharan African soils, if given proper management and necessary input can produce high yields of many crops. However, the cost of the inputs required and measures needed for their proper management differ considerably with different regions of the humid tropics and for different soils within a region. Thus, if these areas are to be utilized successfully, it is necessary to determine the relationship between established soil features and methods of land use. Similarly, Dickson et al. (2002), opined that modern agriculture requires farmers to have direct or indirect knowledge of the soil nutrient status and other chemical and physical characteristics as well as the capability of the soils to be utilized. Such knowledge enables farmers to make informed choices of crops and/or livestock to be raised that are technically feasible (Harrison, 1987). Thus the need for soil characterization, classification and land suitability evaluation studies prior to crop cultivation and other agricultural land uses cannot be over-emphasized.

Soil types differ and exhibits diverse behaviour in Nigeria due to differences in micro-morphological, morphological, physical, chemical and mineralogical properties (Esu et al., 2008; Atofarati et al., 2012; Ukut et al., 2014). These variations are attributed to variations in soil forming factors and processes operating on different parent materials, under different climatic, topographic, and biological conditions over varying periods of time (Soil Survey Staff, 1993). Parent materials, drainage and topography are reported to influence the morphological, physicochemical and mineralogical properties of soils (Akpan-Idiok et al., 2012). According to Housebeek et al. (2000) and Esu et al. (2008), soil topography plays a major role in influencing pedogenesis and in the process that dictates the distribution and use of soils on the landscape. This is because landscape position influences rainfall, drainage and erosion. Water velocity on sloppy land or water body affect deposition of materials in suspension, the larger sized particles, like sand, are the first to drop out of suspension, fine clay particles are carried further away from the originating point of the material before deposition. Topography thus has influence on soil chemical and physical properties and also on pattern of soil distribution over landscape (Kalivas et al., 2002; Esu et al., 2008). Soils on hill slopes differ from those at summits or valleys in terms of moisture distribution, soil depth, cation distribution and organic matter contents Asadu et al. (2012).

Different soil types support different land use and require different management options for sustainable productivity (Ogunkunle and Babalola, 1986). The frequent occurrence of soils in a well-defined and fairly regular sequence is called toposequence. In these sequences, properties (morphological, physical and chemical) and the potential for crop production often vary from crest to valley bottom due to differences in soil types (Nuga et al., 2006). The distribution of individual soil series on a toposequence as well as the spatial distribution of the toposequence itself has considerable influence on the land use pattern of an area. Tuong et al. (2000) reported that most lowlands are characterized by an undulating topography and high spatial variability of environmental conditions. Boling et al. (2008) reported for Southeast Asia that farmers grow their crop in bunded fields on gently sloping land with differences in elevation often a few metres only. In Nigeria, farmers often cultivate the entire toposequence. Even small differences in elevation, however, may lead to differentiation in soil properties and hydrological conditions (Hseu and Chen, 2001; Tsubo et al., 2006). Therefore, the degree of variability in crops stands is high and crop fields tend to decrease from fertile valley bottom soil to generally infertile uplands in Nigeria. In spite of the recorded variability in soil properties and crop yield along the toposequence, recommendation for agronomic practices are often made to farmers without due consideration for specific locations that might influence management options for greater productivity (Oluwatosin et al., 2001).

Nutrient status and soil properties are related to topography of the land area. Osedeke et al. (2005) reported differences in quantity and forms of sesquioxides as influenced by geomorphic positions. Soils of the profiles at higher slopes are dominated by crystalline forms of iron (Fe) and aluminum (Al) –oxides while the soils of the valley bottom are dominated by the amorphous forms of Fe and Al. Similar to the Nigerian situation, Ashenafi et al. (2010) and Beyene (2011) asserted that soil types and characteristics in Ethiopia show great variations across regions owing to the country's wide range of topographic, geologic and climatic features. Furthermore, Ashenafi et al. (2010) and Beyene (2011) in separate studies reported that topographic position largely governs change in soil types and characteristics of soils. Such variation in soil types and characteristics influence not only their pedogenesis and development, but also the use and productivity of soils. Therefore, the need to provide soil information is becoming more demanding than before, since the problem arising from misuse of land is resulting in land degradation (Atofarati et al., 2012).

In the Meander Belt geomorphic region of the Bayelsa State, agricultural production is blanketly carried out mainly on alluvial soils (the upper slope, middle slope, lower slope and back swamps of major rivers and on channels of present active rivers without soil technical information guiding the use. It has been reported that the diversity nature of soil is a major reason behind allocation of land to wrong uses. Consequently, increasing demographic pressures places increasing demand on land resources (Atofarati et al., 2012; Alemayehu et al., 2014) through practices such as deforestation and expansion of croplands, continuous cultivation including sloppy landscapes and marginal areas. The clearing of soils on sloppy landscape and tilling soil without proper soil management practices put in place, leading to land degradation and reduction in the productive capacities of soils. Greenland (1981) therefore traced the failure of agricultural development projects within countries in Sub-Saharan Africa to inadequate consideration given to soil which was confirmed by Zata et al. (2013). Hence, the widespread abuses of soils in SSA exist through bad land clearing for the development for agriculture, road, housing and industrial estates construction, quarrying and mining, grazing, improper use of chemicals and fertilizers without soil testing, etc. The resultant effect is land degradation through desertification, erosion, siltation/flooding, soil acidity, salinity and alkalinity, leading to low crop yields and crop failures. Thus, studying to understand soil properties and their distribution over a landscape is crucial for developing soil management practices that will maintain the productive potential of soil. Obviously, the need to identify and classify soils for proper management taking into consideration the relationship between location in the landscape and soil properties cannot be overemphasized.

Soil characterization data is an aid in the correct classification of the soil and enable other scientists place the soils in their appropriate taxonomies or classification systems and serve as a basis for more detailed evaluation of the soil as well as gather preliminary information on nutrient, physical or other limitations needed to produce a capability class. Esu (2005) considered soil characterization study as a major building block for understanding the soil, classifying it and getting the best understanding of the environment. Climate, topography, hydrology, soil conditions and socio-economic factors determine to a great extent which crops can be grown in any ecological zone (Olaleye et al., 2002; Udoh et al., 2006). The information can be obtained during soil characterization. Certain soil features relate to the inherent ability of soil to support plant growth including nutrient status and physical features such as water-retention characteristics (Greenland, 1981). According to Sharu et al. (2013), agriculture is the predominant economic activity in Nigeria and due to agricultural development and increasing demand for experimental data in Nigeria, much work is being carried out on soil characterization.

Soil characterization provides the necessary information for the understanding of the physical, chemical, mineralogical and microbiological properties of soils which we depend on to grow crops, sustain forests and grasslands as well as support homes and society structure (Ogunkunle, 2005). It provides the basic information necessary to create functional soil classification schemes, and assess soil fertility in order to unravel some unique soil problems in an ecosystem (Lekwa et al., 2004). Moreover, classification helps to organize knowledge, facilitates the transfer of experience and technology from one place to another and helps to compare soil properties (Sharu et al., 2013). Soil characterization and classification contribute to the alleviation of the adverse effect of soil diversity and aid precision agriculture (Ukut et al., 2014). The coupling of soil characterization, classification and mapping provides a powerful resource for the benefit of mankind especially in the area of food security and environmental sustainability (Sharu et al., 2013) Soil characterization and classification is the main information source for precision agriculture, land use planning and management, as characterization and classification provide information for the understanding of micro-morphological, morphological, physical, chemical, and mineralogical and microbiological properties of soil (Ukut et al., 2014). Studies have shown that physico-chemical and mineralogical properties of floodplain soils are essential for the sustainability classification of soils for crop production (Ogban and Babalola, 2009; Egbuchua and Ojobor, 2011; Ayalew and Beneye, 2012). Moreover, mineralogical study helps in the evaluation of mineralogical impacts on soil productivity, mineral transformation, and the degree of soil development and classification of soils at the family level under the USDA Soil Taxonomy (Hossain et al., 2011). Characterization of floodplain soils is important as this enables evaluation of the potentials of soil for effective agricultural production (Akpan-Idiok and Ogbaji, 2013).

The capacity of soil to function can be reflected by measured soil morphological, physical and chemical properties (Buol et al., 2003). These characteristics allow scientists to interpret how the ecosystem function and make recommendations for soil use that have minimal negative impact on the ecosystem. Soil morphological, physical and chemical properties, however, are largely affected by land use/management. Land management/use for crop production in landscapes influence runoff, soil erosion and drainage, which result in varying physical and chemical properties (Mishra et al., 2004). Soil characterization helps to determine the type of crop and land use best suited to a location. It also helps in the process of documenting soil properties of a particular location, which is essential for the successful transfer of research results to other locations (Buol et al., 2003). Characterization of soils is thus fundamental to all soil studies as it is a useful tool for soil classification, which is done based on soil properties.

Classification of soil is a scheme for separating soils into broad groups, each with broadly similar characteristic (Atkinson, 1993). The basic goal of soil classification is to organize knowledge so that the soil properties may be remembered and their relationships understood more easily for specific objectives (Esu, 2010; Zata et al., 2013). Soil classification like any other system of classifying objects, ideas or concepts provides a framework for the storage and retrieval of soil information. It also gives room for the retention of useful soil information collected in the past for the acquisition of new ones. When classification is properly carried out, it can help organize knowledge of extremely complex landscape features into units that can be readily understood and manipulated by man (Esu, 2010). In Rwanda, Habarurema and Steiner (1997) reported that nearly every development project undertakes some pedological studies in order to describe soils in the project region. In Nigeria, several authors (Dickson et al., 2002; Ojanuga et al., 2003; Olaleye et al., 2002; Fasina, 2008; Ande, 2011; Akpan-Idiok and Ogbaji, 2013) have carried out characterization and classification of soils of various origins including soils derived from alluvial parent materials.

Akpan-Idiok and Antigha (2009) for instance, classified floodplain soils in Northern Cross River State of Nigeria as Vertic fluvaquents and Fluvaquentic humaquepts under the USDA soil classification system. The corresponding classes under the World Reference Base of Soil Resources were dystric gleysols or Gleyic cambisols. In a separate study, Akpan-Idiok and Ogbaji (2013) classified Onwu River floodplain soils of Akraba soil unit I as Typic Kandiudults (Soil Survey Staff, 2006) and Haplic Acrisols (FAO, 2006) criteria. The soils in the Akraba soil unit II were classified as Flaquentic Humaquepts in the USDA system and Gleyic/Vertic cambisols in the (FAO, 2006) system. Dickson et al. (2002) classified four well drained soils of the levee crest of Oruma in Bayelsa, southern Nigeria as Typic Eutropept, Udic dystropept, Dystric Udipsamment and Eutric Udipsamment/Eutric Cambisol, Dystric Cambisol, Dystric Fluvisol and Eutric Regosol. The moderately well drained soils of the levee slope were classified as Aquic Eutropept/Eutric Gleysol. For the poorly drained floodplain and back swamp soils of Oruma, Dickson et al. (2002), classified them as Eutric Fluvaquept and Vertic Tropaquept/ Eutric Fluvisol and Verti-Eutric Gleysol In the following section, technical classification methods would be considered.

2.2 Soil Classification Schemes and Systems of Soil Classification

The organized study of soils is rather young, having begun in the 1870s when the Russian scientist V. V. Dukochaev and his associates first conceived the idea that soils exist as natural bodies in nature (Glinka, 1927). Russian Soil Scientists soon developed a system for classifying natural soil bodies, but poor international communications and reluctance of some scientists to acknowledge such radical ideas delayed the acceptance of the natural body concept by scientists in Europe and the United States (Brady and Weil, 2005). It was not until the late 1920s that C. F. Marbut of the U.S. Department of Agriculture, one of the few scientists who grasped the concept of soils as natural bodies, developed a soil classification scheme based on these principles.

The earliest soil classification systems according to Bockheim et al. (2005) were based mainly on geomorphological and geological concepts such as the mineralogical and chemical properties of the parent materials. Soil classification schemes actually began with Dokucheav of Russia and continued in the United States (Marbut, 1928; Baldwin et al., 1938), which are based on the zonality concept. Based on the zonality concept, the United States soils were divided into three broad orders. Soils in the zonal ("normal"soils) order contained well-developed characteristics reflecting the predominant influence of climate and vegetation on well-drained stable sites; soils in the intrazonal order are well developed but had characteristics reflecting local factors such as relief, parent materials, or age; soils in the azonal order are poorly developed (Bockheim et al., 2005). In the evolutionary approach to soil classification developed by Polynov (1923) and Kovda et al. (1967), higher categories were based on different geochemical mass and energy transfers, as evidenced by major stages and trends in weathering, humus and clay mineral formation. Elements of the evolutionary approach are embedded in the French soil classification system (Bockheim et al., 2005). The earlier and the current soil classification schemes in Russia are based on the concept of "genetic profiles" (Goryachkin et al., 2003). The highest categories in the current Russian system are distinguished on the basis of conjugated system of genetic soil horizons that make up the soil profile. Soil horizon definitions are based on the integrity of substantive soil properties dictated by soil-forming processes.

From the inception of crop cultivation activities. humans observed soil differences and classified them. grouping soils according to their suitability for different uses by giving them descriptive names such as black cotton soils. rice soils. or olive soils. Other soil names carry geological connotations. suggesting the parent materials from which the soils are formed: limestone soils. piedmont soils. and alluvial soils. Such terms may convey some valuable meaning to local users. but they are inadequate in helping to organize scientific knowledge of soils. or for defining the relationships among the soils of the world. Two broad systems of soil classification are generally recognized: Natural or Taxonomic Classification also termed Scientific Classification and Technical Classification.

2.2.1: Natural Classification of Soils

Natural Classification system is purposed. in so far as possible. to bring out relationships of the most important properties of the population being classified without references to any single specified and applied objective. In a Natural Classification system. all the attributes of a population are considered and those which have the greatest number of covariant or associated characteristics are selected as the ones to define and separate the various classes. According to Esu (2010) most soil classification systems try to approach a natural classification system as an ideal. though some more weight tend to be given to properties of higher agricultural relevance. There are a number of natural classification systems designed and used in different parts of the world. The refined Russian system with heavy emphasis on factors of soil formation continues to be used. not only in countries of the former Soviet Union. but in some other European countries as well. Also. classification systems have been developed and used in France. China. Belgium. the United Kingdom. Australia. Canada. Brazil and South Africa. each of them designed to meet the needs of the particular country or region (Brady and Weil. 2005). In the United States. Marbut's 1927 classification scheme was improved in 1935. 1938. and 1949. the later revision being widely used for about 25 years. In 1951. the Soil Survey Staff of the U.S. Department of Agriculture began a cooperative effort with soil scientists in the United States and other countries to develop a new comprehensive system of soil classification. which has been in use in the United States since 1965. and it is used. at least to some degree. by scientists in some 65 other countries (Brady and Weil. 2005). At the initiative of FAO. the United Nations Educational. Scientific. and Cultural Organization (UNESCO). the United Nations Environment Programme (UNEP). and the International Society of Soil Science (ISSS). the World Reference Base for Soil Resources (WRB) is produced and adopted by the ISSS Council as the officially recommended terminology to name and classify soils in 1998 and has since become the official reference soil nomenclature and soil classification system for the European Commission (FAO/ISRIC, 2006). According to Esu (2010), the most common examples of a natural soil classification system are the USDA Soil Taxonomy System and the FAO-UNESCO Soil Classification System currently named the World Reference Base for Soil Resources. These two systems which have received worldwide attention are most commonly used in Nigeria.

The basic principles of soil classification which are the foundation of global soil classification systems such as USDA Soil Taxonomy and the World Reference Base (WRB) that are commonly used in Nigeria are summarized by Cline (1949). In the Soil Taxonomy and WRB systems, soils are classified based on diagnostic surface horizons (epipedons), subsurface horizons, and other characteristics. Category of Soil Taxonomy describes a set of classes that are defined approximately at the same level of generalization or abstraction and includes all soils. Soils are classified at six levels in a hierarchical system in the Soil Taxonomy, from the highest to lowest: orders, suborders, great groups, subgroups, families and series (Soil Survey Staff, 1999). Soil orders are differentiated on the basis of soil processes as indicated by the presence or absence of diagnostic horizons and materials: suborders are distinguished primarily from soil climate in 8 out of the 12 orders: and great groups are subdivided on the basis of several criteria. Subgroups are subdivided according to the central concept of the great group versus intergradation to other taxa or extra- gradations to 'not soil'. Families are separated into particle-size, mineralogy, and soil temperature classes while series is based on the kind and arrangement of horizons. Soil series are subdivided into phases on the basis of surface stoniness, slope steepness, amount of previous erosion or other attributes that are not diagnostic in Soil Taxonomy, but are important to land use (Bockheim et al., 2005).

In the WRB for Soil Resources (FAO/ISRIC, 2006) system, soils are also classified on the basis of diagnostic surface horizons (epipedons), subsurface horizons and other diagnostic characteristics (Bockheim et al., 2005). It is interesting to note that the first systems of soil classification are developed in environments strongly influenced by glacial and periglacial phenomena (Russia, Central and Western Europe, North America) and where geologically young parent materials showed the mark of recent climatic conditions (Spaargaren, 2001). As a result, these classification systems are difficult to apply to soils formed on older landscapes and from strongly weathered materials in tropical and subtropical regions (Dudal, 1996). The

1950s witnessed intensification of international communications and the expansion of soil surveys, both in temperate and tropical areas, which greatly enhanced the overall knowledge of the soil cover. Classification systems developed are aimed at embracing the full spectrum of the soil continuum. WRB which aims to provide scientific depth and background to FAO's revised legend of the Soil Map of the World incorporated the latest knowledge relating to the global soil resources and interrelationships (Spaargaren, 2001). WRB comprise of two tiers of categorical details: (1) the "Reference Base" which is limited to the first level only and having 32 Reference Soil Groups (RSGs); (2) the "WRB Classification System" consisting of combinations of a set of prefix and suffix qualifiers that are uniquely defined and added to the name of the RSG, allowing very precise characterization and classification of individual soil profiles. In describing and defining the RSGs and soil units of the WRB, use is made of soil characteristics, properties and horizons, which in combination define soils and their interrelationships. The RSGs are allocated to sets on the basis of *dominant identifiers*, i.e., the soil forming factors or processes that most clearly condition the soil formation.

2.2.1.1: Limitations of Soil Classification

Technical information from soil characterization and classification in most cases is effectively utilized for development projects and extension services. In Rwanda, nearly every development project undertaken, according to Habarurema and Steiner (1997), involved some pedological studies in order to describe soils in the project region. Classification systems employed in Rwanda included the FAO World soil legend, the USDA Soil Taxonomy, the French soil classification, etc. Whereas the importance of such studies and the value of the data base created cannot be questioned, their usefulness for technology development and extension is limited, especially with regard to the genetically oriented soil classifications (Habarurema and Steiner, 1997). Similarly, it has been observed that for land development projects in the tropics, only limited information from soil surveys is being used (Woode, 1981). In Zambia, land evaluation for agricultural use is conducted after an area has been surveyed to determine the nature of the land resources. However, very few land users ever read the reports, other than technical experts. The low usage of the reports among other factors is attributed to the highly technical language used in the reports (Woode, 1981). In the light of the low usage of very technical information, it was emphasized that what is needed by farmers and extensionists is not so much soil classification but land evaluation, preferably using less sophisticated terms for specific soil management and cropping systems. Such systems in the opinion of Habarurema and Steiner (1997) should allow the identification of soil types or classes by relatively simple means, such as yields (fertility), indicator plants and soil position, as well as simple soil characteristics (smell, colour, texture, depth, etc.), to facilitate real dialogue between farmers, extensionists and researchers. Soil surveys are indeed carried out, but their application is confined to two functions: hazard avoidance – for example, preventing the cultivation of steep slopes; and the allocation of land to different kinds of use – arable, grazing, forestry, conservation, etc. Accordingly, much of the detailed information on soil types and their distribution, gathered in the field at no small effort and expense, are never used in agricultural planning and economic assessment. To obtain the much needed data by agriculturists, economists and development planners during soil surveys, Young and Goldsmith (1977) suggested that proportionately less time should be spent on basic soil mapping, and more time spent on field activities directed towards land evaluation. In particular, soil-specific estimates of crop yields and other aspects of land productivity should form part of a soil survey. Land soil suitability evaluation is part of the inventory and evaluation makes the data relevant and applicable to the problem at hand: it is created to solve a specific problem (Esu, 2010). Harrison (1987) opined that in addition to the technical feasibility of land for any particular use, the land use to the farmer must be socially acceptable and economically feasible and viable. Otherwise recommendations from soil characterization, classification and land suitability evaluation will not be perceived as worthwhile innovations by the recipient farmer (Dickson et al., 2002).

2.2.2: Technical Classification of Soils

Technical Classification, on the other hand, is one which is aimed at a specific, applied practical purpose. The classification of soils for agriculture or engineering purposes or even the more specific classification of soils for maize production or rainfed- and/or irrigated agriculture are examples of technical classification. The most common examples of a technical classification system widely used worldwide are the USDA Land Capability Classification System and the FAO Land Suitability Classification for rainfed agriculture (Esu, 2010). In the following section, Land Capability Classification, Fertility Capability Classification, and the Framework for Evaluation (FAO, 1976) are discussed.

2.2.2.1 Land Capability Classification Systems

Natural classification systems indeed, are very helpful in the understanding and remembering of the properties and behaviour of soils and play vital role for communication, among soil scientists and between them and other agriculturists or professionals that deal with soil both within a given region and/or from one ecological region to another. It is unfortunate to note that taxanomic names often convey very little or no meaningful information to many users of land, especially the farmers. Moreover, the ultimate interest of most land users is in the response of soils to management and manipulation including:

a. The use to which a piece of land is best suited or the relative suitability of a piece of land for alternative uses;
b. The crops that are most suited and most profitable to be raised on that land;
c. The limitation(s) of the land to a particular use or several alternative uses and how such limitation(s) can be overcome (Ogunkunle and Babalola, 1986).

Consequent upon these facts, for the present soil survey information to be made useful to the people of Bayelsa State and other land users in the area, the information generated must be translated into units with practical implications for use of the soils characterized and classified. Only land evaluation can inform farmers how suitable their land is, in terms of soil limitations, crop yield or profit (Olaleye et al., 2002). FAO (1983) defined land evaluation as the assessment of land performance when used for specific purposes. For land evaluation to be meaningful to the end user of land, the evaluation needs to be made in terms relevant to the conditions of the country or ecological region of interest. In as much as the principles are the same, the relevant land qualities and their critical values for determining suitability classes differ to a great extent, between countries or ecological regions. FAO (1976), defined land as an area of the earth's surface, the characteristics of which embraced all reasonably stable or predictably cyclic attributes of the biosphere (vertically) above and below this area, including those of the atmosphere, soil, geology, hydrology, plant and animal populations, and the result of past and present activity. Land classification involves assigning classes, categories, or values to areas of the earth's surface (tracts of land) generally excluding water surface, for immediate or future use. The project, product or proposal resulting from this activity may be generally referred to as land classification. Land classification thus deals with land use, land evaluation, land systems, land capability, land inventory and terrain evaluation (Esu, 2010). Land classification is also concerned with soil survey, soil survey interpretation, and soil capability, suitability and limitations. Many kinds of resources inventories such as vegetative, climatic, geologic, topographic, hydrologic, economic, sociologic, and demographic surveys relate to land classification. Thus, a standard soil survey map shows the different kinds of soil that are significant and their location in relation to other features of the landscape.

Land evaluation is a process of estimating the potential of land for alternative kinds of use or the prediction of land performance when the land is used for specified purposes. Land evaluation is concerned with the assessment of land performance when used for specific purposes. It involves the execution and interpretation of basic surveys of climate, soils, vegetation and other aspects of land in terms of the requirements for alternative forms of land use (FAO, 1976). Land evaluation is, therefore, a key tool for land use planning both for individual land users such as farmers, or by groups of land users such as co-operatives or villages or by society as a whole as represented by governments. Land evaluation is considered to be an interface between land resources surveys and land use planning and management. Conducting a land evaluation involves the integration of a number of factors including soil properties, the ways in which soils react to various farming methods, climatic variables, topography, geology and geomorphology and social and technical consideration (Adesemuyi, 2014; Nahusenay and Kibebew, 2015). To be valuable in planning, the range of land uses considered has to be limited to those which are relevant within the physical, economic and social context of the area considered, and the comparison must incorporate economic considerations (Gong et al., 2012; Singh, 2012). The results of a land evaluation are a prediction of the use potential of land for several actual or potential land-use systems. In other words, land evaluation predicts how each land area will behave if it is used according to each of these systems (Rossiter and Van Wambeke, 1997).

Land suitability classification is an interpretative grouping made primarily for agricultural purposes. In fact, land suitability evaluation is an examination process of the degree of land suitability for specific utilization type (Sys et al., 1991a; 1991b) and/or description method or estimation of potential land productivity (Sys et al., 1991b). FAO (1976) defined land suitability as the fitness of a given tract of land for a specified kind of land use or the degree of appropriateness of land for a certain use. Ritung et al. (2007) reported that in any engineering activity, it is unwise to invest too much in the early stages of a project without being sure that the methods to be employed will work. Hence, 'rapid prototyping', i.e., the idea of producing a working prototype to illustrate the essential features of the proposed engineering solution as quickly as possible. This gives the opportunity to the client to react to the ideas-made-visible in the prototype. Applied to land evaluation, it implies that it is often more cost-effective to build simplified models incorporating the most critical factors for a selected set of the most important or best understood land uses, identify and enter data for a set of the most important or most representative evaluation units, and assure that this evaluation gives reasonable and useful results. It is possible to map land suitability for rainfed maize, sorghum or for surface irrigation in general or for sprinkler irrigated sugarcane. This is in contrast to the USDA land capability classification system, which is a more broad classification of soils for widely defined land uses and management systems such as agriculture, forestry, wildlife and aesthetic appreciation (Esu, 2010). Soils are usually grouped in different ways according to the specific needs of the map user. Soils are grouped in different ways through several systems of land capability/suitability evaluation methods, some of which are discussed below.

2.2.2.1.1: Land Capability Classification

The land capability classification system devised by the U.S. Department of Agriculture has been used since in the 1950s to assess the appropriate uses of various types of land (Klingebiel and Montgomery, 1961; Brady and Weil, 2005). According to the "Land Judging and Homesite Evaluation Guide Book" of the Kansas State University Agricultural Experiment Station and Cooperative Extension Service (undated), land capability classes developed by the USDA Natural Resource Conservation Service are widely used in the preparation of conservation plans. The land capability classification based on the detailed soil survey is generally published at scales of 1:10,000 to 1:20,000 in the United States. The system consists essentially of grouping various soil mapping units, "primarily on the basis of their capability to produce common cultivated crops and pasture plants over a long period of time" (Klingebiel and Montgomery, 1961). A soil mapping unit is a portion of the landscape that has similar characteristics and qualities and whose limits are fixed by precise definitions. Within the cartographic limitations and considering the purpose for which the map is made, the soil mapping unit is the unit about which the greatest number of precise statements and predictions can be made. Soil mapping unit provides the most detailed soil information needed for developing capability units, forest site groupings, crop suitability groupings, range site groupings, engineering groupings and other interpretive groupings (Klingebiel and Montgomery, 1961). Land capability classification is useful in identifying limitations and hazards of using land for agricultural purposes. The system is used to determine whether an area of land is best suited for crops, pasture, or woodland. It is especially helpful in identifying land uses and management practices that can minimize soil erosion, especially that induced by rainfall (Brady and Weil, 2005). The capability groupings are made at three levels of management: land capability class, land capability subclass and land capability unit.

Capability classes are groups of capability subclasses or capability units that have the same relative degree of hazard or limitation (Brady and Weil, 2005). The capability classes are useful as a means of introducing the map user to the more detailed information on the soil map. The classes show the location, amount, and general suitability of the soils for agricultural use. Only information relating to general agricultural limitations in soil uses are obtained at the capability level. There are eight land capability classes (I-VIII) which range from the best and the most easily farmed land (Class I) to land which has no value for cultivation, grazing or forestry, but may be suited for wildlife, recreation or for watershed protection (Class VIII). The risks of soil damage or limitation in use become progressively greater from class I to class VIII. They all fall into two broad groups of land (Brady and Weil, 2005; Esu, 2010) one suited for cultivation (Class I-IV); the other not suited for cultivation V-VIII. Classes I, II and III include land suited for regular cultivation.

Land capability subclasses represent convenient groupings of subordinate characteristics within a land capability class. Subclasses are groups of capability units which have the same major conservation problem. The capability subclass provides information as to the kind of conservation problem or limitations involved. Reasons for placing certain soil mapping units in a class lower than Class I are often indicated by adding the letters e, w, s and c as suffixes, singly or in combination to the class number to show the nature of the deficiencies or limitations which necessitated the down grading of the class from Class I. Thus, whereas the eight land capability classes express degree of usefulness, the subclasses express kinds of limitations within each class. The four subclasses, which may be recognized in most of the land capability classes except Class I, are:

e - Land dominantly subject to wind or water erosion, or both and runoff.

w - Land subject to presence of excess wetness or to overflow.

s - Land limited chiefly by soil conditions, such as excessive sandy texture, excess gravel or stones, or shallow depth which is considered root zone limitation.

c - Land limited chiefly by climate, either inadequate precipitation or low temperature (Brady and Weil, 2005; Esu, 2010).

Within each subclass, lands suited for essentially the same kind of management and the same kind of conservation treatment is designated as a land capability unit (Esu, 2010). A capability unit is a grouping of one or more individual soil mapping units having similar potentials and continuing limitations or hazards. Soils in a capability unit are sufficiently uniform to: (a) produce similar kinds of cultivated crops and pasture plants with similar management practices; (b) require similar conservation treatment and management under the same kind and condition of vegetative cover; (c) have comparable potential productivity (Klingebiel and Montgomery, 1961). Hence, a land capability unit is uniform in all major characteristics that affect its management and conservation. It is the smallest unit recognized in the land capability classification system and may be likened to a soil phase – within a soil series. Land capability units are designated by ordinary Arabic numerals as IIe-1, IIe-2, IIIe-1, IIIes-1, IIIes-2, etc.

Slight modifications of the original system are commonly introduced by scientists in the use of LCC. Ogunkunle and Babalola (1986), in Nigeria modified the system by the non-inclusion of total soluble salts (TSS) as a criterion and the use of ranges instead of absolute values for some of the criteria (e.g. slope gradient and rock outcrop). In the original system, subclasses are designated by symbols relating erosion (e), excess water (w), soil root zone (s) and climatic (c) limitations. However, because there are different kinds of limitations within each of these groups which may have different effects on crop performance, Ogunkunle and Babalola (1986), considered that it is better to separate each of these and designate them differently and used soil texture (t), angle of slope (a), soil depth (d), wetness (w), nutrient holding capacity (n) as the designations for limitations. Five of the eight classes (I, II, III, IV and VI) were encountered by Ogunkunle and Babalola. Similarly, owing to the peculiar nature and kinds of limitations in the meander belt soils and the absence of characteristics such as rock outcrop, soluble salts etc., Dickson et al. (2002) excluded percent rock outcrop, permeability and available water capacity and modified the subclass designations in the capability grouping of some soils in the Niger Delta of Nigeria. Instead of using erosion (e), excess water (w), soil rooting zone limitations (s) and climate (c), Dickson and colleagues used angle of slope (a), soil texture (t), wetness (w), and nutrient holding capacity (n). Of the eight capability classes, they encountered only three (II, III and V). Class II is the most extensive covering about 88% of the study area, having medium to high capability for arable cropping, followed by class V which have limitations due to excessive wetness and is recommended for lowland rice production and fish farming. Class III covered about 5% of the study area, limited by gravely sand 45 cm layer on the topmost part of the profile which could inhibit water holding properties of the soil.

2.2.2.1.2: Fertility Capability Classification

Land evaluation (land capability classification, land suitability evaluation) can tell farmers how suitable a land is in terms of soil limitations, crop yield or profit (Olaleye et al., 2002). Report by Minh (2011) indicates that data from field tests or from yield provided by individual farmers records are usually local, spotty, and sometimes not reliable; and are generally difficult to extrapolate. Therefore, evaluation is normally conducted indirectly on the basis of soil properties. Evaluations made require validation finally with real constraints and yield data. According to Sanchez et al. (2003), soil taxonomy has the problem of quantifying only permanent soil parameters, most of which are located in the subsoil. Soil taxonomy also ignores many dynamic parameters crucial to crop productivity, which are mostly in the subsoil where majority of plant roots are located, both in natural and agricultural systems. To overcome this limitation, a Fertility Capability Classification (FCC) was developed to interpret soil taxonomy and soil tests in a quantitative manner that is relevant to growing plants (Buol et al., 1975). It is now widely used and included in the FAO soil database (FAO, 1995).

The FCC system is designed to group soils having similar limitations of fertility (WARDA, 1998). It provides a guide for the extrapolation of the fertilizer response experience. The FCC focuses attention on surface soil properties most directly related to management of field crops and is best used as an interpretative classification in conjunction with more inclusive natural soil classification (Olaleye et al., 2002). Based on quantitative topsoil attributes and soil taxonomy, the FCC system is probably a good starting point to approach soil quality for the tropics and is widely used. FCC does not deal with soil attributes that change in less than 1 year, but those that are either dynamic at time scale of years or decades with management, as well as inherent ones that do not change in less than a century (Sanchez et al., 2003). As earlier stated (Sanchez et al., 2003), the limitation of soil taxonomy, the FAO legend and the World Reference Base for Soil References is that they quantify only permanent soil attributes, most of which are located in the subsoil. In a quest to identify undisturbed soil and cultivated soil in the same taxa, these soil classification systems ignore many inherent or dynamic attributes crucial to plant productivity which are located mostly in the topsoil, where majority of plant roots are, both in natural ecosystems and agro-ecosystems. To overcome this limitation, the FCC system, developed over 25 years ago, interprets soil taxonomy and additional soil attributes in a way that is directly relevant to plant growth (Buol and Couto, 1981; Sanchez et al., 2003).

The initial version of FCC system (Buol and Couto, 1981; Sanchez et al., 1982) was replaced by a second version (Buol, 1986), which includes specific interpretations for wetland rice soils. A third version (Smith, 1989), added a new condition modifier for permafrost and subdivisions of some existing ones. Smith (1989) developed a thorough rationale for each FCC class and provided detailed interpretations for tropical food crops, pastures and tree crops. Yost et al. (1997) later developed an algorithm of this third version with software that converts soil profile data into FCC units plus a series of automatic interpretations and recommendations (http://www.fao.org/ag/AGL/AGLL/fcc3/faorep.htm). The FCC system is widely used and included in the worldwide FAO digitized soils map at a resolution of 10 km^2 (FAO, 1995). It is also used in several countries.

The FCC system according to Olaleye et al. (2002), consists of three classification levels: Type (top soil texture), Substratum Type (subsoil texture), and certain other soil properties considered as condition modifiers or fertility constraints. The FCC version 4 introduced by Sanchez et al. (2003), consists of two categorical levels. The first category --- type/strata type – describes topsoil and subsoil texture and is expressed in capital letters (S – sandy throughout; SC – sandy topsoil underlain by clayey subsoil, for example). The second category – condition modifier – consists of 17 modifiers defined to delimit specific soil conditions affecting plant growth with quantitative limits. Each of the condition modifiers is expressed as a lower case letter. The subscripts + or – indicate a greater or lesser expression of the modifier (Sanchez et al., 2003).

The Type/Substrata and condition modifier are the attributes in terms of their capability for plant growth. Several methods are given in order of decreasing preference and reliability but increasing ease of determination for assessing each attribute, following the quantitative approach of soil taxonomy (Soil Survey Staff, 1999). Condition modifiers are originally conceived as soil constraints in the mid-1970s. However, the integrated natural resource management framework (INRM) paradigm and the need to scale-up from a pedon (measured once) to higher temporal and spatial scales have changed interpretations of some modifiers as positive attributes. In the Version 4 introduced by (Sanchez et al., 2003), the main changes are to combine the former 'h' condition modifier (acid, but not Al-toxic) with "no major chemical constraints" because field experience has shown little difference between the two and to introduce a new condition modifier 'm' that denotes a critical decline in soil organic matter. In addition, the symbol of gravel is changed from an apostrophe (') to r, for clarity and uniformity, and moved some soil pH limits slightly. The other major change in Version 4 is the introduction of the first biological based modifier because economic circumstances in many areas of the tropics, from semi-arid to humid regions, force farmers to rely largely on organic inputs, soil organic matter (SOM) or soil organic carbon (SOC) and biological processes for managing soil fertility, with mineral fertilizer inputs playing a secondary role or no role at all (Palm et al., 2001a; Palm et al., 2001b).

Based on soil constraints for rice cultivation, Minh (2011) proposed the Rice Soil Fertility Classification system (RSFCC), a system based on the FCC system with some modifications, which are easy to apply and classify by using the simple methods for identification in the field or laboratory. The system adapted the FCC system, with some modifications, dealing with soil morphology, physical and chemical characteristics. Most of the class limits are based on soil taxonomy (Soil Survey Staff, 1994) or the FAO/UNESCO soil classification system and consists of two categorical levels. The first category: type/substrata/subsoil type – describes topsoil, substrata and subsoil texture at three soil depths and is expressed in capital letters. The second category: condition modifiers, expressed with lower case letters, defined to delimit specific soil conditions affecting rice growth with quantitative limits. The type/ substrata/subsoil type and condition modifiers are the soil attributes in terms of their capability for rice plant growth. The system placed emphasis on features that are easily detectable in the field, such as texture, colour, depth of horizons, presence or absence of mottles, etc. Soil analytical laboratory data are only used to support the classification if available.

The FCC system has been used by various authors in assessing the capability groupings of soils. Ogunkunle and Babalola (1986), assessed the capability groupings of some soils in the low lands of Benue River in Nigeria using different land capability classification systems. Using the FCC system, the authors discovered that two of the soils (Nos. 9 and 13) are excellent flooded rice soils, covering about 38% of the area. With supplemental irrigation in the dry season, an additional 17% (Nos. 2, 4, 5 and 6) can be suitable for lowland rice production, bringing the total to 56% of the study area being fairly to very suitable for rice production. Soil No. 1 is reported excellent for any arable crop while soil nos. 3 and 12 are considered average, bringing the total area having medium-high capacity for arable agriculture to 76%. Using the FCC system, Dickson et al. (2002) rated Oruma soils in Bayelsa State of Nigeria as having medium to high capacity for arable farming. The poorly drained soils of the flood plain and back swamps, covering 7% of the survey area (Oruma-6 and-7) are rated to be particularly suited to lowland rice production. With additional water supply through irrigation, an additional 13% (Oruma-5) of the lower levee slope could be brought into lowland rice production. The middle slope soils (Oruma-3) and upper slope soils (Oruma-4) are recommended for leguminous crop production while Oruma- and-2 are recommended for the production of plantain, banana, cocoyam and vegetable crops.

2.2.2.1.3: Soil Fertility Status Assessment using Soil Fertility Index and Soil Evaluation Factor

The complexity of soil properties is a hindrance to finding an appropriate method to evaluate soil conditions in the tropical rainforest (Lu et al., 2002). Soil scientists have taken giant steps at developing methods to assess soil conditions. Soil quality for example, is a combination of the physical, chemical, and biological properties that contribute to soil function (Knoepp et al., 2000). Knoepp et al. (2000), Page-Dumrose et al. (2000) and Schoenholtz et al. (2000) attempted to construct soil quality standards and guidelines to assess soil capacity to support sustainable developments in forest but find it difficult to establish such a soil quality standard because of the diversity of soil properties, climate conditions in the ecosystem, appraisal techniques, and soil uses. According to (Lu et al., 2002), to date, an effective method to evaluate soil fertility is still lacking in the humid tropical region. Moran and his colleagues (Moran et al., 2000a; Moran et al., 2000b) developed and used soil fertility index (SFI) to explore relationship between soil fertility and secondary succession rate and crop choice. Lu et al. (2002) used soil evaluation factor (SEF) as a comprehensive factor that represents soil fertility and indicated that soil with SEF value of less than 5 signified extremely poor soil fertility and those having higher values indicated good soil fertility. According to (Arifin et al., 2008a), the assessment of soil fertility and site quality is important in forest management because it reflects the productive capacity of the forest to support plant growth.

2.2.2.1.4: The Framework for Land Evaluation

Various methods are used for land suitability evaluation. The 'Framework for Land Evaluation' as proposed by FAO (1976) is considered a standard reference system in land evaluation throughout the world, and has been applied both in the developed as well as the developing countries (Dorronsoro and undated). The framework is considered to be an approach, not a method. It is designed primarily to provide tools for the formulation of each concrete evaluation. The following concepts guide the system: (i) the land is qualified, not only the soil; (ii) Land suitability must be defined for a specific soil use (crop management); (iii) land evaluation is to take into account both the physical conditions as well as economic ones; (iv) the concept of land evaluation is essentially economic, social and political; (v) the evaluation requires a comparison between two or more alternative kinds of use; (vi) the evaluation must propose a use that is sustainable; and (vii) a multidisciplinary approach is required.

In this scheme, four categories are recognized, the highest category being the order, that is, it reflects, in broad features, whether a soil is suitable or not suitable for a given use. There are two orders, "Suitable" (S) (land in which the benefits exceed the costs and sustained use does not incapacitate the soil over a sufficiently long period of time) and "Not Suitable" (N) for use. A land is considered Not Suitable if the proposed use is technically impracticable e.g. cultivating very shallow (rocky) soils is environmentally undesirable as use may lead to severe erosion or is economically unprofitable. Frequently, the not suitable reason is economic, in that the profit expected does not justify the cost required (Dorronsoro and undated). The second category is the class that reflects degrees of suitability within the order, numbered consecutively in Arabic numerals. Within the Order "Suitable" (S) there are three classes, indicating the degree of suitability – highly suitable (S1) – without limitations for sustained use or minor limitations that do not affect productivity nor appreciably increase in costs, moderately suitable (S2) – with moderately serious limitations that reduce profits or involve risks of degradation in the sustained use of the soil, and marginally (S3) suitable – the limitations for the sustained use are serious and the balance between the costs and benefits make the use only marginally justifiable. Its use is normally justified on other grounds rather than economic grounds. In the 'Not Suitable' (N) Order, there are two classes: not currently suitable (N1) i.e. can be made suitable by new technology or more costly modifications but these changes are at present unfeasible; and permanently not suitable (N2) – serious limitations generally of physical nature, which are assumed to be beyond solving over the long term (Dorronsoro and undated). The highly suitable class (S1) does not indicate perfection but relative quality while the difference between S3 and N1 varies with relative costs and prices over time. The symbol NR (not relevant) is used where the basic assumptions of the evaluation excludes this portion of land from the use under consideration (Esu, 2010). Dorronsoro included X – land for conservation as the third class under not suitable which is land unsuitable for exploitation, being land of special protection, due to conservation, wildlife, of special scientific , ecological or social interest (e.g., parks, reserves or recreation zones.

The limits between the orders (S and N) and between the different classes (S1, S2, S3 and N1, N2) are established by the presence of limiting factors. One limiting factor is a characteristic of the soil that hampers its use, reduces productivity, increases costs and implies degradation risks, or all of the above. These limiting factors are used to define the third category of the system, which is the subclass. Suitability subclasses therefore indicate kinds of limitations e.g., moisture deficiency or erosion hazard. They are indicated by lower-case letters placed after the class symbol, e.g., S2m, S2e, S3me. There are no subclasses for S1. There is no limit to the number of limitations that can be recognized in a survey. However, two guidelines are used to distinguish between the chosen limitations:

- The number of subclasses should be kept a minimum.
- As few limitations as possible should be used in the symbol for any subclass i.e., for each subclass, the number of limitations involved should be kept to the minimum one letter or, rarely two.

The limitations proposed include: t, slope; e, erosion risk; p, depth; s, salinity; d, drainage; c, bioclimatic deficiency; r, rockiness; i, flood risk.

The fourth category is the unit that establishes the differences within the subclasses as a function of the desired use. Land suitability units therefore, are subdivisions of a subclass. All the units within a subclass (S2rA, S2rM, …) have the same degree of suitability at the class level (S2) and analogous characteristics of limitations at the subclass level (r). The units differ from each other in their production characteristics or in minor aspects of their management requirements. Their examination enables a detailed interpretation at the planning level of the exploitation. Suitability units are distinguished by upper-case letters that are placed at the end or Arabic numbers following a hyphen, e.g. S2e-1, S2e-2. There is no limit to the number of units recognized within a subclass (FAO, 1976). Those defined are: A, intensification in the agricultural use without need for great improvements; M, intensification in agricultural use with need of major improvements (irrigation, etc.); P, use for pasture for livestock; F, forestation (Dorronsoro and undated). In some cases, the designation "conditionally suitable" can be added so long as certain conditions are satisfied.

Several concepts are in use to give a clearer perspective to the use of the framework. A *Major Kind of Land Use* is a major subdivision of rural land use, such as rainfed agriculture, irrigated agriculture, grassland, forestry, or recreation. Major kinds of land use are usually considered in land evaluation studies of a qualitative or reconnaissance nature (FAO, 1983). A very important role in the framework is represented by the concept of *Land Utilization Type (LUT)*. A *Land Utilization Type* is a kind of land use described or defined in a degree of detail greater than that of *A Major Kind of Land Use*. It consists of a set of technical specifications in a given physical, economic and social setting (FAO, 1976). According to Dorronsoro (undated), it represents a thorough description of soil for a proposed use, in terms of crop (type and rotation), soil management (working the soil, additives and possible irrigation) and socio-economic framework (labour cost, market, distribution, expenses, profits and subsidies).

In an attempt to propose any certain *LUT*, the crop must meet certain requirements of the land that satisfy the *LUT* and these are grouped under the concept of *Land Use Requirements (LUR)*. *Land Use Requirement* is a condition of the land necessary for successful and sustained implementation of a specific *LUT*. For example, plants require water in order to grow, this might be called moisture requirement (Rossiter, 1994). *LURs* can be assembled into understandable groups, e.g., 'crop requirements', 'management requirements', 'conservation/environmental requirements', etc. *LURs* are the demand side of the land use equation. For these requirements to be fulfilled, the land must have certain features, known as *Land Qualities (LQ)*. A *Land Quality* is (a) complex attribute of land which acts in a manner distinct from the actions of other land qualities in its influence on the suitability of land for specific kind of use" (FAO, 1983). van Diepen et al. (1991) defined *LQ* as the ability of the land to fulfill specific requirements" for the *LUT*. Land Qualities are the supply side of the land-land use equation: what the land can offer to the use. For example, the land can supply a certain amount of water to the crop which might be called 'moisture availability' Land Quality. On the other hand, the crop has a requirement for water; this 'moisture requirement' *LUR* corresponds to the 'moisture requirement'.

Land qualities are usually complex attributes of the land, i.e., they cannot be directly measured or estimated in routine survey but are supported by particular land characteristics called *Land Characteristics (LC)*. On the other hand, *Land Characteristics* are directly measured or estimated. *Land Characteristics*, therefore, represent characteristics of the soil that can be examined and measured in the profile or in the laboratory, while *Land Qualities* are complex qualities that are not directly measureable but rather are estimated from a certain combination of *LCs*. The FAO definition of *Land Characteristics* says *Land Characteristics* are simple attributes of the land that can be directly measured or estimated in routine survey in any operational sense, including by remote sensing and census as well as by natural resource inventory e.g., surface soil texture and organic matter, current land use, distance to the nearest road. Obviously, the effects of a *LC* on suitability are not direct, but through their effect on *land qualities* (Rossiter, 1994). This is because a single *LC* may affect several qualities often in contradictory ways, e.g., sandy soils may have low fertility and water holding capacity, but may be easy to till and there are no problems with aeration of the roots. Here the soil texture is the *LC*, the others are *LQ*. Rossiter (1994), opined that the FAO Framework does not allow the use of *LCs* directly to assess suitability, but it is generally clearer to use *LQ* as an intermediate level of evaluation. This is because the total complexity of the problem is broken down into more manageable units and *LQs* in themselves provide useful information to the evaluation.

Land characteristics and land qualities influence the suitability of land that will depend on whether some of these characteristics/qualities are optimal, marginal or suitable. Hence evaluation of characteristics and qualities, for specific land-use is essential in the overall evaluation work (Sys et al., 1991a). This can be achieved through the use of relative limitation scale (limitation approach or a parametric approach. The use of land limitations is a way of expressing the land characteristics or land qualities in a relative evaluation scale. Limitations are deviations from the optimal land characteristics/land quality which adversely affect a kind of land-use. If a land characteristic is optimal for plant growth it has no limitations but when the characteristic is unfavourable for plant growth, it has severe limitations. Though the relative evaluation of land qualities (characteristics) is normally realized in several degrees of the limitation, (Sys et al., 1991a) suggested the following five level scales in the range of degree of limitation:

- No limitations: the characteristic (quality) is optimal for plant growth;
- Slight limitations: the characteristic is nearly optimal for the land utilization type and affects productivity for not more than 20% with regard to optimal yield;

- Moderate limitations: the characteristic has moderate influence on yield decrease; however, benefit can still be made and use of the land remains profitable;
- Severe limitations: the characteristics has such an influence on productivity of the land that the use becomes marginal for the considered land utilization type; and
- Very severe limitations: such limitations will not only decrease the yields below the profitable level but may even totally inhibit the use of the soil for the considered land utilization type.

The limitation levels can be assigned to land classes. This means that for each characteristic or quality one can define an S1 level (very suitable), an S2 level (moderately suitable), an S3 level (marginally suitable), and N1 level (unsuitable but susceptible for correction) and an N2 level (unsuitable and non-susceptible for correction). In this case, no or slight limitations define the S1 level, moderate limitations the S2 level, severe limitations the S3 level and very severe limitations the N1 and N2 levels. The definition of the classes can be done according to simple limitation method or limitation method regarding number and intensity of limitations.

The simple limitation method involves producing requirement tables for each land utilization type. Such a table indicates for each characteristic the class level criteria. For instance, an evaluation of the climatic characteristics (rainfall, temperature, relative humidity and radiation) is to come out with the introduction of one class level in the total evaluation. The class level of climate corresponds with the lowest class level of only one or more climatic characteristics. Land classes are defined according to the lowest class level of only one or more characteristics. On the other hand, the limitation method regarding the number and intensity of limitations defines classes according to the number and intensity of limitations. In the requirement tables for this method, the limitation level of each characteristic is defined. In the evaluation of climate using this method, the climatic characteristics are regrouped into 4 groups:

- Characteristic (s) related to radiation;
- Characteristic (s) related to temperature;
- Characteristic (s) related to rainfall; and
- Characteristic (s) related to relative air humidity.

For each climatic characteristic group, the most severe limitation will be considered to determine the climatic suitability class as well as the corresponding limitation level to be used in the total land evaluation. The following criteria in Table 2.1 (Sys et al., 1991a; Sys et al., 1991b) are used:

Table 2.1 Climatic Suitability Class Determination Criteria

CLASS	CRITERIA	LIMITATION
S1	climate has no limitations; or climate with maximum 3 slight limitations	0
		1
S2	climate with 4 slight limitations or with Maximum 3 moderate limitations	2
S3	climate with 4 moderate limitations or with 1 or more severe limitations	3
N	climate with 1 or more very severe limitations	
		4

The land suitability classes (Table 2.2) as defined (Sys et al., 1991a) are as follows:

Table 2.2: Land Class definitions

LAND CLASSES	DEFINITIONS
S1 (very suitable)	land units with no, or only 4 slight limitations
S2 (moderately suitable)	land units with more than 4 slight limitations, and/or no more than 3 moderate suitability
S3 (marginally suitable)	land units with more than 3 moderate limitations, and/or no more than 2 severe limitation(s)
N1 (actually unsuitable and potentially suitable)	land units with very severe limitations which can be corrected
N2 (unsuitable)	land units with very severe limitations which cannot be corrected

The evaluation is carried out by comparing the land characteristics with the limitation levels of the requirement tables

According to Sys et al. (1991b), the second method is more difficult but a more accurate approach. Based on the first method, land unit with 1 or with 4 or even with more S2 levels will be classified as S2, although it is clear that the land with 4 moderate limitations will have a lower net return as compared with land with only 1 moderate limitation. The second method considers land with severe limitations of the same level as a lower class.

The parametric approach of land characteristics evaluation consists of a numeral rating of the different limitation levels of the land characteristics in a numerical scale from a maximum (normally 100) to a minimum value. If a land characteristic is optimal for the considered land utilization type, the maximum rating of 100 is attributed; if the same land characteristic is unfavourable, a minimum rating is applied. The successful application of the parametric approach according to Sys and colleagues hinges on respect for the following rules:

- The number of land characteristics to consider has to be reduced to a strict minimum to avoid repetition of related characteristics in the formula, leading to a depression of the index. Therefore all land qualities expressed by one characteristic should be rated together. For instance, the single rating of texture should be done with regard to the capacity to retain nutrients, water availability, permeability and one should avoid introducing separate ratings for these single qualities.
- An important characteristic is rated in a wide scale (100-25), a less important characteristic in a narrower scale (100-60), introducing the concept of weighting factor. For example, in studying suitability for irrigation, the very important factor of texture is rated from 100 to 25 and the less important factor of calcium carbonate content from 100 to 80.
- The rating of 100 is applied for optimal development or maximum appearance of a characteristic. If, however, some characteristics are better than the usual optimal, the maximum rating can be chosen higher than 100. For instance, if the most common organic carbon content of the top 15 cm in a specific area varies from 1 to 1.5%, the rating of 100 is applied for that carbon level. Soils having more than 1.5% O.C. are attributed a rating of more than 100 for organic matter.
- The depth to which the land index has to be calculated must be defined for each land utilization type. If one considers that for a specific land utilization type, all horizons have a similar importance, the weighted average of the profile section must be the same until the considered depth is calculated for each characteristic. If on the other

hand one considers that the importance of a horizon becomes greater when his position is nearer the surface, a different proportional rating can be given to the depth sections of the profile in such a way that they increase when approaching the surface. Therefore the profile can be subdivided into equal sections; to each of these sections one attributes a "depth correction index" (weighting factor) starting with a minimum value in depth and becoming gradually greater when approaching the surface section.

The depth to be considered should coincide with the normal depth of the rooting system in a deep soil.

Land suitability can be assessed for present condition (Actual Land Suitability) or after improvement (Potential Land Suitability). Actual land suitability is a land suitability that is based on current soil and land conditions, without applying any input. The information used for this purpose is based on physical environment data generated from soil or land resources survey, i.e. soil characteristics and climatic data related to growth requirements of crops being evaluated (Ritung et al., 2007). Potential land suitability is the suitability that can be reached after land is improved. The land evaluated can be natural (conversion) forest, abandoned or unproductive lands, or land currently used for agriculture, at a sub-optimal level of management in such a way that the productivity can be improved by changing to more suitable crops.

The framework for land evaluation recognizes four main kinds of suitability classification i.e., whether it is qualitative or quantitative, and whether it is current or potential suitability. Qualitative classification is when relative suitability is expressed in qualitative terms only, without precise calculation of costs and returns. Quantitative classification on the other hand, is one in which the distinctions between classes are defined in common numerical terms, which permits objective comparison between classes relating to different kinds of land uses. A classification of current suitability refers to the suitability for a defined use of land in its present condition without major improvements while a classification of potential suitability refers to the suitability for a defined land units in their condition at some future date, after specified major improvements have been completed where necessary (FAO, 1976).

Decisions on land use are based on comprehensive analysis of the production and potentials of natural resources such as climate, soil, topography and hydrology (Adesemuyi, 2014). Land evaluation provides the necessary information on the potentials and constraints for the defined land use type in terms of crop performance as affected by the physical environment. Land evaluation is a veritable guide to the farmer to know the suitability of the land for specific uses as well as its limitations (Udoh et al., 2011). The farmer is better placed to make informed choices on the use of his land and take soil management decisions for increased productivity. It has been reported that soil suitability evaluation involves characterizing the soils in a given area for specific land use type (Ande, 2011). According to Esu (2004), one of the strategies to achieve food security with sustainable environment is to study soil resources to details through soil characterization and land evaluation for various land utilization types. The information collected in soil survey helps in the development of land-use plans, evaluates and predicts the effects of the land use on the environment. Land degradation problems can be solved by land evaluation leading to rational land use planning (FAO, 1976), appropriate and suitable use of natural and human resources as well as optimizing the use of a piece of land for a specified use (Sys et al., 1991a). Jafarzadeh and Abbasi (2006), in Iran observed that suitable land change after degradation by salinity and alkalinity requires suitable land use. According to FAO (1976) methodology, the suitability of a given piece of land is strongly related to land qualities such as erosion resistance, water availability and flood hazard that are not measurable. Characteristics such as slope angle and length, rainfall and soil texture derived from land characteristics, are measureable or estimable, and helpful in determining soil suitability for crop production. Suitability is largely a matter of producing yield with relatively low inputs and there are two stages of finding land that is suited to a specific crop. First and foremost, the requirements for the crop need to be known, or alternatively which soil and site attributes adversely influence the crop. The second stage is to identify and delineate land with the desirable attributes but without the undesirable ones.

Assessing the suitability of soils for crop production requires knowledge of the nutrient requirements of the various crops (Ande, 2011). Also, these requirements must be understood within the context of limitations imposed by landform and other features which do not form part of the soil but may have a significant influence on the use that soil can be made use of (FAO, 1978). For instance, the climatic and soil requirement for lowland rice cultivation is well documented (Olaleye et al., 2002). All of the above authors determined the optimum requirements for successful productive cultivation of rice. Olaleye et al. (2002) affirmed that climate, topography, hydrology, soil conditions and socio-economic factors determine to a great extent which crops may be grown in any ecological zone in Nigeria. In assessing the suitability of selected wetland soils for rain fed rice cultivation using conventional (nonparametric) and parametric methods, Olaleye et al. (2002), used climate, soil physical properties, wetness and chemical fertility as the land qualities for the evaluation. The study revealed that Nigeria is climatically suitable for rice production, with major limitations like texture (% Clay), low exchangeable cations (K^+, Ca^{2+} and Mg2+), CEC, and organic carbon. Other soil characteristics that are sub-optimal include contents of total N, available P, and in some pedons high Fe^{2+} levels. The parametric method is found to be more accurate and the authors recommended that these soils be evaluated with the parametric method. In another study, Olaleye et al. (2008), again used two approaches (conventional or nonparametric and parametric) to evaluate representative soils of southwestern Nigeria for lowland rice cultivation. In the conventional approach, the overall current/actual/present aggregate suitability rating of a pedon is determined by the lowest suitability rating of *land qualities (LQ)* and *land characteristics (LC)* when all the LQ/LC are used. The potential aggregate suitability is determined by using soil properties that are not easily altered by soil management practices (e.g., cation exchange capacity). In the parametric method, however, the current/actual and potential suitability rating is determined using equation, and the differences in the overall suitability rating are determined by fertility score 'f' (Olaleye et al., 2008). Comparing the two methods of evaluation, Olaleye et al. (2008), reported that the nonparametric method rated all the pedons as currently unsuitable (N1) whereas the parametric method rated 50% of the pedons as marginally suitable (S3) for rice cultivation. Fertility (low CEC, deficiency of P and exchangeable K) and suboptimal textures are the major constraints in the soils. In another study, (Ande, 2011) carried out soil suitability evaluation and management for cassava production in the derived savanna area of south western Nigeria and recorded that Dystric Arenosols are moderately suitable, Plinthic Ferrasols are marginally suitable and Dystric Fluvisols are not suitable. High gravel content, shallow depth, seasonally high water table and low CEC are limiting factors. Ande therefore, recommended the use of organic fertilizers, mulching and leguminous cover crops as soil management options to enhance soil quality and increase the yield of cassava. Fasina et al. (2007), also examined the properties, classification and suitability evaluation of some selected soils of South-Western Nigeria for cocoa production and discovered gravelly concretional nature of the soils, poor fertility and low rainfall distribution as the major limitations of the soils, thus classifying the soils as marginally suitable.

Determining the suitability of land for irrigation requires a thorough evaluation of soil properties, the topography of the land within the field and the quality of water to be used for irrigation (Fasina, 2008). In a study, Fasina (2008) discovered that the parameters investigated (soil texture, soil depth, $CaCO_3$, electrical conductivity (EC), soil drainage and slope) all fall within the tolerable limit for irrigation purpose. The soils are therefore, considered suitable for both surface/gravity and drip/localized irrigation at various rating levels (highly and moderately suitable). In evaluating the irrigation suitability of Asu River Basin soils in southeastern Nigeria, Udoh et al. (2011), used conventional (non-parametric) methods as well as the parametric method to evaluate the suitability of eight pedons for rice and cocoa cultivation in soils developed from alluvial deposits. In the non-parametric method (FAO, 1976), pedons are first placed in suitability classes by matching their land characteristics with the agronomic requirements of rice and cocoa. By the parametric method, each limiting characteristics is rated (Ogunkunle, 1993). The index of productivity (IP) (actual and potential) is then calculated. The study revealed that soil fertility is a serious constraint to both rice and cocoa cultivation in the area. Climate, soil depth and clay content are optimum or near optimum, for rice and cocoa cultivation. However, ground water table, soil fertility status and toxicity rendered 50% of the area "not suitable" for rice, potentially and currently and only 50% is marginally suitable potentially, by the parametric (more strict) evaluation method. By the non-parametric evaluation, the entire area potentially and currently, is only marginally suitable for rice cultivation. The situation is very similar for cocoa, except that at least 25% of the area is moderately suitable while 75% is marginally suitable for the cultivation of the crop. Udoh et al. (2011), therefore concluded that for optimum production of these crops in this area, appropriate land preparation methods should be employed to reduce the depth to water table and increase the suitability of the land for irrigation. Furthermore, soil amendments should be introduced to control soil pH, and ameliorate iron toxicity and aluminum saturation. Other authors (Olowolafe and Patrick, 2001; Adefisan et al., 2007; Akinbile et al., 2007), investigated the effective factors to be considered when evaluating soils for irrigation, irrigation systems and water supplies and concluded that a basic understanding of soil/water/plant interaction will help irrigator efficiently manage their crops, soils, irrigation systems and water supplies.

In Southeast Asia, Mutert (1999), reported that, although the majority of oil palm roots are found within the first 60 cm of the soil, firm anchorage of adult palms of more than 8 m height can only be assured in a deep soil (greater than 90 cm). Thus, soil physical properties such as depth, texture and structure are major criteria and important factors for assessing suitability of land for large scale oil palm planting in Southeast Asia. Terrain is also of great importance, and in order to avoid greater cost of establishment, problems of harvesting, and losses from run-off and erosion, areas exceeding slopes of 15 percent should be avoided. In

Iran, Jafarzadeh and Abbasi (2006), evaluated land suitability for the growth of onion, potato, maize and alfalfa on soils of the Khalat pushan research station using Sys method. In that study, simple limitation method, limitation method regarding number and intensity and parametric methods (Storie and Square root), were employed and suitability classes determined. According to their findings, the simple limitation method results are similar to those of the limitation method regarding number and intensity. The accuracy of results obtained by the square root is high and more realistic when compared with the limitation method results. Jafarzadeh and Jafarzadeh and Abbasi (2006), recommended the cultivation of alfalfa, potato and onion using the square root method except for soil profile 2 which is not suitable for onion. According to Khordebin and Landi (2011), any utilization of the land over its capability will cause degradation and yield reduction on the long run. Khordebin and Landi (2011) therefore compared land qualitative suitability with the use of FAO method and *ALES* model for major crops in Sardasht of Behbahan Khuzestan Province of Iran. Qualitative suitability classification of land using the different methods showed that most units in the study area fall under suitable class (S1) for wheat and barley, moderately suitable class (S2) and severe suitability (S3) for rice. They suggested that land suitability in the area should be evaluated using *ALES* model and square root instead of other methods including storie and limitation method.

2.3 River Plain or Flood Plain Soils

2.3.1 Definition, Formation and Characteristics of River Plain or Flood Plain Soils

Different soils exhibit diverse behaviour due to differences in micro-morphological, morphological, physical, chemical and mineralogical properties (Ukut et al., 2014). Variations in soil types are due to variations in soil forming factors and processes operating on different parent materials (Esu, 2010), under different climatic, topographic, and biological conditions over varying periods of time (Soil Survey Staff, 1993). The diversity nature of soils is one major reason behind wrong allocation of soils and uses. Soil characterization and classification contribute to the alleviation of the adverse effect of soil diversity, wrong allocation of soils, wrong uses of soils and aid precision agriculture, land use planning and management. This is because the information needed for understanding the micro-morphological, morphological, physical, chemical, mineralogical and microbiological properties is provided by soil characterization and classification. Morphology deals with spatial distribution pattern of the soil characteristics while morphological characteristics are useful in distinguishing between different soils and in the classification of soils (Soil Survey Staff, 1998). Soil formation involves complex pedogenic processes such as addition, losses, translocation, and transformation. In as much as climate and organisms actively influence soil formation, topography indirectly affects rates of pedogenesis and distribution of soil nutrients (Pidway, 2006; Onweremadu and Mbah, 2006). Pedogenesis is concerned with the processes that determine the morphologically significant properties, such as horizons of clays or sesquioxide enrichment and leached horizons. It also influences the functional properties of soil, such as the ability to retain and recycle nutrients, the environment for soil micro flora, and the medium presented to a developing root. According to Foth (2006), soils are formed by basic processes of addition, removal, transformation and transfer after an initial step of parent material deposition. River formed landscapes are therefore, reasonably similar the world, over in terms of land forms and processes. Nevertheless, major differences occur among alluvial soils of river basins and the differences tend to reflect the larger geomorphological and climatic system which includes the rivers. For instance, many tropical and subtropical rivers have their headwaters in deeply weathered igneous areas and the deposits there-from are quartz and other minerals resistant to weathering leading to limited clay and silt deposits (Foth, 2006). Differences in soil characteristics associated with landscape position are usually attributed to differences in the runoff, erosion and deposition processes which affect soil genesis (Canton et al., 2003). Topography brings about the difference in soil properties of some related soils, the sequence, referred to as toposequence (Brady and Weil, 2005) which is defined as a succession of soils from crest to valley bottom which contains a range of soil profiles that are representative of the landscape and soils. Topography according to Foth (2006), modifies profile development by influencing the quantity of precipitation absorbed and retained in the soil; by influencing the rate of removal of the solids by erosion, and by directing the movement of materials in suspension or solution from one area to another.

River plain or floodplain soils fringes present active river channels or abandoned river channels and include levee soils, backswamp soils, clay plain soils that are seasonally flooded, and permanently swampy soils. Natural levees, consisting of sand sediments, occur adjacent to or fringes present active river channel or abandoned river channels, forming the highest parts of the landscape and are freely drained. Behind the levees are the lower-lying areas, with deposits of heavier textured and sometimes, impermeable silts and clays. Accumulation of organic matter, silts and clays in the back-swamps is common. The soils vary in texture and drainage, ranging from well drained to poorly drained (Effiong and Ibia, 2009). Flood plain soils usually are considered young or underdeveloped but strictly in pedological sense, not all such soils are underdeveloped, since some changes that resemble soil formation might have taken place. Stratification, the alteration of pedological layers and layers of new materials, is a particular characteristic of alluvial soils. Floodplain soils exhibit both sediment transport and deposition, and soil formation. Soil formation and sedimentation overlap in sites protected from erosion as slight vertical accretion lead to development of distinct horizons. It is therefore necessary to examine soil profiles with relation to sedimentary environments as sediments stratification is common which has a considerable effect on the development of pedogenic properties. Within the channel belt, soils are of light-coloured horizons and their sub soils stratified with little pedogenic weathering. Meander belt soils show thicker dark coloured surface horizons and the sub soils show some pedogenic processes (Okonny et al., 1999). Failure to take stratification into consideration leads to overestimation of the rates of pedogenic processes (Dengiz, 2010). Therefore, separation of sedimentological from pedological characteristics is important.

The processes of sedimentation and erosion vary spatially and temporally, and thus contribute to the heterogeneity of the whole floodplain system (Dengiz, 2010). The combined processes of ripening and homogenization obliterate stratification in floodplain soils. Ripening involves the drainage and evaporation of excess water, and the development of drying cracks which allows air to penetrate the soil which may lead to loss of part of the organic matter by oxidation. Homogenization refers to the elimination of depositional layering by biological agents such as roots, worms, termites and various microorganisms. With time, clay translocation is evident and the presence of peds is indication of soil formation in progress. Crumb-like and/or fine sub angular blocky peds are common in the root zone but their development is restricted by wetting and drying stresses, especially in soils with a high water table. Most floodplain soils characteristically, are associated with water logging and flooding. Alluvial sediments along streams and rivers or marine sediments along ocean shorelines are products of weathering of bedrock at one place which are transported and deposited at another location (Foth, 2006).

Seasonal flooding from river overflows lead to continuous deposition of alluvial materials forming floodplains. The soils usually, are of recent origin and lack characteristic well-developed profiles. As earlier stated, the alteration of pedological layers and layers of the new materials is a particular characteristic of alluvial soils. Therefore, the characteristics of alluvial soils change from region to region or from place to place (Dengiz et al., 2006). This change is however, not coincidental. Alluvial soils are the result of processes of erosion and deposition, and therefore exhibit the various characteristics reflecting the composition and properties of the materials transported (Weber and Gobat, 2006). The nature of the alluvial soil greatly vary, depending on the geology and soils of the catchments area and on the environment of deposition as well as the degree of weathering the materials are subjected to. Moreover, the processes of sedimentation and erosion vary spatially and temporally, and thus contribute to the heterogeneity of the whole floodplain system (Dengiz, 2010). Texture and depth of alluvial soils also vary greatly depending on nature of the sediments and the environment deposited. Coarser suspended materials carried by the river floods are deposited near the channels while the finer materials are further away. Hence, the nature of the deposited materials and their stratification varies within short distances. Alluvial soils, which have the capacity for high productivity, therefore, often show large variations in their properties over short distances (Dengiz, 2010). There is usually no characteristic soil profile or weak profile develops with no consistent relation between successive horizons. Much of the finer materials transported by large rivers is not deposited in the floodplains but carried on in suspension and deposited in deltas where alluvials are usually silts and clays and are more fertile and uniform than on the terrace of the river plains. Furthermore, Foth (2006), emphasized that when rivers causes rapid down cutting, the deposited alluvial materials at the fringes of the river plain become elevated relative to the river, so that such areas are no longer flooded. Terraces are formed, and since there is no longer flooding and deposition from the river, the soils develop normally with time.

The surface horizon of recently deposited alluvial soils is the least weathered because it is the most recently deposited alluvium. It is common for alluvial soils to be very deep. After subsoil material is buried by more recent alluvium, the subsoil receives very little additional organic materials from root growth and the organic matter continues to mineralize. Therefore, gradual decrease in soil organic matter content with increasing soil depths is a common phenomenon for floodplain soils (Idoga and Azagaku, 2005; Esu et al., 2008). Studies state that seasonal submergence and drying are the most active factors in developing redoximorphic features such as mottles, iron and manganese concretions, chroma diagnosis of 2 or less, gleyed soil matrix (Ogban and Babalola, 2009; Egbuchua and Ojobor, 2011; Hossain et al., 2011). The mineralogical characteristics such as quartz, kaolinite, illite, smectite, vermiculite and interstratified types are common in the silt-clay fraction of floodplain soils (Ukubiala, 2012).

Daniels (2003) and Weber and Gobat (2006), defined three alluvial pedofaces for semiarid, cut and fill floodplains. The three soils develop different pedogenic features through time as a result of different aggradation rates. Daniels (2003), defined 'A' horizons as soil stratigraphic markers and indicators of relative aggregation rates. Thus, identification of different soil horizons, reflecting different aggregation phenomena due to floods or development of weak structure, seems to be the ideal approach for precisely describing the variability and complexity of alluvial soil profiles (Dengiz, 2010). In his study of floodplain soils on terraces of the Tigris River in Turkey, Dengiz (2010), observed that soils formed on the youngest terrace of the study area had alluvial clay deposits, with moderate granular and medium sub angular blocky structures in the surface horizons and a strong prismatic structure characterizing the subsoil horizons. In some areas, structure was not developed after 72 cm depth. In addition, floodplain soils where there is water table fluctuation, had redoximorphic features seen as brownish red mottles at less than 2 m depth. The standard ABC profile development model therefore, is sometimes not appropriate for soils derived from floodplain alluvium. Soil profiles containing different stratigraphic soil layers complicate the classification process (Finkl, 1980). In the standard ABC model, it is assumed that the organic matter on top the 'A' horizon form after the parent material is deposited. In seasonally flooded floodplain soils, some organic material may add at the surface before the next flood that brings new deposits. Thus, the subsoil is a former 'A' horizon and the present A horizon which is the most recent alluvial deposit has to develop on top a new superficial C material. The 'B' horizon will develop from a former 'A' horizon. Therefore the genetic pathway is not 'C' transformed to 'A' or 'B' directly but a new superficial 'C' into a new 'A' and a former 'A' into a 'B'. The former 'B' horizon becomes a substratum not to be confused with 'C' horizon. Therefore, systems such as that of FitzPatrick (1980), which does not rely on the unity of the soil profile, or that of (Marinkovic, 1964), which is based on factors of topsoil texture and depth, might be more applicable to floodplain soils. (Alexandrovskiy et al., 2004) asserted that floodplain soils reflect in their profiles the character of environmental changes and represent a record of alternating processes of alluviation and pedogenesis; the character of pedogenic features in the sequence of buried soils is also subjected to certain alterations. Furthermore, buried soils have different thickness and degree of development and as well differ in the character of pedogenesis. Along with typical fluvisols having A-C profile and distinct alluvial stratification, are also soils with a well develop humus horizon called Phaeozems or Mollic Fluvisols.

2.3.2 Characterization and Classification of Flood Plain soils.

Variation in soil characteristics associated with landscape position have been attributed to differences in the runoff, erosion and deposition processes which affect soil genesis (Canton et al., 2003). As alluvial soils are related to specific landforms (floodplains) that occur in a variety of climatic regions, they have always been outside the main classification schemes. Early classification schemes classified soils as normal/zonal, transitional or abnormal. Alluvial soils were placed in the abnormal category. The terms transitional and abnormal were later replaced with intrazonal and azonal. Azonal soils to which alluvial soils belonged are the soils that did not reflect the characteristics of any particular climatic zone, usually because they are too young. Thus, markedly different soils can be classified as alluvial soils and such soils may or may not have some of the local zonal influences affecting their characteristics. In the more recent soil classification work in the USSR, more emphasis is given to the moisture characteristics of the soil (Kovda et al., 1967). This has a special significance for alluvial soils as it is difficult to classify alluvial soils. According to Autin and Aslan (2001) alluvial soil morphology varies according to landscape position and overbank lithoface s as well as river modifications through time, such as embankments and dam construction. These geomorphic processes produce a landscape mosaic reflected in abrupt juxtapositions of soils of different ages and degrees of profile development. Furthermore, alluvial soils and floodplains formed under ephermeral flow regimes, especially in arid and semi-arid regions, lack many of the relationships between hydrology, sedimentology and morphology that apply to perennial rivers (Alexander et al., 1999). They emphasized that the concept of pedogenic maturity is used to infer sediment accumulation rates at different locations in ancient floodplain environments. That is, weak soil development is assumed where sedimentation rates are rapid and strong development presumed where sediment accumulation is slow.

Various studies (Ogban and Babalola, 2009; Egbuchua and Ojobor, 2011; Ayalew and Beneye, 2012), have shown that physicochemical and mineralogical properties of floodplain soils were essential for sustainability classification for crop production. In addition, mineralogical study helps in the evaluation of mineralogical impacts on soil family level under USDA Soil Taxonomy (Hossain et al., 2011). Alluvial soils have been classified into the orders of Entisols, Inceptisols, Vertisols, Alfisols (Nuga et al., 2006; Dengiz, 2010; Sharu et al., 2013). Entisols were characterized by absence of pedogenic horizons and a dominance of mineral soil materials. Most floodplain soils developed on recent alluvium may fall into this category and into the suborder of fluvents. Fluvents are mainly brownish or reddish soils which are formed on recent floodplain sediments that are frequently flooded and in which stratification is very obvious. However, waterlogged soils, with the mottled greyish and bluish horizons are aquents and some sandy soils on levees are psamments (Soil Survey Staff, 1999). (Dickson et al., 2002), classified some alluvial soils into entisols and inceptisols orders. These soils were more developed with one or more pedogenic horizons but still with little accumulation of translocated materials apart from carbonates or amorphous silica. Alluvial soils subjected to ground water influence in part of the year would be included in the aquepts suborder. Their natural drainage is poor and the water table is close to the surface during reasonable part of the year. They usually have grey to black surface horizon that begins at a depth less than 50cm. Soils developed on alluvium classify as vertisols because of the swelling nature of the clays. Ciolkosz and Waltman (1995) reported the presence of cambic horizons in Inceptisol, Mollisol, Aridisol, Andisol and Vertisol orders, but only Inceptisols and Mollisols have cambic horizons in Pennyslavania floodplains as Pennyslavania floodplain soils are too young to have had a significant amount of illuvial clay accumulated in the subsoil. Entisols, Inceptisols and Mollisols are present in Pennyslavania floodplains (Ciolkosz and Waltman, 1995). In the WRB system of classification, most alluvial soils fall into the Fluvisol category although some more matured soils are classified as Regosols, Cambisols, Plinthosols, Luvisols or Xerosols (FAO/ISRIC, 2006). Some of the problems of classifying floodplain soils are caused by a lack of agreement on criteria to separating gley soils as not only alluvial soils exhibit gleying characteristics. More so, floodplain soils require appreciation of factors concerned with geomorphology, hydrology and climate as well as pedology.

In Turkey (Dengiz, 2010), reported the absence of diagnostic epipedons in surface soils of the profiles studied except ochric epipedon in one while cambic and argillic horizons were seen in the subsoil layers. The soils of the alluvial deposits on different terraces and floodplain of the Tigris River at Diyarbakir, South-eastern Turkey are highly heterogeneous, displaying distinctive pedologic characteristics due to frequent depositional disturbances through flooding, as well as erosional processes. All profiles, except for profile IV, were generally fine textured due to excessive weathering. Typic Haploxerept, Typic Haploxeralf, Typic Haploxerert and Typic Xeropsamment taxonomic classes were encountered in the USDA Soil

Taxonomy while Eutric Cambisol. Haplic Luvisol. Eutric Vertisol and Eutric Regosol were the corresponding taxonomic classes in the WRB.

In Nigeria. several authors have carried out characterization and classification of River plain soils of various origins including soils derived from alluvial parent materials. Babalola et al. (2011). in evaluating two wetland soils in Ado-Ekiti and Kabba in Nigeria reported that Kabba soil was embryonic in nature with few diagnostic horizons and classified as Typic Haplaquept and Eutric Gleysol in the USDA soil taxonomy and WRB system. respectively. Ado-Ekiti study site pedon because of its embryonic nature. characteristic wetness. high water table at 55 cm soil depth. gleyic characteristic and irregular decrease in carbon content between 25 and 125 cm. classified as Fluvaquentic Endoaquent in the USDA system and Dystric Fluvisol in the WRB system. Ernest and Onweremadu (2016). classified Ogechie River floodplain soils in Ngor-Okpala. Imo State. Southeastern Nigeria into Aeric Khandic Plinthiaquults (foot slope). Aeric Typic Hydraaquent (Midslope). and Aeric Aquandic Fluvents (summit) in the Soil Taxonomy which correlated with WRB as Haplic Plinthosol. Haplic Fluvisol and Haplic Fluvisol. respectively. Earlier Igwe (2003). working on pedogenc horizons of five soil profiles located on an east-west chronoseqence at different depositional stages of the Niger River in eastern Nigeria. classified the soils into Dystric Fluvisol. Dystric Gleysol. Dystric Gleysol. Eutric Gleysol and Eutric Gleysol in the FAO/UNESCO system.

In southern Nigeria Akpan-Idiok and Antigha (2009). classified floodplain soils in Northern Cross River State of Nigeria as Vertic Fluvaquents and Fluvaquentic Humaquepts under the USDA soil classification system. The corresponding classes under the WRB of Soil Resources were Dystric Gleysols or Gleyic Cambisols. In another study. Akpan-Idiok and Ogbaji (2013). classified Onwu River floodplain soils of Akraba soil unit I as Typic Khandiudults in the USDA Soil Taxonomy and Haplic Acrisols in the (FAO. 2006) criteria. The soils in the Akraba soil unit II classified as Flaquentic Humaquepts in the USDA system and Gleyic/Vertic Cambisols in the FAO (2006) system. Dickson et al. (2002) classified four well drained soils of the levee crest of Oruma from the Meander belt deposits in Bayelsa. southern Nigeria as Typic Eutropept. Udic Dystropept. Dystric Udipsamment and Eutric Udipsamment in the USDA Soil Taxonomy and Eutric Cambisol. Dystric Cambisol. Dystric Fluvisol and Eutric Regosol in the FAO/UNESCO Soil Classification system. respectively. The moderately well drained soils of the levee slope classified as Aquic Eutropept and Eutric Gleysol in the USDA Soil Taxonomy and FAO UNESCO Soil Classification systems.

respectively. For the poorly drained floodplain and back swamp soils, Dickson et al. (2002) classified them as Eutric Fluvaquept and Vertic Tropaquept in the USDA Soil Taxonomy and Eutric Fluvisol and Verti-Eutric Gleysol in the FAO/UNESCO Soil Classification systems, respectively. From the report of Dickson and colleagues, the studied soils belonged to Entisol and Inceptisol soil orders in the USDA Soil Taxonomy.

2.3.3 Utilization of Flood Plain soils

Floodplain soils worldwide, are very useful for agricultural production as they constitute a huge reserve of available nutrients for utilization by crop plants (Akpan-Idiok and Ogbaji, 2013). Alluvial soils form as a result of transportation and re-deposition of parent materials by river and sea which have higher organic matter content. From the point of view of Effiong and Ibia (2009) the agricultural potentials of alluvial soils have not been fully exploited because of lack of understanding of their physical and chemical properties and the changes they undergo under intensive cultivation. The main limitation to the utilization of alluvial soils is either low permeability of the soils and/or presence of high water table. Alluvial soils occur in almost all climatic zones and constitute approximately 66 million hectares of land area of the humid tropics (FAO, 1976). According to Udo (1995) alluvial soils occupy about two percent of African soil, over three percent of South American soil, a quarter of the soils of India and a high proportion of the agriculturally productive soils of both Pakistan and Bangladesh. Alluvial soils are fertile grounds for swamp rice and other dry season crops. Floodplain soils are used for aquaculture (Sheriff et al., 2008; Nagabhatla and van Brakel, 2010). About 47% of the floodplain soils distributed along major active rivers in West Africa are being utilized for rice production. In spite of this, crop production in upland soils over the years has remained very popular while alluvial soils are grossly under-utilized (Udoh et al., 2011). The situation where upland soils presently face stiff competition with non-agricultural land uses, especially those related to urbanization and industrialization, calls for greater attention being given to floodplain soils. It has been established that an efficient management of river basins will assist significantly in solving the problems of poor agricultural productivity in any country.

Agricultural projects under River Basin development scheme involved arable crop production utilizing mainly the floodplain and valley bottom soils and to some extent the adjoining upland (Fasina, 2008). In Africa, about 12 million hectares of floodplain have been put into agriculture. In West Africa, about 47% of floodplain soils have been put to rice cultivation

(Wakatsuki, 2005), while about 65,783 hectares of floodplains, constituting 7.2% of the total land area have been identified in Nigeria (Ojanuga et al., 2003). In Cross River State of Nigeria, Akpan-Idiok et al. (2012) identified about 79,995 hectares of floodplain, most of which are useful for agricultural production especially in areas where the flood level is low enough for rice cultivation during the rainy season.

2.3.4 The Flood Plain Soils of the Niger Delta

The alluvial soils in the Niger Delta area are poorly understood. Sutton and Loganathan (1986), described them as more fertile soils and different in many respects from soils of other geomorphologic units owing to recentness of the sediments that formed the soils coupled with high and well distributed rainfall and temperature. The Soils of the Niger Delta area vary from sandy through loam to clay (Ilaco, 1966.). Depending on the parent materials from which the soils are formed, the soils range from low through medium to high in fertility (Anderson, 1967; Dickson et al., 2002). Based on geomorphic units in the area, the following soil associations have been identified (Anderson, 1967; Okonny et al., 1999):

(i) Soils of the Lower Niger Floodplains
(ii) Soils of the Coastal Plain Sands
(iii) Soils of the Sombreiro-Warri Deltaic Plain
(iv) Soils of the Fresh water Alluvial Plain
(v) Soils of the Mangrove Swamp Zone
(vi) Soils of the Beach-Ridge Zone

The study is concentrated on soils of the Lower Niger floodplains and soils of the Fresh water alluvial plain. The lower Niger Floodplain is an extensively wide floodplain consisting of two portions centered at Onitsha. The upper portion is a triangular-shaped, extensive floodplain stretching for a distance of about 107 km from Idah to Onitsha and including the tributary floodplains such as the Anambra River. The lower portion stretches from Onitsha to the point where the Niger bifurcates into the Nun and Forcados Rivers. It is about 94 km long, and between 3– 46 km wide. The Lower Niger Floodplain varies in width from about 45km in its widest part to 30km in its mid-section and tapers to only about 7 km just north of Onitsha.

The soils of the Lower Niger floodplains include levee soils fringing the river channels or abandoned river channels, back swamp soils, clay plain soils that are seasonally flooded, and permanently swampy soils. These soils intersperse with ponds which never or seldom dry out. Mutter (1973) report on these soils indicate that the levee soils are mainly yellowish brown sandy loams which may be flooded to shallow depths (less than 2 m) annually from August to November when the Niger River is in high flood peak. The back swamp soils and the clay plain soils are flooded annually to a greater depth (up to 5 m). They are poorly to very poorly drained, mottled silty clays and clays which receive a load of silt annually due to flooding. The swampy soils are perennially waterlogged. The soils along the tributary floodplains are heterogeneous ranging in texture from loamy sands to clay. They are seasonally flooded to shallow depths (rarely exceeding 1m in most places).

The freshwater alluvial zone or the meander belt soils occupy a greater portion of Bayelsa State. The area covers the upper and lower delta plains that form the relatively low-lying broad and more gently sloping portion of the Niger Delta basin, comprising small meander oxbow lakes, flood plains, alluvial covers, and alluvial fans, natural levees of rivers and creeks, and back swamps. The landscape consists of a system of natural levees bordering the river channels and of low-lying flood-plains behind the levees. As stated above, soon after entering the state, the Niger River splits into two branches – the Nun and the Forcados Rivers. These two branches flow sea-wards, giving a succession of smaller distributaries. All these channels are bordered by raised levees. Levees also border ox-bow lakes, old channels which have been silted up and so on.

The freshwater alluvial soils are grouped as northern freshwater alluvial soils for those in the upper delta plain and southern freshwater alluvial soils for those in the lower delta plain. The depth and duration of flooding of these soils varies. In the northern Delta, the plain is usually flooded deeply (up to 10 feet) at the peak of the Niger flood but the flood water drains away after a few weeks. At the sea-ward edge of the freshwater zone (southern freshwater alluvial soils), flood depths does not exceed 1.5 to 2 feet but the water does not drain away easily and the soils are swampy (anaerobic) for 6 to 9 months of the year. However, based on texture and length of time flooding is experienced, the following soil types are recognized:

(i) Levee crest soils
(ii) Levee slope soils
(iii) Flood plain soils
(iv) Back swamp soils
(v) Back swamp forest soils (permanent swamps)
(vi) Recent alluvial soils in silted up channels
(vii) Recent alluvial soils in channels of present active river (Anderson, 1967)

The levee crest soils occupy the highest position of the land in the Meander Belt and are located near rivers, creeks, ox-bow lakes, old silted up Channels, etc. Their heights above the sea level make them the least flooded soils hence they are the main agricultural soils of the Niger Delta area and towns and villages are located on them. Those in the upper (northern) delta are well above water level (8 m or more) for most part of the year with depth to ground water table of about 3 m or more. The levee crests of the lower (southern) delta plain are much lower with only about 1m above the groundwater table. Thus, for a long period, the water table is very near the surface during the floods. Since the levees are built by the deposition of alluvium from flood-water, even the crests are liable to be flooded at the peak of heavy floods in September or early October, to a depth of 10 – 15 cm for about 2-3 weeks. During low flood years, the levee crest soils are never flooded, especially in the upper delta. Further south the crests of the levees are much lower, since the flood heights diminishes as the flood spreads out over the Delta. At the sea-ward edge of the fresh-water zone, the levees may be only 45 cm above the dry season river level. The water-table will be at about 45 cm in the dry season, will start to rise in June and will continue to rise until the soils are flooded in September. In late October the floods begin to fall but the water table will not reach its original level until the following year (about February). Thus, although the soil is actually flooded for only a few weeks, as in the upper delta, there are long periods when the water-table is very near the surface. This restricts the use of these soils.

The levee slope soils occur at the back slope of the levee between the levee crest and the flood plains. Some of the soils are submerged at the peak of heavy floods up to 2m or more. Generally, the heights of the levees decline from the upper delta plain southwards, towards the sea where the levee slope is narrower. Where the levees are low and are completely submerged to a depth of 30cm at the peak of the flood, the soils of such levees are placed under the levee slope group (Anderson, 1967). Some of the levee slope soils, once flooded like the ones above, are now better drained. The levee slope soils close to Otuake and Kolo Creeks are now flooded for not more than a few centimeters deep at the peak of the flood (Okonny et al., 1999). This is attributed to the fact that the Niger River flood no longer extends to this part of the delta and the Orashi River is not large enough to flood the area the way the Niger flood use to flood the area. Though, not deeply flooded, these soils remain very wet in the wet season because their drainage channels are silted up, and swollen easily with the rain water. Such water does not drain away so easily and causes ponding on depressions in the levee slopes.

The flood plain soils are the low-lying stretches of land bounded by the levee slope and the back swamp. When flood water starts rising, they usually pass through several breaks through the levees, allowing the flood water which fills the flood plain to drain away when the river water level falls. Therefore, the flood plains are better drained than the back swamps. These soils however, are highly dissected by creeklets, river beds and by seasonal or permanent lakes creating a rather uneven surface making it impossible for effective flood control, which restricts their use for large-scale rice cultivation (Anderson, 1967).

The back swamps soils are soils flooded for more than 3 months in a year. Due to the low heights of the levees, especially in the lower delta, the flood water in some flood plains is very close to the dry season river level, making it difficult for the water to flow back into the river even when the floods recede in October/November. Such areas are called back swamps. In some cases, the flood plains lack channels connecting them to the river and drainage of water after the floods is slow. These soils are very similar to the recent alluvial soils in silted-up channels except that they develop as banks on the insides of bends of the larger rivers. They are found along Ekole Creek, Forcados River and Nun River and part or all of the area may be submerged for months during the floods. They have characteristics that are similar to soils in silted-up channels but for higher phosphorus content (Ayolagha et al., 1994). They are of immense agricultural value in the Bayelsa state. With continuous deposition of alluvial materials, the soils develop into levee slope or levee crest soils (Okonny et al., 1999).

In the floodplains covering upper slope, middle slope, lower slope, back swamp and recent alluvium on channels of present active rivers in Bayelsa State, rotational cultivation of food and cash crops, fisheries and forestry constitutes the major economic activity with over 65 percent of the people engaged in the sector Allison-Oguru (Allison-Oguru, 1995) .The major cultivated food crops include plantains/bananas (*Musa spp.*), cassava (*Manihot esculenta Cramts*), water yam (*Dioscorea alata*), cocoyam (*Colocasia esculenta*), and swamp rice (*Oryza sativa*). In addition, oil palm (*Elaeis guinensis*), rubber (*Hevea brasiliensis* M.A.), cocoa (*Theobroma cacao* L.), coconut and cola nut are cultivated as cash crops. Minor cultivated crops include sugar cane (*Saccharum officinarum L.*), pineapple (*Anana comosus*), sweet potato (*Ipomea batata*), groundnut (*Arachis hypogea*), melon (*Colocynthis vulgaris*), pepper (*Caspinum spp.*), eggplant (*Solanum melongena*), fluted pumpkin (*Telfaria occidentalis*), okra (*Abelmuscus esculenta*), maize (*Zea mays*), etc. (Hartoungh, 1966.; Allison-Oguru et al., 1999).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the Study Area

The Niger Delta region is located in the Southern part of Nigeria, bounded by the Atlantic Ocean in the south. The region is considered to be the largest delta in Africa and home to the largest contiguous Mangrove forest in Africa and third largest in the world, following Indonesia and Brazil (Adegoke et al., 2010). Geographically, Ologunrisa (2004) defined the Niger Delta region as a low lying accurate deltaic plain with a northern apex a little south of Onitsha at Aboh (5° 33' 44" N, 6° 31' 38" E), a Western apex by the estuary of the Benin River (5° 44' 11" E), and Eastern apex at Imo River Estuary (4° 27' 16" N, 7° 32' 37" E). The southernmost point is at the palm point (4 16' 22" N, 6° 05' 27" E) (NDES, 1997). It is estimated to cover almost 26,000 km^2, approximately 2.8% of the land area of Nigeria (Ologunrisa, 2004).

This study focuses on the Bayelsa State which is one of the 36 states in Nigeria from the South-South geo-political zone (Figure 3.1). Bayelsa state is located in the heart of the Niger Delta geographical aspects. The study was carried out between longitudes 05 22' 03.9" N and 04 59' 08.9" N and latitude 006 30' 21.1" E and 006 06' 54.1" E. The names of the study locations are Elemebiri by the Lower Niger River, Odoni by the Nun River and Trofani by the Forcados River, all in Sagbama Local Government area, Odi by the Nun River in Kolokuma/Opokuma Local Government area, Koroama by the Taylor Creek in Yenagoa Local Government area and Niger Delta University Teaching and Research Farm by Igbedi Creek in the Southern Ijaw Local Government area, all in Bayelsa State.

3.1.1 Land, Soil and Water

The region is endowed with immense natural resources, especially hydrocarbon deposits which dominate the Nigerian economy, accounting for over 90% of the nation's total foreign exchange earnings. The Niger River bifurcates to form delta with several rivers through which the river drains into the Atlantic ocean and the continuous switching make up the depositional profiles of Niger Delta sedimentary geology (Okonny et al., 1999). The land forms that result from this depositional profile are levee crest, levee slope, flood plains, back swamp and recent alluvial soils in channels of present active rivers.

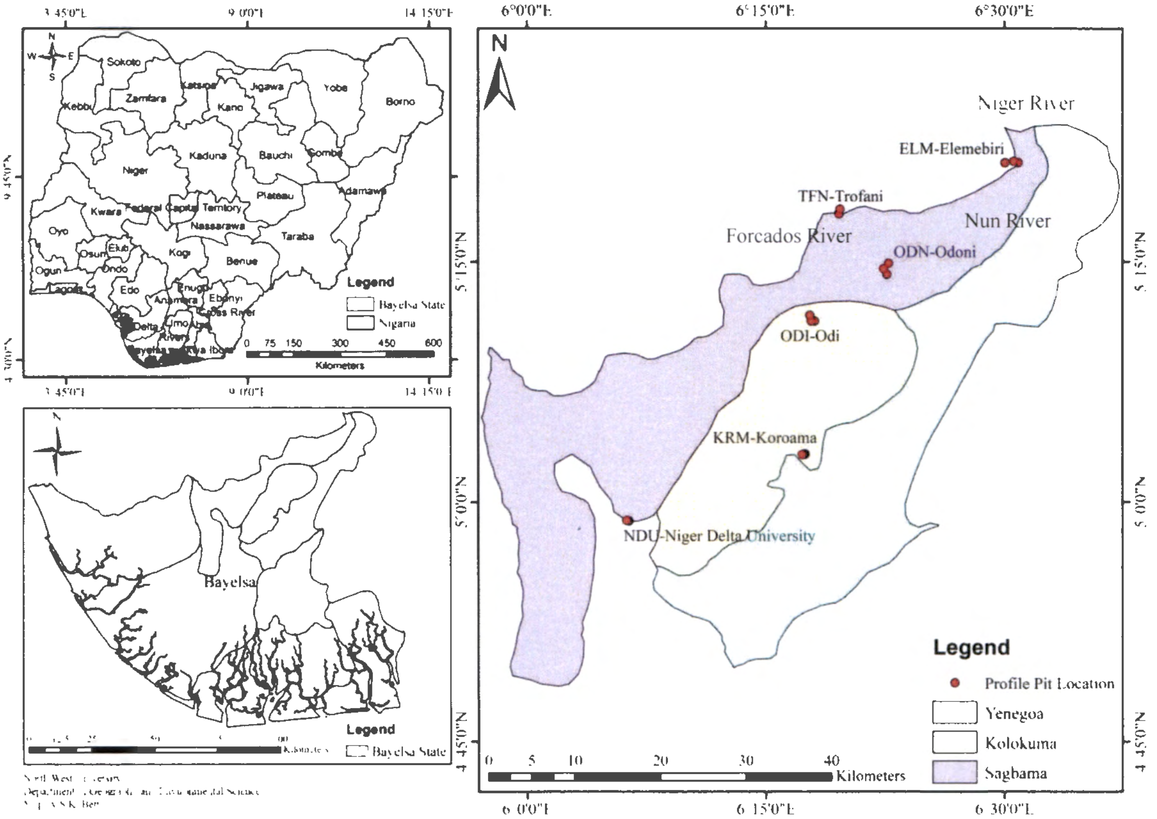


Figure 3.1: Map of Bayelsa State indicating the Sampling Points

The levee crest soils are the least flooded soils among the landforms, hence, the towns and villages in the state are located on them. The levee slope or middle slope soils occur at the back slope of the levees i.e., between the levee crest and the flood plains. Part of the levee slope soils are submerged at the peak of annual floods that are heavy. The flood plain or lower slope soils are on the low-lying stretches of land bounded by the levee slope and the back swamps. The flood plain soils are flooded yearly but are better drained than the back swamps (Okonny et al., 1999). Alluvial soils in the channels of present active rivers are flooded yearly by the river floods and receive yearly alluvial materials from the annual floods.

The Niger River flows south and breaks up into the Forcados and Nun Rivers close to the northern extremity of the state, and this begins to define the triangular shape of the delta from this point. The Nun River, running north and south, down the middle of the state, remains the most direct tributary of the Niger River, while the Forcados River demarcates the western borders of the state. Bayelsa State comprises the core of the present Niger Delta, embracing the vast majority of the rivers, directly discharging waters of the Niger River into the Bight of Benin.

3.1.2 Climate

The climate of Bayelsa State is identified as a humid semi-hot equatorial climate of the Af type of Koppen's system of climate classification (Oyegun, 1999). Weather conditions over the state are brought about by the moist tropical maritime air mass and the dry and dust laden tropical continental air mass. The former is prevalent during the rainy season and blows from the Atlantic Ocean while the latter originates from the high pressure belt of the Sahara Desert and blows over the state in the dry season.

The mean annual rainfall ranges from 2000 to 4000 mm and spreads over 8 to 10 months of the year between the months of March and November which coincides also with the wet season with a mean rainfall of 2500 mm (Chude, 2012). There is a slight break between July and September. This short dry season is called the August break. The duration of the dry season is comparatively short beginning from December to February – a period of about three months. It is not uncommon to experience occasional rainy days and storms even in the short dry season.

Temperature is fairly constant throughout the year over the entire state with a maximum of 30 C. Mean temperature is between 26 C to 27 C (Chude, 2012). Variation in temperature begins in the month of February and peaks at 30 C in the month of September only to decrease to 26°C in November at the onset of the harmattan winds. Sunshine hours are reduced to a minimum over the state because of uniform and continuous cloud cover. The region receives less than twenty (20) hours of sunshine per month between the months of June and September each year (Oyegun, 1999). According to Chude (2012), daily sunshine hours are generally low, ranging between 1.5 hours in September to 6.1hours in December. The mean annual evapotranspiration is estimated at about 1000 mm per annum and evapotranspiration losses are at maximum in February (about 129 mm) and lowest in September (about 70 mm).

Relative humidity is comparatively uniform over the state because of the proximity of the region to the Atlantic Ocean. The months of June and October record a mean of over 80%. The dry season month of January records a lower value of 65%. The value rises with the onset of the rains, peaking at 78% in the month of May. Coastal locations have relatively higher values most of the year with an average relative humidity of 90%. Relative humidity is considerably reduced in the month of December with values ranging between 55 and 65%.

3.1.3 Geology/Geomorphology

Bayelsa State and Rivers State in Nigeria have a common geology as they lie in the Niger Delta. In geological parlance, the Niger Delta is a modern Delta as it is under 100 million years old. It ranks 10th among the world's most prominent Deltas. The Niger River traverses some five other countries, namely Guinea, Mali, Niger, Burkina Faso and Benin before entering Nigerian territory. It traverses across Nigeria in a northwest to southeastern direction. The thousands of kilometers of drainage with the attendant sediment load has ensured that the delta platform ends up as flat terrain, bearing in mind the number of years, this process of deposition has been going on. The sediment profile, vegetation, and the fact that Niger Delta, essentially, is a wave and tide dominated delta (Coleman, 1976), makes it a unique geological environment.

The sedimentary profile shows three main formations that are map-able and of distinct rock units. Beginning from the bottom are mainly Shales from a marine source called the 'Akata formation'. Next to this unit is the Agbada formation: a mix of sand and shale units confirming marine and continental mix of sediments.

The Niger River, its tributary, and the Benue River carry a heavy sediment load to the Atlantic Ocean and as these areas get heavy laden, bifurcate and display braiding, meandering and switching. These features are typical of all fluviatite dynamic systems. It thus follows that meanders in the delta have a natural character. The rivers cut a profile, fill it up and move to another channel. It cuts again and fills it up, and these continuous switching make up the depositional profiles of Bayelsa Sedimentary geology. Eventually, the two main trunks of the Niger and Benue Rivers form one trunk, the Niger River, which at its full load bifurcates just south of Samabiri into the Forcados and Nun Rivers (Figures 3.1). The two rivers eventually lead to some twenty other rivers that fan out into a lobate structure. They all debouch into the Atlantic Ocean, whatever is left of their sediment load. From the tip of the beginning of Bayelsa State to where the Niger River bifurcates into Nun and Forcados Rivers is the Lower Niger Floodplains. However, three geomorphologic units namely the Beach Ridge deposits (BRD) also called Barrier Islands, Mangrove Swamps deposits (MSD), and the Meander Belts deposits (MBD) make up greater part of the surface geology of Bayelsa State. The geological materials consisted of recent deltaic deposits, including sands, silts and clays of Holocene age Ogunkunle et al. (1999). The freshwater flood plains consisted of levees (crest and slope), basins and basin swamps.

3.1.4 Vegetation

The natural vegetation of the area is moist lowland tropical rainforest. According to (Nyananyo, 1999), the primary tropical forest has a stratified structure of closed strands of three stories. The first or top stratum consists of relatively few species with wide spreading crowns not in lateral contact with each other, dominated by plants with canopy of 40 m and above in height. The second or middle stratum is from 15 to 40 m in height consisting of large variety of species with small crowns generated in lateral contact with each other. The third stratum or under-storey consists of trees of less than 15 m high, with rather spreading crowns often bound together with woody climbers (lianes). At the fringes of the forest is the herbaceous layer. Occasional oil palm trees are encountered in the primary forest which is evidence of former disturbance by man. Some of the plants present include *Irvingia gabonensis, Mitragyna ciliate, Lophira alata Elaeis guinensis*, etc.

Secondary forests are dense, non-storied regrowth forest having trees and shrubs. Some of the species encountered include *Lophira alata, Elaeis guineensis, Aspilia africana, Chromolaena odorata*, etc. Farming is done more on the regrowth forest due to the limited capacities of farmers to clear the primary forests.

3.1.5 Land Use and Cropping Systems

In Bayelsa State, agriculture (rotational cultivation of food and cash crops), fisheries and forestry constitute the major economic activities with over 65 percent of the people engaged in the sectors (Allison-Oguru, 1995). The state is covered by a mixture of primary, secondary and or regrowth forests, blessed with seasonal lakes and fish ponds. Fallow lands characterized by sparse vegetation in the state point to the fact that land rotation is still a common agricultural practice.

The major cultivated food crops include plantains/bananas (*Musa spp.*), cassava (*Manihot esculenta Cramts*), water yam (*Dioscorea alata*), cocoyam (*Colocasia esculenta*), and swamp rice (*Oryza sativa*). In addition, oil palm (*Elaeis guinensis*), coconut (*Cocos nucifera*), rubber (*Hevea brasiliensis* M.A.), cocoa (*Theobroma cacao* L.) and cola nut are cultivated as cash crops. Minor cultivated crops include sugar cane (*Saccharum officinarum L*), pineapple (*Anana comosus*), sweet potato (*Ipomea batata*), groundnut (*Arachis hypogea*), melon

(*Colocynthis vulgaris*). pepper (*Caspium spp.*). eggplant (*Solanum melongena*). fluted pumpkin (*Telfaria occidentalis*). okra (*Abelmuscus esculenta*). maize (*Zea mays)* (Allison-Oguru. 1995). Although intercropping is the dominant practice. sole cropping is also practiced by some farmers (Allison-Oguru et al.. 1999). The slash and burn system is the main method of bush clearing. However. in recent times. the use of herbicides for land clearing by the locals is increasing. Fallowing of land or land rotation aimed at naturally enriching the fertility of the soil is a common practice in the area. but with increasing population. fallowing of land is dwindling and where practiced. fallow period is getting reduced. Generally speaking. the cultivation of these crops by farmers is usually without scientific investigation to ascertain the suitability of land for the cultivated crops.

3.2 Selection of Sampling Sites

Figure 3.1 is the map of Bayelsa State showing the study locations while on figures 4.1 to 4.6 are maps showing the study area and the profile pit locations. The study locations are agricultural lands from six communities. namely Elemebiri by Lower River Niger. Odoni and Odi by Nun River. Trofani by Forcados River. Koroama by Taylor Creek and Niger Delta University by Igbedi Creek. These locations were chosen because they are major agricultural communities that meet the food needs of the state. Moreover. some of these sites in which agriculture is practiced are very unique because of the alluvium depositional trend. Table 3.1 shows the list of the study locations indicating soil mapping units. geo- reference of profile pit and land area.

Table 3.1: Soil Mapping Unit, Profile Pit Location and Land Area

Study Location	Soil Mapng Unit	Geo-reference Point of Profile Pit	No. of Profile Pit	Land Area (Hectares)	Land Area (%)
Elemebiri	ELM1	N 05 21′ 11.5″ E 006 30′ 02.2″	1	29.08	2.4
	ELM2	N 05 21′ 12.4″ E 006 30′ 51.3″	1	21.25	1.7
	ELM3	N 05 21′ 22.6″ E 006 30′ 51.3″	1	162.14	13.3
Odoni	ODN1	N 05 14′ 12.4″ E 006 22′ 37.2″	1	89.94	7.4
	ODN2	N 05 14′33.3″ E 006 22′25.5″	1	52.10	4.3
	ODN3	N 05 14′ 53.3′ E 006 22′ 43.4″	1	90.57	7.4
Trofani	TFN1	N 05 18′ 01.5″ E 006 19′ 36.0″	1	87.61	7.2
	TFN2	N 05 17′ 58.6″, E 006 19′ 37.1″	1	51.50	4.2
	TFN3	N 05 18′ 17.1″, E 006 19′ 41.2″	1	148.51	12.2
Odi	ODI1	N 05 11′ 17.4″ E 006 18′ 04.6″	1	142.49	11.7
	ODI2	N 05 11′ 17.1″, E006 17′ 52.3″	1	65.06	5.3
	ODI3	N 05 11′ 38.7″ E 006 17′ 47.0″	1	138.65	11.4
Koroama	KRM1	N 05 02′ 59.9′, E 006 17′ 28.8″	1	13.18	1.1
	KRM2	N 05 02′ 59.2″,E 006 17′ 26.9″	1	10.65	0.9
	KRM3	N 05 02′ 58.1″, E 006 17 14.0″	1	21.43	1.8
Niger Delta University	NDU1	N 04 58′ 49.1′ E 006 06′ 23.7″	1	24.05	2.0
	NDU2	N 04 58′ 49.9′, E 006 06′ 17.5′	1	7.53	0.6
	NDU3	N 04 58′ 50.5′, E 006 06′ 15.7′	1	60.53	5.0
Total Hectrage			**18**	**1,216.26**	

3.3 Sampling Techniques

All soil sampling procedures adopted followed the standard methods of the Soil Survey Staff (2014) and the Reference Soil Groups of World Resource Base (FAO/ISRIC, 2006). Baseline was formed and transects cut perpendicular to the baseline to cover each survey area after a reconnaissance visit to each of the study sites. The rigid grid technique was employed for the survey with augering and observations made at 100 m intervals (Alemayehu et al., 2014) to a depth of about 200 cm. Texture, colour, drainage, mottling pattern and intensity, and soil depth, were examined. Based on soil colour change, mottling pattern and intensity and change in drainage condition, boundaries were delineated between levee crest, levee slope and flood plain. Where sudden or visible change in surface features such as vegetation, slope, etc. were observed, the augering distance was either reduced or increased to cover that area in order to ascertain possible differences in soil in the area and the need for a separate profile pit dug to represent that area. Points with similar texture, colour, mottling pattern and intensity and drainage class were considered as part of the same mapping unit and the major soil types were identified as representing the levee crest, levee slope, flood plain and/or recent alluvial soils in the channels of the present active river. Following the identification of the mapping units in each study location, 1 modal profile pit was dug to represent each mapping unit or soil type (levee crest, levee slope, flood plain, and/or recent alluvial soils in the channels of the present active river) making a total of 3 modal pits per study site. Special consideration was given to the landforms on which the communities concentrate their agricultural production in locating the profile pits. As much as possible, representative soil profiles were located on uncultivated areas (fallow areas to guide against recent fertilizer application or other human influences that may affect certain soil characteristics), in a north-south transect (six levee crest, six levee slope, four flood plain and two from recent alluvial soils in channels of present active river).

During the site mapping, slope and geographic coordinates of the land unit boundaries and the soil profile pit locations were recorded. The dimension of each profile pit was 2m long, 1m wide and 2m deep. Eighteen soil profile pits were dug and described between the months of January to March, 2015. Three soil profiles were dug in each of the six study locations namely, Elemebiri (ELM1, ELM2 and ELM3), Odoni (ODN1, ODN2 and ODN3), Trofani (TFN1, TFN2 and TFN3), Odi (ODI1, ODI2 and ODI3), Koroama (KRM1, KRM2 and KRM3) and the Niger Delta University Teaching and Research Farm (NDU1, NDU2 and NDU3) representing levee crest, levee slope and flood plain or recent alluvial soils in the channel of the present active river. All the levee crest soils were attached with the number 1, thus the levee crest profiles were designated ELM1, ODN1, TFN1, ODI1, KRM1 and NDU1. The number '2' was attached to the levee slope soils and the profiles were designated: ELM2, ODN2, TFN2, ODI2, KRM2 and NDU2. The flood plain soils and recent alluvial soils in the channels of the present active river were attached with the number 3, giving the profile designations: ELM3, ODN3, TFN3, ODI3, KRM3 and NDU3. The ODN3, ODI3, KRM3 and NDU3 profiles belonged to the flood plain while ELM3 and TFN3 were recent alluvial soils in the channel of the present active Lower Niger River and Forcados River, respectively. The levee crest, levee slope and the flood plain and/or recent alluvial soils in the channel of the present active river are the landscapes agricultural cultivation is frequently carried out in the respective communities.

3.4 Field Description of Modal Profile Pits

The morphological properties of the modal profile pits were described in the field using the criteria of the USDA soil taxonomy (Soil Survey Staff, 2014) and the Reference Soil Groups of World Resource Base (FAO/ISRIC, 2006). For each modal profile, information was gathered on the profile location, the field legend, the surrounding vegetation, drainage pattern and other environmental characteristics. For each modal profile pit, a digital camera was used to capture the pit and the surrounding landscape while global positioning system (GPS) device was used to reference the geographic coordinates. Then individual horizons in the modal profile were delineated, differentiated and described. Parameters examined in the various horizons after taking horizon depths include texture, colour, clay eluviation and illuviation, consistence, pore characteristics, mottling, root activity, horizon boundaries, content of mineral fragments, etc. Soil samples were collected from each identified pedogenic horizons, for laboratory analyses. A total of 18 profile pits representing the 18 soil mapping units were examined and 122 soil samples collected for physico-chemical analysis in the laboratory. At each sampling location, 3 profile pits were sunk. Profile pit samples were bulked into 18 for mineralogical analysis. Analyses of physico-chemical parameters were carried out in the Green River Project laboratory of the Nigerian Agip Oil Company and Zadell laboratory while mineralogical analysis was done in the Geology Department Laboratory of the Potchefstroom Campus of North-West University, South Africa.

3.5 Laboratory Analyses of the Soil Samples

Soil samples collected from the identified pedogenic horizons in each of the soil profile pits of sampling locations were air-dried, crushed and sieved to pass through a 2 mm sieve (IITA, 1997). Particle size distribution was determined by the hydrometer method as described by Day (1965) while pH was determined in both water and 0.01M $CaCl_2$ solution at 1:2 salt/solution ratio using a pH meter as described by Estefan et al. (2013). Electrical conductivity (EC) was determined using conductivity bridge (Estefan et al., 2013). Exchangeable acidity was extracted with 1M KCl, determined by titration with NaOH solution using phenolphthalein indicator as described by Anderson and Ingram (1993) and the content of exchangeable Al was with 0.01 M HCl (Sumner and Stewart, 1992). Total nitrogen was determined by the macro kjeldhal method as described by Houba et al. (1995) Organic carbon content determined by the modified dichromate oxidation method of Walkley and Black as described by Estefan et al. (2013) while available Phosphorus was by Bray P-1 method (Bray and Kurtz, 1945). Exchangeable cations were extracted with neutral normal ammonium acetate solution as described by Estefan et al. (2013); Effective Cation Exchange Capacity (ECEC) was determined by summation of the exchangeable bases (Kamprath, 1970). Potassium and Sodium in the extract were measured by flame photometry and Calcium and Magnesium by atomic absorption spectrophotometry. Micronutrients [copper (Cu), zinc (Zn), manganese (Mn), iron (Fe)] were extracted by the DPTA (Diethylene triaminepenta-acetic) acid method as described by Estefan et al. (2013), and measured by atomic absorption spectrophotometry. Percent base saturation (PBS) and Aluminum saturation were also computed, using the respective equation as follows:

$$\%BS\ (cmol/kg) = \frac{Ca+Mg+K+Na}{ECEC} \times 100 \qquad (1)$$

$$Al\ (\%) = \frac{Al}{ECEC} \times 100 \qquad (2)$$

Effective cation exchange capacity (ECEC) is sum of the exchangeable bases plus exchange acidity.

3.6 Classification of the Soils

The soils were classified according to the USDA Soil Taxanomy (Soil Survey Staff, 2014) and the Reference Soil Groups of World Resource Base (FAO/ISRIC, 2006). Morphological properties examined include texture, colour, clay eluviation and illuviation, consistence, pore characteristics, mottling, horizon boundaries, content of mineral fragments, depth to water table, root presence and other biological activities, etc. Other general information on the soil considered include parent material, drainage characteristics, soil moisture condition, atmospheric temperature, annual rainfall, slope, evidence of erosion, human influence, etc. Field observations were complimented by the results of laboratory analyses, annual precipitation, drainage, as well as air temperature information in forming the basis for classifying the soils.

3.7 Mineralogical Analyses

The mineralogical study on the clay fraction of the soil samples ($\leq 2\ \mu$) was carried out based on random powder analysis using X-Ray diffraction (Loubser and Verryn, 2008). X-Ray diffraction (XRD) is a non-destructive analytical technique for the identification and quantification of different crystalline phases present in a sample. A PANalytical X'Pert Pro instrument (XRD) was used to do a broad range identification to characterize these crystal structures of the crystalline materials present in the samples. Sample preparation was done using a back loading technique and the samples were loaded onto a spinner stage inside the XRD. The samples were then scanned using X-rays generated by a Cu X-Ray tube. As a result of the different crystalline structures detected in the sample, using an X'Celerator detector, a unique diffractogram for each sample was generated. The diffractogram showed the different phases (peak positions) and phase concentrations (peak heights) of all the crystalline materials present in each sample. Different phases were identified using X'Pert Highscore plus and an International Centre for Diffraction Data (ICDD) (PDF 4+) program which consist of a database of more than 300,000 different crystalline phases. These phases identified in the sample were used to do a Rietveld quantification to determine the weight percentage present of each mineral in the individual samples.

3.8 Land Capability Classification and Fertility Capability Classification

From the morphological, physical and chemical characteristics, the soils were assessed for their capabilities using Land Capability Classification (LCC)- a slight modification of the system of Klingebiel and Montgomery (1961) and LCC modified by Van Ranst and Verdoodt (2005) and Fertility Capability Classification, FCC. (Sanchez et al., 2003). Land capability was estimated by calculating capability index or soil index, being a product of ratings attributed to six soil characteristics:CS= $A\,x\,\frac{B}{100}\,x\,\frac{C}{100}\,x\,\frac{D}{100}\,x\,\frac{E}{100}\,x\,\frac{F}{100}$

Where CS = capability index or soil index

A = rating for profile development

B = rating for texture

C = rating for soil depth

D = rating for colour/drainage conditions

E = rating for pH/base saturation

F = rating for the development of the A horizon

On Annexures 21, 22, 23, 24, 25, 26, 27, and 28 are tables from Van Ranst and Verdoodt (2005) showing Evaluation of capability index for different groups of crops, Definition of Land Capability Classes, Ratings for Profile Development, Rating for soil texture of the fine earth, Ratings for soil depth, Rating of colour/drainage class, Rating of pH and base saturation and Ratings for the development of the topsoil, respectively.

For the LCC system, instead of using rock outcrop, permeability, effective depth, etc. the soils are placed in the appropriate class of the eight capability classes using modifiers such as erosion (e), soil texture (t), wetness (w) and nutrient holding capacity (n), etc. For the FCC system, class designations from the three categorical levels (Type, Substrata type and modifiers) were combined to form the FCC unit.

3.9 Land Suitability Evaluation for Rain-fed Agriculture

The non parametric method proposed by FAO (1976) commonly referred to as "Framework for Land Evaluation", modified by Sys (1985), was used to evaluate the soils for rain-fed agriculture. The suitability of the soils for the production of maize, upland rice, cassava, plantain, oil palm, coconut and rubber was assessed following the method of Sys (1985) and as modified by Djaenudin et al. (2003). Soils were placed into suitability classes by matching the environmental characteristics and soil properties with the land use requirements (LUR) for the respective crops. Pedons were subsequently classified into highly suitable, moderately suitable, marginally suitable and not suitable presently but potentially suitable for the crops. The suitability class scores for each land qualities/characteristics and the aggregate suitability rating was indicated by the most limiting characteristics. In Tables 3.2, 3.3, 3.4, 3.5, 3.6, 3.7 and 3.8 are presented the land use requirement of maize, upland rice, cassava, banana/plantain, oil palm, rubber and coconut, respectively.

Table 3.2: Land use requirement for maize cultivation modified from Sys (1985)

Land Quality and Classification	100-95 S1	94-85 S2	84-40 S3	39-20 N1	19-0 N2
1 Climate (c)					
Annual rainfall (mm)	850-1250	850-750	750-600	600-500	-
		1250-1600	1600-1800	>1800	-
Length of dry season (days	150-220	130-150	110-130	90-110	-
Mean annual max. temp. (C)	22-26	22-18	>32		
Relative humidity (%)	50-80	50-42	42-36	36-30	-
2 Topography (t)					
Slope	0-2	2-4	4-8	8-16	
	0-4	4-8	8-16	16-30	>30
3 Wetness (w)					
Flooding	F0	F0	F1	F2	F3
Drainage	good	moderate	imperfect	poor	v. poor
4 Soil physical characteristics					
Texture	SiC, SiCL, CL, SiL	SL, LS, LfS	LcS, fS	-	S
Coarse fragments (%) 0-10cm	<3	3-15	15-35	35-55	
Depth (cm)	75-100	50-75	20-50	-	<20
5 Fertility					
CEC (cmol kg)	>24	16-24	<16		
Base saturation (%)	>50	35-50	20-35	<20	-
pH	>5.5-7.0	5.5-7.0	5.0-8.0	5.0-8.0	
OC (%) 0-15cm	2	1.2-2	0.8-1.2	<0.8	
Av. P (ppm)	>22	13-22	7-13	3-7	<3
Total N (%)	>0.15	0.10-0.15	0.08-0.10	0.04-0.08	<0.04
Extr. K (cmol kg)	>0.5	0.3-0.5	0.2-0.3	0.1-0.2	<0.1

F0=No flooding; F1 1-2 months seasonal flooding in >10years; F2=not more than 2-3 months flooding in 5years out of 10; F3 2-4 months flooding every year; SiC silty clay; SiCL=silty clay loam; SiL=silt loam; SL=sandy loam; LS loamy sand; LfS=loamy fine sand; S=sand

Table 3.3: Land use requirements for rainfed upland rice cultivation modified from Sys (1985)

Land Quality/Characteristics	S1	S2	S3	N1	N2
1 Climate (c)					
Annual rainfall (mm)	>1400	>1000	>800	<800	<800
Mean temp. (°C) crop dev. Stage	24-36	18-42	10-45	-	-
Relative humidity (%) veg. stage	50-90	any			
Relative humidty (%). milky stage	40-70	>30	<30		
2 Topograhy (t)					
Slope (%) (1)	<4	<8	<16	<25	<25
(2)	<8	<16	<30	<30	<30
3 Wetness (w)					
Flooding	None	None	None-slight	None-slight	Any
Drainage	Good	Moderate better	Imperfect/better	Good. moderate or Imperfect	
4 Soil physical characteristics (s)					
Texture	Loam	Clay loam	Clay	Any	
Coarse fragments (%) surface	<15	<35	<55	<55	<55
Depth (cm) to impermeable layer	>90	>50	>20	>20	>20
Subsurface coarse fragments	<35	<55	<55	<55	<55
5 Fertility (f)					
CEC (cmol kg)	>16	>0, -charge	>0, -charge		
Base saturation (%)	>50	>35	>15		
pH	7.5-6.0	6.0-5.0	<5.0	Any	
Av. P (mg kg)	>15	6-15	<5	Any	
Exchangeable K (cmol/kg)	>0.31	0.30-0.11	<0.11	Any	
Exchangeable Ca (cmol/kg)	12-6	6-3	<3	Any	
Exchangeable Mg (cmol/kg)	12-6	6-3	<3	Any	

Table 3.4: Land use requirements for cassava cultivation (modified from Sys (1985)

Land Quality/Characteristics	S1	S2	S3	N1	N2
1 Climate (c)					
Annual rainfall (mm)	1000-1800	1000-600	500-600	-	<500
length dry season (months)	3-5	5-6	6-7	-	>7
Mean temp. (°C) crop dev. Stage	26-30	>30			
Relative humidity (%)					
2 Topograhy (t)					
Slope (%)	0-8	8-16	16-30	30-50	>50
3 Wetness (w)					
Drainage	good	Moderate	Imperfect	poor drainage	poor non drainage
4 Soil physical characteristics (s)					
Texture	L. SCL. SL. SiL SiC. SiCL. CL. SC	LfS. LS. LC. fS	CS	-	Si
Coarse fragments (%) 0-10cm	No	<15	<35	-	>35
Depth (cm	>100	>75	>50	-	>50
5 Fertility (f)					
CEC (cmol kg)	>16	Any			
Base saturation (%)	>35	<20			
OC (%) 0-15cm	>15-8	<8			

L=loam: SCL= sandy clay loam: SiC=silty clay: SiCL=silty clay loam: SiL=silt loam: SL=sandy loam: LS–loamy sand: LfS=loamy fine sand: S=sand: LC= loamy clay: CS=clayey sand: Si=silt: fS–fine sand: CL=clay loam: SC=sandy clay

Table 3.5: Land use requirements for oil palm cultivation modified from Sys (1985)

Land Quality Characteristics	S1	S2	S3	N1	N2
1 Climate (c)					
Annual rainfall (mm)	›2000-1700	1450-1000	1250-1000	-	‹1250
length dry season	1-2	2-3	3-4	-	›4
Mean temp. (°C) crop dev. Stage	›29-27	24-27	22-24	-	‹22
Relative humidity (%)	›70-75	65-70	60-65	-	‹60
2 Topograhy (t)					
Slope (%)	0-8	8-16	16-30	›30	-
3 Wetness (w)					
Flooding	F0	F1	F2	-	F3
Drainage	perfect	mod. Well	poor, aeric	poor, drainable	poor, non-drainable
4 Soil physical characteristics (s)					
Texture	L, CL, SCL,	SCL	SCL-LfS	Any	C, CS
Structure	Blocky				massive, single grained
Coarse fragments (%) 0-10cm	3-15	15-35	35-55	-	›55
Depth (cm)	›100-90 50-90		25-50	-	‹25
5 Fertility (f)					
CEC (cmol kg)	10-8	6-8	‹6	-	-
Base saturation (%)	20-35	‹20	-	-	-
pH	5.5-6.0	5.5-60	6.5-7.0	‹4 ›7.0	‹4 ›7.0
OC (%) 0-15cm	›12-8	‹8	-	-	-
Exchangeable K (cmol kg)	›1.75-1.5	1.2-0.5	‹1.2	‹1.2	‹1.2
Mg : K ratio	›3.5	2-3.5	1.2	-	-

L=loam; CL=clay loam; SCL=sandy clay loam; LfS=loamy fine sand; C=clay; CS=clayey sand

Table 3.6: Land use requirements for plantain cultivation (Djaenudin et al., 2003)

Land Quality/Characteristics	S1	S2	S3	N1	N2
1 Climate (c)					
Annual rainfall (mm)	1250-1750	1750-2000	2000-2500	>2500	-
		1000-1250	750-1000	<750	-
Temp. (°C)	20-23	23-30	30-40	>40	
		18-20	15-18	<15	-
2 Topograhy (t)					
Slope (%)	<8	8-16	16-30	>30	
3 Wetness (w)					
Flooding	F0	F1	F2	F3	
Drainage	Good	Mod. Poor		very poor, rapid	-
	Moderate		Poor, mod. Rapid		
4 Soil physical characteristics (s)					
Texture (surface)	fine, slightly Fine, medium	-	slightly coarse	coarse	-
Coarse fragments (%) 0-10cm	<15%	15-35	35-55	>55	-
Depth (cm)	>100	75-100	50-75	<50	-
5 Fertility (f)					
CEC (cmol kg)	>16	≤			
Base saturation (%)	>35	20-35	<20		
OC (g/kg) 0-15cm	>1.2	0.8-1.2	<0.8		
pH-H$_2$0	5.0-6.0	4.5-5.0	<4.5		
		6.0-7.5	>7.5		
Salinity (ds m)	<4	4-6	6-8	>8	

Table 3.7: Land use requirements for rubber cultivation (Djaenudin et al., 2003)

Land Quality/Characteristics	S1	S2	S3	N1	N2
1 Climate (c)					
Annual rainfall (mm)	2500-3000	2000-2500	1500-2000	<1500	-
		3000-3500	3500-4000	>4000	-
Dry months	1-2	2-3	3-4	>4	-
Temp. (°C)	26-30	30-34	-	>34	
		24-36	22-24	<22	
2 Topograhy (t)					
Slope (%)	<8	8-16	16-30	>30	
			16-45	>45	
3 Wetness (w)					
Flooding	F0	-	F1	>F1	
Drainage	Good	Moderate	Mod. Poor, poor	very poor, rapid	-
4 Soil physical characteristics (s)					
Texture (surface)	fine, slightly Fine, medium	-	slightly coarse	Coarse	-
Coarse fragments (%) 0-10cm	<15%	15-35	35-55	>55	-
Depth (cm)	>100	75-100	50-75	<50	-
5 Fertility (f)					
CEC-clay (cmol kg)	-	-	-	-	-
Base saturation (%)	<35	35-50	>50		
OC (g/kg) 0-15cm	>0.8	<0.8	-		
pH-$H_2$0	5.0-6.0	6.0-6.5	>6.5		
		4.5-5.0	<4.5		
Salinity (ds m)	<0.5	0.5-1	1-2	>2	

Table 3.8: Land use requirements for coconut cultivation (Djaenudin et al., 2003)

Land Quality/Characteristics	S1	S2	S3	N1	N2
1 Climate (c)					
Annual rainfall (mm)	2000-3000	1300-2000	1000-1300	<1000	-
		3000-4000	4000-5000	>5000	-
Dry months	0-2	2-4	4-6	>6	
Temp. (°C)	25-28	28-32	32-35	>35	
		23-25	20-23	<20	-
2 Topograhy (t)					
Slope (%)	<8	8-16	16-30	>30	
3 Wetness (w)					
Flooding	F0	-	F1	>F1	
Drainage	Good	Mod. Poor	Poor, Mod. Rapid	very poor, rapid	-
4 Soil physical characteristics (s)					
Texture (surface)	Fine, slightly Fine, medium	Slightly fine	Very fine	Coarse	-
Coarse fragments (%) 0-10cm	<60	15-35	35-55	>55	-
Depth (cm)	<140	75-100	50-75	<50	-
5 Fertility (f)					
CEC-clay (cmol/kg)	-	-	-	-	-
Base saturation (%)	>20	<20			
OC (g/kg) 0-15cm	>0.8	<0.8	-		
pH-$H_2$0	5.2-7.5	4.8-5.2	<4.8		
		7.5-8.0	>8.0		
Salinity (ds/m)	<12	12-16	16-20	>20	

3.10 Soil Fertility Evaluation

Soil Fertility index (SFI) (Moran et al., 2000b) and Soil Evaluation Factor (SEF) (Lu et al., 2002) were used to estimate the fertility and site quality of each soil pedon as represented by each of the profile pits. This was done to appraise the productive capacity of each of the pedon.

SFI = pH + organic matter (% dry soil basis) + Avail. P (mgkg^{-1}dry soil + Exch. K (cmol$_c$kg^{-1}) + Exch. Ca (cmol$_c$kg^{-1}) + Mg (cmol$_c$kg^{-1}) – Exch. Al (cmol$_c$kg^{-1})

SEF = [Exch. K (cmol$_c$kg^{-1}) + Exch. Ca (cmol$_c$kg^{-1}) + Exch. Mg (cmol$_c$kg^{-1}) –] x organic matter (% dry soil basis) + 5

The SFI and SEF were used to assess the fertility and productive capacity of the levee crest, levee slope, flood plain and recent alluvial soils in the channels of the present active rivers. Turkey's t-test was used to detect significant differences between SFI and SEF in the different sampling points.

3.11 Data Analysis

Data analysis involving several soil profile pits during soil surveys are complex, due to the large amounts of data generated from the various horizons in the soil. Principal Component Analysis (PCA) is the most common pattern recognition method used in multvaraite analysis and used as the multivariate statistical tool to detect patterns or clusters between objects and variables. The complexity and large amount and variance of the data limit the use of univariate statistical methods in developing a better understanding and assessment of soil processes. One of the strengths of a large data set is that changes in several variables can be considered simultaneously, and multivariate analyses provide powerful methods to achieve this. Multivariate statistical methods are able to detect similarities between variables which make for more profound interpretation of analytical data (Carlon et al., 2001; Gallego et al., 2002; Sena et al., 2002). Multivariate data analysis is beneficial in that large amounts of data can be processed for exploring and understanding relationships between different parameters. This is typically achieved through the procedures of pattern recognition, classification and prediction techniques. Three common multivariate approaches utilized for assessing data obtained through soil and water investigations consisted of Principal Component Analysis (PCA), Discriminant Analysis (DA) and PROMETHEE (Dawes, 2006) hence, PCA was used to analyze the data.

PCA is a multivariate data set of physical and chemical properties of soil analyzed to reduce the original complicated dimensionality and give a few principal component scores that explain the variation in the data (Arifin et al., 2008b). PCA was therefore performed to detect the most important soil parameters that influence the fertility of the soils, identifying the components based on Varimax rotation with Kaiser's Normalization. The relationship between the selected soils parameters were determined by Pearson's correlation analysis. All statistical analyses were performed using SPSS version 21.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Results

When all the study land areas were added together, the total area surveyed was 1,216.26 square hectares. Of this area, ELM3 SMU located on recent alluvial soil on the channel of the presently active Lower Niger River, occupied 162.14 hectares, occupying 13.3% of the study area (the largest) followed closely by TFN3, also located on recent alluvial soil on the channel of the presently active Forcados River, occupying 148.51 hectares, which occupied 12.2% of the total area studied. Following TFN3 soil were the ODI1 and ODI3 soils occupying 142.49 hectares and 138.65 hectares, covering 11.7% and 11.4% of the study area, respectively. The NDU2 SMU occupied the least land area (7.53 hectares), covering less than 1% of the area studied. An interesting observation made during the study was that the levee crest portion of the landscape is fast loosing land to river bank erosion. This was more prominent in Koroama, Odoni, Trofani and Elemebiri study sites. Presented on figures 4.1, 4.2, 4.3, 4.4, 4.5 and 4.6 are maps showing the Elemebiri, Odoni, Trofani, Odi, Koroama and the Niger Delta University Teaching and Research Farm study areas, respectively.

4.1.1 Morphological Characteristics

4.1.1.1 The Soils of Elemebiri

Table 4.1 presents the summary of the morphological characteristics of the Elemebiri soils. The Elemebiri SMUs (Figure 4.1) were designated ELM1, ELM2 and ELM3. The ELM1 SMU occurred on the levee crest or upper slopes of the alluvial plain terraces of the Niger River. They were found on the levee crests of the Niger River, moderately well drain, and free of redoximorphic features up to a depth of 118 cm from the mineral soil surface. The soils fringed the Niger River and were best in terms of drainage as they were no longer flooded by the annual floods of the Niger River. The relief was flat to gently undulating with slopes ranging between 0 and 1%. The horizonization sequence of the pedon was Ap-Ap2-B1-B2-C1-C2-C3-C4 (Plate 1). Soil texture varied from fine silt loam in the surface layers through silty clay loam to silt loam in the subsurface layers. Surface soil colour under moist condition was very dark grayish brown (10 YR 3/2) while colour of the subsurface soil layers

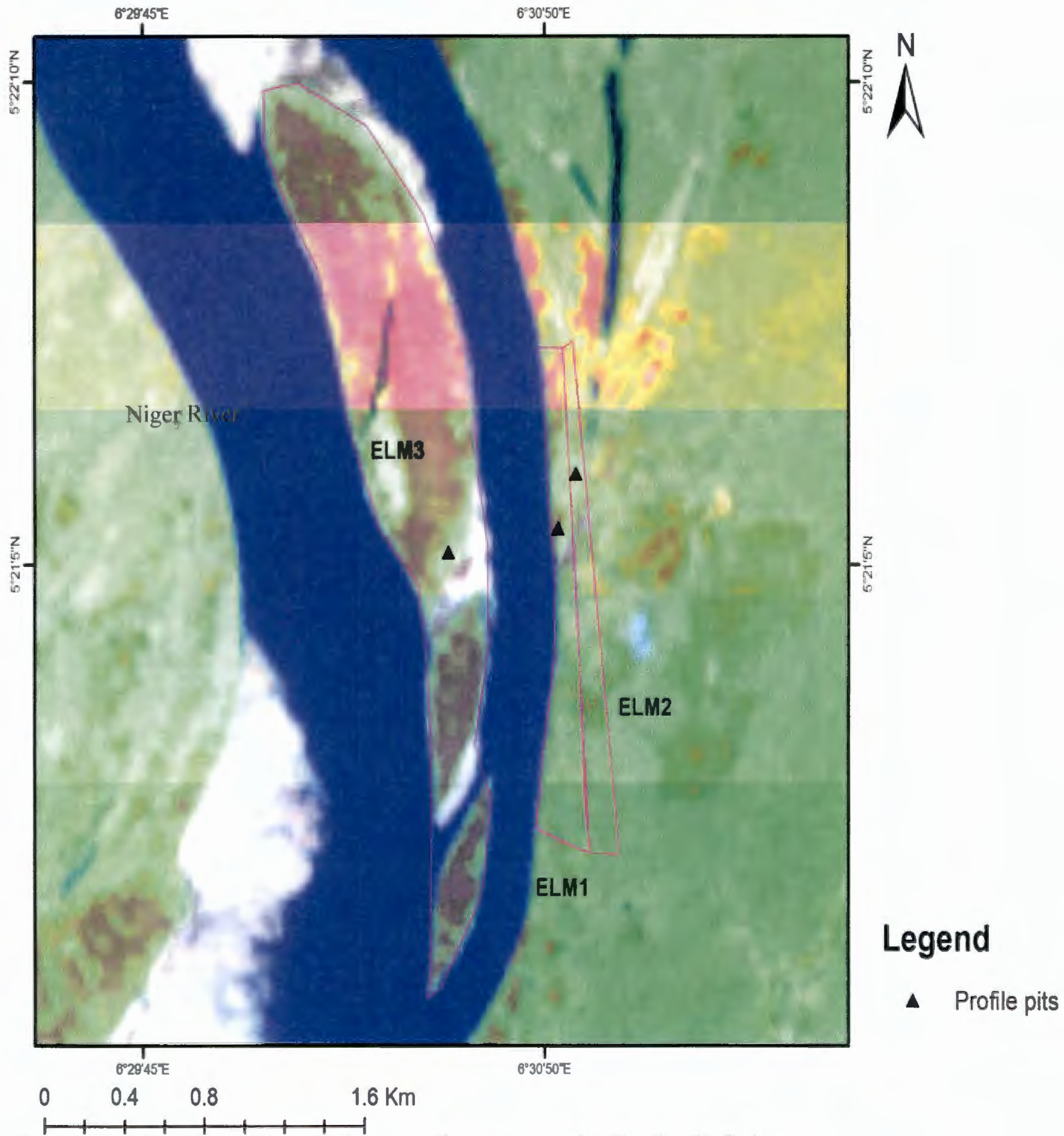


Figure 4.1: Map of the Elemebiri (ELM) Study Area with Profile Pit Points

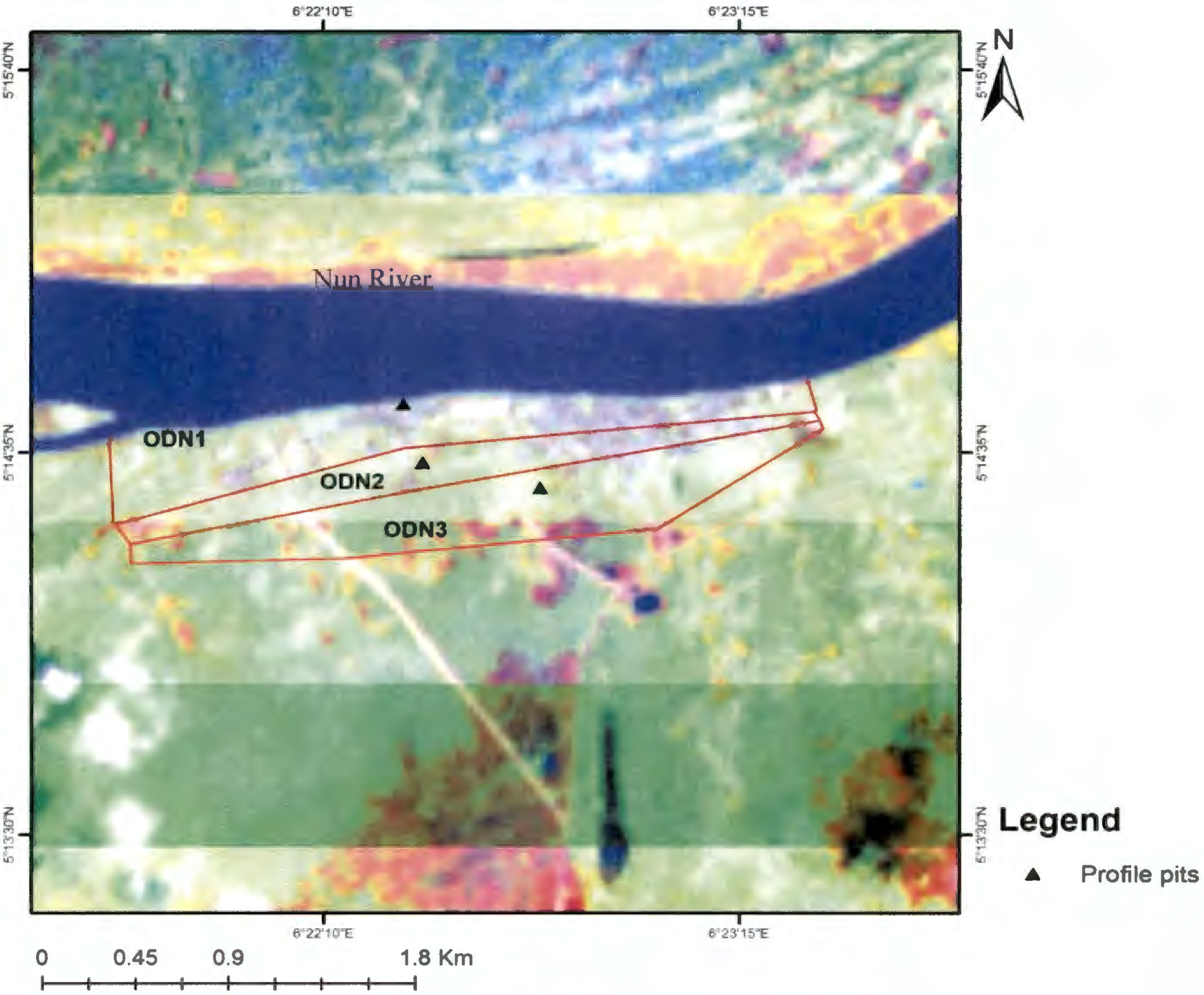


Figure 4.2: Map of Odoni Study Area with Profile Pit Points

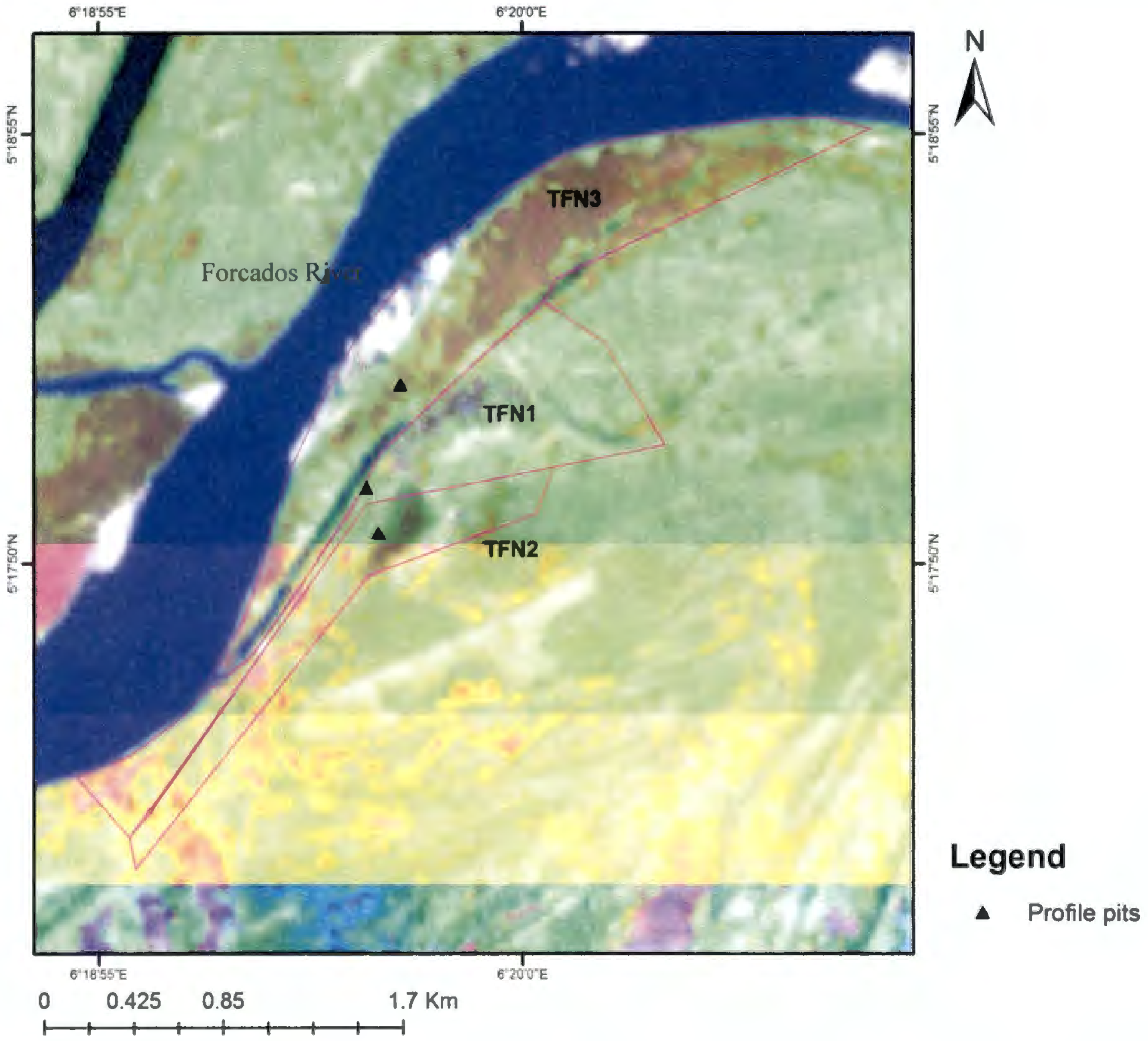


Figure 4.3: Map of Trofani (TFN) Study Area with Profile Pit Points

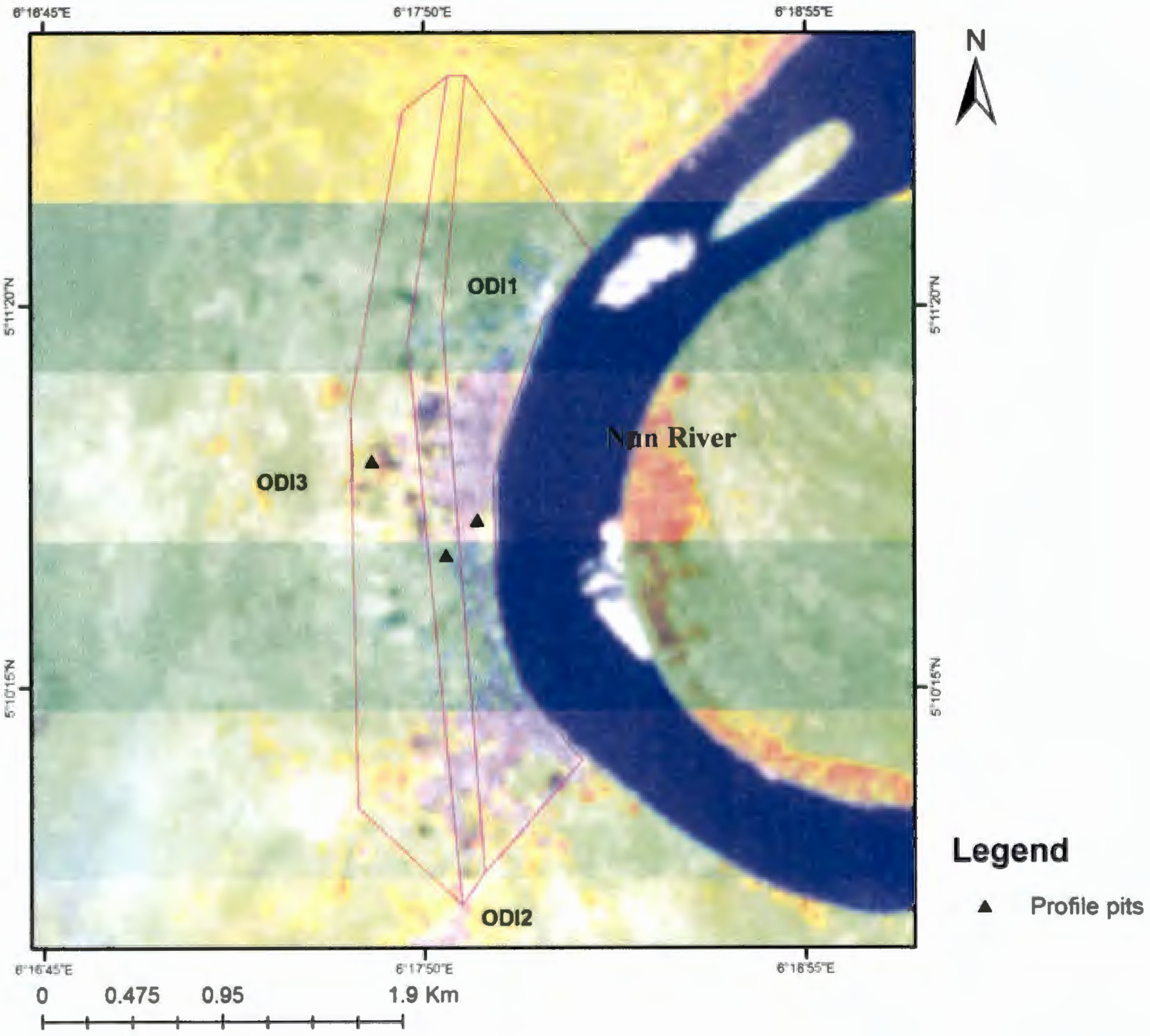


Figure 4.4: Map of Odi (ODI) Study Area with Profile Pit Points

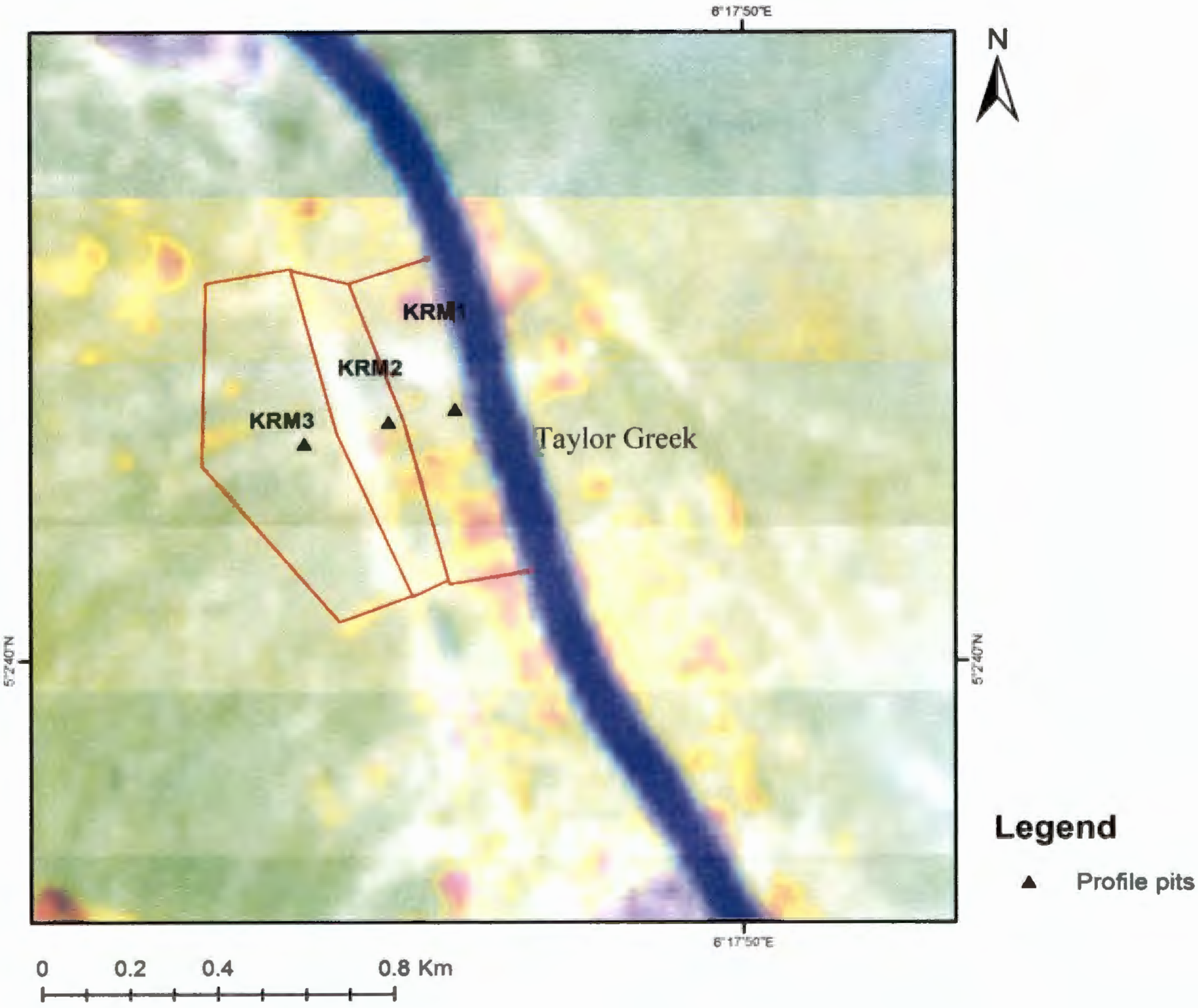


Figure 4.5: Map of Koroama (KRM) Study Area with Profile Pit Points.

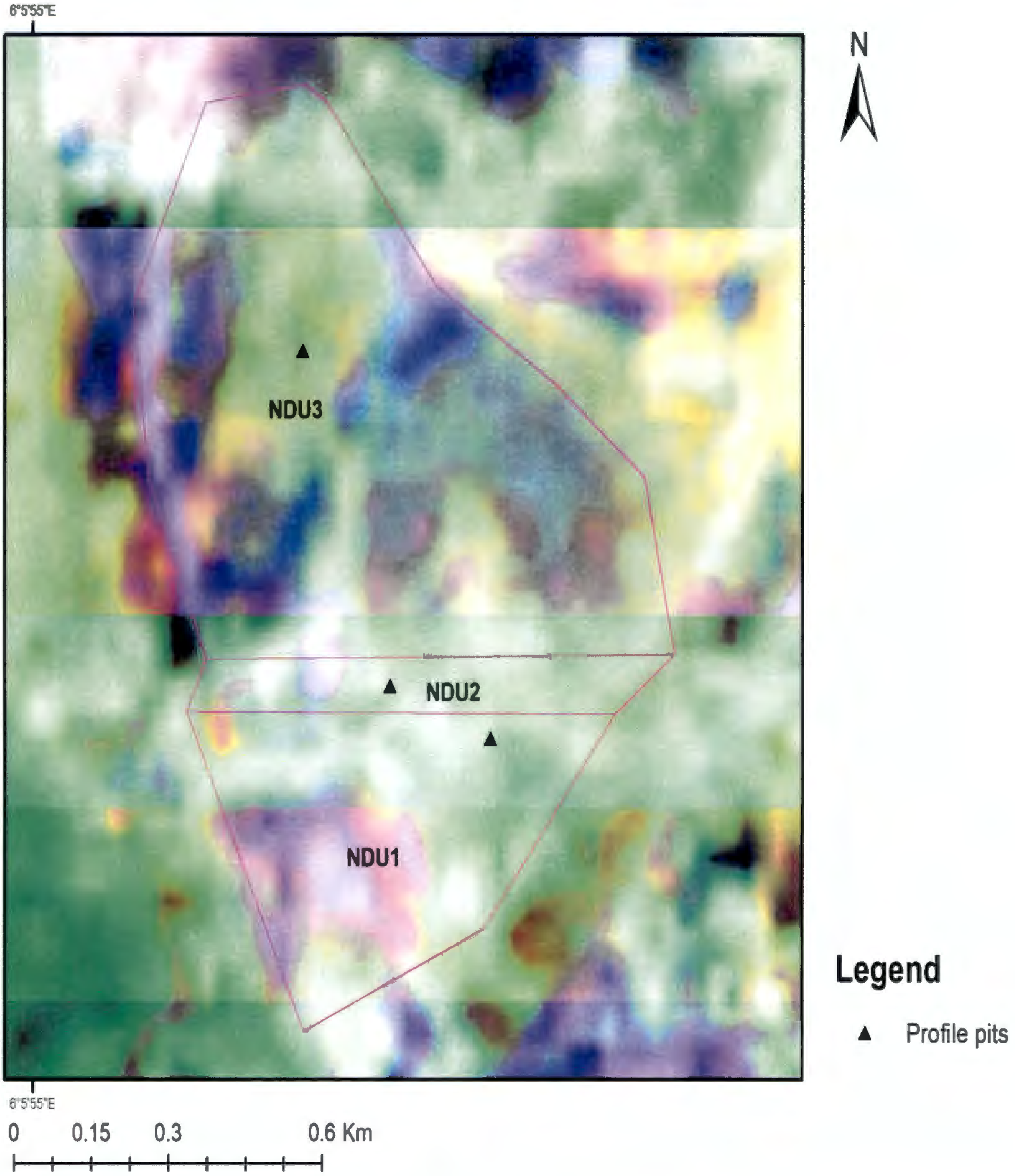


Figure 4.6: Map of Niger Delta University (NDU) Study Area with Profile Pit Points

graded from dark brown (10 YR 3/3) through dark yellowish brown (10 YR ¾), yellowish brown (10 YR 5/4) to brown (10 YR 5/3). Surface soil structure was crumbly to weak sub angular blocky while subsurface structure was sub angular blocky. The moist consistence was friable at the surface layer and moderately firm to slightly firm at the subsurface soil layers. Under wet conditions, surface and subsurface soil consistence were slightly sticky and slightly plastic. Many mica flakes occurred all through the soil profile indicating the presence of weatherable minerals and medium to fine roots were found in the upper layers. The various soils layers were separated by clear smooth boundaries.

Table 4.1: Morphological Characteristics of the Elemebiri Soils

Horizon Designation	Depth (cm)	Soil Colour Moist	Mottles		Texture	Structure	Consistence		Roots	Concret.	Boundary	Mica flakes
			Clour (moist)	Pattern			Moist	Wet				
						ELM1						
Ap	0 – 8	10 YR 3/2			Fine silt loam	crumb to weak subangular blocky	friable	Slightly sticky, Slightly plastic	many fine medium	-	Clear smooth	Many
Ap2	8 – 21	10 YR 3/3			Fine silty clay loam	weak subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	Common medium	-	Clear smooth	Many
B1	21 – 34	10 YR ¾			Fine silty clay loam	subangular blocky	Moderatelyfirm	Slightly sticky, Slightly plastic	Common medium	-	Clear smooth	Common
B2	34 – 65	10 YR ¾			Fine silt loam	subangular blocky	Moderatelyfirm	Slightly sticky, Slightly plastic	Common medium	carbon	Clear smooth	Many
C1	65 – 90	10 YR 4/4			Fine silt loam	subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	Few medium	-	Clear smooth	Common
C2	90 – 118	10 YR 4/4			Fine silty clay loam	subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	-	-	Clear smooth	Common
C3	118 – 150	10 YR 5/4	7.5 YR 5/6	F2D	Fine silt loam	subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	-	-	Clear smooth	Common
C4	150 – 200+	10 YR 5/3	5 YR 4/6	C2D	Fine silt loam	subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	-	-		Many
						ELM2						
Ap	0 – 11	10 YR 2/2			Silt loam	crumb to weak subangular blocky	Friable	Slightly sticky, Slightly plastic	Many fine medium	-	Clear smooth	Many
Ap2	11 – 19	10 YR 3/3			Silty clay loam	subangular blocky	Moderately firm	Slightly sticky, Slightly plastic	Many medium large	-	Clear smooth	Many
B1	19 – 32	10 YR 3/2			Silty clay loam	subangular blocky	Moderately firm	Slightly sticky, Slightly plastic	Common medium large	-	Clear smooth	Many
B2	32- 42	10 YR 4/3			Silt loam	subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	Common large	-	Clear smooth	Many
B3	42 – 57	10 YR 5/3	7.5 YR 4/3		Silt loam	subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	Few large	-	Clear smooth	Many
B4	57 – 88	10 YR 5/2	7.5 YR ¾	M2D	Silt clay loam	subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	-	-	Clear smooth	Many
C	88 – 106	10 YR 5/2	7.5 YR 4/6	M2D	Silt loam	subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	-	-	Clear smooth	Many
C2	106 – 190+	10 YR 5/1	7.5 YR 4/6	M2D	Silt loam	subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	-	-		Many

Table 4.1 Cont.

Horizon designation	Depth (cm)	Soil Colour Moist	Mottles		Texture	Structure	Consistence		Roots	Concret.	Boundary	Mica flakes
			Clour (moist)	Pattern			Moist	Wet				
						ELM3						
A	0 18	10 YR 3.6			Fine sandy loam	crumbly	Very friable	Non sticky, non plastic	Many fine medium	-	Clear smooth	Many
Ap1	18 -31	10 YR 3 3	2.5 YR 3 3	F2D	Fine sandy loam	Single grain	friable	Non sticky, non plastic	Common fine medium	-	Clear smooth	Many
Ap2	31 44	10 YR 6 4	-	-	Loamy sand	Single grain	friable	Non sticky, non plastic	Few medium	-	Clear smooth	Many
C1	44 68	10 YR 4 6	-	-	Sandy loam	Single grain	friable	Non sticky, non plastic	-	-	Clear smooth	Many
C2	68 81	10 YR 5 4	-	-	Sandy loam	Single grain	friable	Non sticky, non plastic	-	-	Clear smooth	Many
C3	81 123	10 YR 3 4	-	-	Loamy sand	Very weak subangular blocky	Slightly friable	Non sticky, non plastic	-	-	Clear smooth	Many
C4	123 160	7.5 YR 4/4	-	-	Loamy sand	weak subangular blocky	Slightly friable	Non sticky, non plastic	-	-	Gradual	Many
C5	160 – 200+	7.5 YR 2.5 3	-	-	Loamy sand	Very weak subangular blocky	friable	Non sticky, non plastic	-	-		Many

Abbreviations: Mottle pattern- The first letter denotes abundance (F=few; C=common; M=many); The centre number denotes size (1=fine; 2=medium; 3=coarse); The second letter denotes contrast (D=distinct; P- prominent).

Plate 1: The Elemebiri 1 (ELM1) Profile Pit
{Soil classification: Aquic Dystruepts (USDA) and Fluvic cambisol (RSG-WRB)}

The ELM2 SMU (imperfectly drained) occurred on the levee slope of the old terraces of the Niger River, in the transitional zone between the moderately well drain levee crest and the poorly drained flood plain or lower slopes of the Niger River. The relief was almost flat with slopes ranging between 1 and 2%. The arrangement of the horizons in this pedon followed the sequence Ap-Ap2-B1-B2-B3-B4-C1-C2 (Table 4.1). Soil texture at the surface layers ranged from fine silt loam to silty clay loam while in the subsurface layers, texture varied between silty clay loam to silt loam. The colour of the surface soil was very dark brown (10 YR 2/2) while in the subsurface layers, colour graded from dark brown (10 YR 3/3) through very dark grayish brown (10 YR 3/2), brown (10 YR 4/3), grayish brown (10 YR 5/2) to gray (10 YR 5/1). Soil structure at the surface was crumbly to weak sub angular blocky but break into crumbs under slight pressure. Structure of the subsurface soil layers was sub angular blocky. The consistency at the surface layer was very friable when moist and non-sticky and non-plastic when wet while in the subsurface layers, consistence was slightly firm when moist and slightly sticky and slightly plastic when wet. Many mica flakes were present all through the profile, sometimes in abundance. Many, and sometime common large, medium and fine roots occurred in the upper layers of the pedon. Horizons in this pedon were separated by clear smooth boundaries.

The ELM3 SMU formed from recent alluvium on the channel of the present actively flowing Niger River. Yearly deposition of alluvium, occurring over reasonably long period, formed a point bar covering over 162 hectares (Plate 3). The ELM3 soils also have deep profile and relief was gently undulating with slope ranging between 0 and 4%. The horizon differentiation was in the order A-Ap1-Ap2-C1-C2-C3-C4-C5 (Plate 2). The first 'A' horizon encountered was the recent alluvium deposition of the immediate past flood season. Texture varied between loamy sand and sandy loam all through the profile (Table 4.1). Surface soil colour was dark yellowish brown (10 YR 3/6). In the subsurface layers, colour varied from dark brown (10 YR 3/3) through light yellowish brown (10 YR 6/4), dark yellowish brown (10 YR 4/6), yellowish brown (10 YR 5/4), dark yellowish brown (10 YR ¾), brown (7.5 YR 4/4), to very dark brown (7.5 YR 2.5/3). Surface soil structure was crumbly while subsurface soil structure varied from single grain to very weak sub angular blocky indicating very little or no structural development. Consistence of the surface soil layer was very friable to friable when moist and non-sticky and non-plastic when wet. In the subsurface layers, consistence varied from friable to slightly firm when moist and non-sticky and non-plastic when wet. Many medium to fine roots were present in the upper layers of the profile. Also, many mica flakes occurred in all the layers of the profile.

Plate 2: The Elemebiri 3 (ELM3) Profile Pit
{Soil classification: Eutric Udifluvents (USDA) and Haplic-Fluvic Fluvisol (RSG-WRB)}

Plate 3: The Landscape of Elemebiri 3
{Soil classification: Eutric Udifluvents (USDA) and Haplic-Fluvic Fluvisol (RSG-WRB)}

4.1.1.2 The Soils of Odoni

The ODN1 soils (Figure 4.2) were located on the levee crest or upper slopes of the old terraces of the Nun River, at Odoni community. The soils were deep, moderately well drain, free of redoximorphic influence up to 117cm (Table 4.2) and relief was flat with slopes ranging between 0 and 1%. Surface and subsurface soil textures were silt loam and the horizonization sequence was Ap-Ap2-B1-B2-B3-C (Plate 4). Surface soil colour was dark brown (7.5 YR 3/2). Subsurface soil colour varied from brown (7.5 YR 4/4) through strong brown (7.5 YR 4/6); brown (7.5 YR 4/3) to strong brown (7.5 YR 4/6). There was evidence of mottling at the 117 cm depth from the mineral soil surface. Structure was very weak sub angular blocky at the surface and weak sub angular blocky to sub angular blocky at the subsurface layers. Soil consistence was slightly firm at the surface when moist and slightly sticky and slightly plastic when wet. Consistence of subsurface layers was slightly firm to moderately firm when moist and slightly sticky and slightly plastic when wet. Plant roots occurred in the upper layers of the soil. Mica flakes were many in the surface and common in the bottom layers. Layers were separated by clear smooth boundaries at the surface and diffuse wavy boundaries in the lower layers.

Table 4.2: Morphological Characteristics of Odoni Soils

Horizon designation	Depth (cm)	Soil	Mottles		texture	structure	Consistence		roots	Conc	Boundary	Mica Flakes
		Colour Moist	Colour moist	Pattern			Moist	Wet				
						ODN1						
Ap	0 – 23	7.5 YR 3/2			Fine silt loam	Very weak subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	Many, fine	-	Clear smooth	Many
Ap2	23 – 30	7.5 YR 4/4			Fine silt loam	weak subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	Many, medium	-	Clear smooth	Many
B1	30 – 63	7.5 YR 4/4			Fine silt loam	subangular blocky	Moderately firm	Slightly sticky, Slightly plastic	Common, large	-	Diffuse wavy	Common
B2	63 – 117	7.5 YR 4/6			Silt loam	subangular blocky	Moderately firm	Slightly sticky, Slightly plastic	Few,large	-	Diffuse wavy	Common
B3	117 – 160	7.5 YR 4/3	5 YR 4/4	M3D	Silt loam	subangular blocky	Moderately firm	Slightly sticky, Slightly plastic		-	Diffuse wavy	Common
C	160 – 200+	7.5 YR 4/6	5 YR 4/6	M3P	Silt loam	subangular blocky	Moderately firm	Slightly sticky, Slightly plastic		-		Common
						ODN2						
Ap	0 – 20	10 YR ¾			Fine silt loam	Crumbly	Friable	Non sticky, non plastic	Many medium, fine	-	Clear smooth	Many
A	20 – 40	10 YR 5/4			Loam	weak subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	Many medium	-	Clear smooth	Common
B1	40 – 110	10 YR 5/3	5 YR 6/4	F2D	Silt loam	subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	Common medium	-	Clear smooth	Many
B2	110- 141	7.5 YR 5/4	5 YR 4/4	M3D	Silt loam	subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	Few large	-	Diffuse wavy	Common
B3	141 – 180	7.5YR 5/2	5 YR ¾	M3P	Silt loam	subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	Few large	-	Clear smooth	Common
C	180 – 200+	10 YR 5/1	5 YR ¾	M3P	Silt loam	subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	Few large	-		Common

Table 4.2: Cont.

Horizon	Depth (cm)	Soil Colour moist	Mottles Colour moist	Pattern	Texture	Structure	Consistence Moist	wet	Roots	Conc	Boundary	Mica Flakes
						ODN3						
A	0 – 5	7.5 YR 3/2			Fine silt loam	Weak subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	Many, medium fine	-	Diffuse gradual	Common
Ap1	5 – 11	7.5 YR 4/4	5 YR 5/3	C2D	Silt loam	Weak subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	Many medium fine	-	Diffuse wavy	Common
Ap2	11 – 25	7.5 YR 4/4	5 YR 6/4	C2D	Silt loam	subangular blocky	Slightly firm	Moderately sticky, moderately plastic	Common medium	-	Diffuse radual	Common
B1	25 – 41	7.5 YR 6/2	5 YR 6/1	C2D	Silt loam	subangular blocky	Moderately firm	Moderately sticky, moderately plastic	Common medium	Fe-Mn	Clear smooth	Common
B2	41 – 48	7.5 YR 4/4	5 YR 5/2	C2D	Silty clay loam	subangular blocky	Moderately firm	Moderately sticky, moderately plastic	Common	Fe-Mn	Clear smooth	Common
B3	48 – 56	7.5 YR 5/4	5 YR 4/4	M3P	Clay loam	subangular blocky	Moderately firm	Moderately sticky, moderately plastic	Few large	-	Clear smooth	Common
C1	56 – 122	7.5 YR 5/6	5 YR 4/4	M3P	Loam	subangular blocky	Moderately firm	Moderately sticky, moderately plastic	Few large	-	Clear smooth	Common
C2	122 – 200+	7.5 YR 4/6	5 YR 4/6	M3P	Loam	subangular blocky	Moderately firm	Moderately sticky, moderately plastic	-	-		Common

Abbreviations :Mottle pattern- The first letter denotes abundance (F=few; C=common; M=many); The centre number denotes size (1=fine; 2=medium; 3=coarse); The second letter denotes contrast (D=distinct; P- prominent).

Plate 4: The Odoni 1 (ODN1) Profile Pit
{Soil classification: Humic Dystrudepts (USDA) and Fluvic Cambisol (RSG-WRB)]

The soils of ODN2 occurred on the levee slope or middle slopes of the alluvial plain of the Nun River, in the transitional zone between levee crest and flood plain. The soils were deep, no lithic contact, with relief that was nearly flat and slopes ranging between 0 and 3%. The sequential arrangement of the various horizons was Ap-Ap2-B1-B2-BC-C1-C2 indicating stratification (Plate 5). Surface soil texture was silt loam while subsurface soil texture varied from silt loam through silty clay loam to loam (Table 4.2). The surface soil clour was brown (7.5 YR 4/2) while subsurface soil colours graded from dark brown (7.5 YR 3/2), brown (7.5 YR 4/2), strong brown (7.5 YR 4/6) to brown (7.5 YR 4/4). Many, coarse, prominent, yellowish red mottles (5 YR 4/6), many, coarse prominent, dark reddish brown mottles (5YR 3/3), and many, coarse, prominent, reddish brown mottles (5 YR 4/3) occurred on the three bottom layers (Table 4.3) which were free of water at the time of sampling. Structure of the surface soil layer was weak sub angular blocky while that of subsurface varied from weak sub angular blocky to sub angular blocky. Consistence of surface soil layer was slightly firm when moist and slightly sticky and slightly plastic when wet. The subsurface soil layers consistence graded, from slightly to moderately firm when moist and slightly sticky and slightly plastic to moderately sticky and moderately plastic when wet. Many roots occurred in the surface layers and few in the bottom layers. Mica flakes occurrence varied from common to many in the profile. Soil layers were separated by clear smooth boundaries except one boundary in the middle of the profile which was separated by diffuse wavy boundary.

Plate 5: The Odoni 2 (ODN2) Profile Pit
{Soil classification: Typic Epiaquepts (USDA) and Fluvic Cambisol (RSG-WRB]

Plate 6: The Odoni 3 (ODN3) Profile Pit
{Soil classification: Fluvaquentic Epiaquepts (USDA) and Fluvic Cambisol (RSG-WRB)

The soils of ODN3 were situated beyond the levee slope, that is, in between the levee slope and the fresh water swamps or drainage basins of the alluvial plain of the Nun River at Odoni community. They formed galloping terrain with drift alluvium as parent materials. The relief was almost flat with slopes ranging between 0 and 4%. The sequential arrangement of horizons in this pedon was A-Ap1-Ap2-B1-B2-B3-C1-C2 (Plate 6). The Ap1 horizon was formed by alluvial deposits of the immediate past flood season. Surface soil texture was silt loam while subsurface texture graded from silt loam to silty clay loam. Surface soil colour (moist) was dark brown (7.5 YR 3/2) while subsurface soil colours graded from brown (7.5 YR 4/4), pinkish gray (7.5 YR 6/2), brown (7.5 YR 5/4), strong brown (7.5 YR 5/6) and brown (7.5 YR 4/6) (Table 4.3). Common, medium, distinct, reddish brown (5 YR 5/3), light reddish brown (5 YR 6/4), gray (5 YR 6/1), and reddish gray (5 YR 5/2) mottles occurred on the second, third, fourth and fifth layers, respectively. On the sixth, seventh and eighth layers, many coarse, prominent, reddish brown (5 YR 4/4), reddish brown (5 YR 4/4) and yellowish red (5 YR 4/6) mottles occurred. Structure of the surface soil was weak sub angular blocky. Structure of the second layer was also weak sub angular blocky while the remaining layers have sub angular blocky structure. Consistence of the surface soil layer was slightly firm when moist and slightly sticky and plastic when wet. Soil consistence in the second layer was moderately firm when moist and slightly sticky and slightly plastic when wet. For the remaining soil layers, consistence was moderately firm when moist and moderately sticky and moderately plastic when wet. Mica flakes were common all through the profile. Roots were distributed all through the profile while dark brown to black concretions occurred in the fourth and fifth layers indicating anthropogenic influence.

4.1.1.3 The Soils of Trofani

The TFN1 soils (Figure 4.3) occurred on the upper slopes of the old terraces fringing the Forcados River in Trofani. They were developed on the alluvial plain of the Forcados River with deep profile, free of redoximorphic influence up to 140cm. Similar to ODN1 the relief was flat with slopes ranging between 0 and 1%. Surface soil texture was silt loam while structure was sub angular blocky both in the surface and subsurface layers. Subsurface soil texture varied from silt loam through silty clay loam to silt loam (Table 4.3). Ap-A-B1-B2-B3-C reflected the sequential arrangement of horizons as they occurred in the profile (Plate 7). Surface soil colour (moist) was dark yellowish brown (10 YR ¾) while subsurface colour varied from dark yellowish brown (10 YR ¾) through dark grayish brown (10 YR 4/2) to dark yellowish brown (10 YR 4/4). Soil consistence at the surface layer was slightly firm when moist and slightly sticky and slightly plastic when wet. In the subsurface layers, consistence varied from slightly firm to moderately firm when moist and slightly sticky and slightly plastic to moderately sticky and moderately plastic when wet. Many mica flakes occurred in the first four layers while mica flakes occurrence in the remaining two layers of the profile was common.

The soils of TFN2 occurred on the levee slope or middle slope of the terraces of the alluvial plain of Forcados River, transiting levee crest and lower slope. The soil profile was deep, no lithic contact and the sequential arrangement of horizons was Ap-Ap2-B1-B2-C1-C2 indicating stratification. Relief was flat with slopes ranging between 0 and 2%. Surface soil texture was loamy sand while subsurface soil textures varied from silt loam through silty clay loam, silt loam to silty clay loam to loam (Table 4.3). The surface soil colour (moist) was dark brown (7.5 YR 3/3) while subsurface soil colours graded from dark yellowish brown (10 YR 4/4), through grayish brown (10 YR 5/2), brown (10 YR 5/3), brown (10 YR 5/2) to light brownish gray (10 YR 6/2).

Table 4.3: Morphological Characteristics of Trofani Soils

Horizon	Depth (cm)	Soil Colour	Mottles		Texture	Structure	Consistence		Roots	Concret.	boundary	Mica flakes
			Clour	pattern			Moist	Wet				
						TFN1						
Ap	0 14	10 YR 3 1			Fine silt loam	Subangular blocky	Slightly firm	Slightly sticky, slightly plastic	Many medium fine	-	Clear smooth	many
A	14 31	10 YR 3 1			Silt loam	Subangular blocky	Slightly firm	Slightly sticky, slightly plastic	Few fine	-	Clear smooth	common
B1	31 55	10 YR 3 1			Silt loam	Subangular blocky	Moderately firm	Slightly sticky, slightly plastic	Few fine	-	Clear smooth	many
B2	55 140	10 YR 3 6			Silt loam	Subangular blocky	Moderately firm	Slightly sticky, slightly plastic	-	-	Clear smooth	many
B3	140 150	10 YR 4 2	2 5 YR 3 1	C2D	Silty clay loam	Subangular blocky	Moderately firm	Moderately sticky, moderately plastic	-	carbon	Clear smooth	common
C	150 200+	10 YR4 4	5 YR 4 6	M3P	Silt loam	Subangular blocky	Moderately firm	Moderately sticky, moderately plastic	-	-		common
						TFN2						
Ap	0 11	7 5 YR 3 3			Fine loamy sand	Crumbly	Very friable	Non sticky, non plastic	Many large medium	-	Clear smooth	Many
Ap2	11 35	10 YR 4 4			Silt loam	Subangular blocky	Slightly firm	Slightly sticky, slightly plastic	Many large medium	Carbon	Clear smooth	many
B1	35 44	10 YR 5 2			Silty clay loam	Subangular blocky	Moderately firm	Slightly sticky, slightly plastic	Many large medium	-	Clear smooth	common
B2	44 70	10 YR 5 3	5 YR 5 6	C2D	Silt loam	Subangular blocky	Slightly firm	Slightly sticky, slightly plastic	Common large	-	Clear smooth	common
C1	70 126	10 YR 5 2	5 YR 3 3	M3P	Silt loam	Subangular blocky	Slightly firm	Slightly sticky, slightly plastic	Few large	-	Diffuse gradual	common
C2	126 200+	10 YR 6 2	5 YR 3 3	M3P	Loam	Subangular blocky	Slightly firm	Slightly sticky, slightly plastic	Few large	-		common
						TFN3						
A	0 -13	10 YR 3 3			Fine sandy loam	Massive	Slightly firm	Slightly sticky, slightly plastic	Many fine medim	-	Diffuse wavy	common
Ap1	13 -23	10 YR 3 1			sandy loam	Granular	Friable	Non sticky, non plastic	Many fine medim	-	Diffuse wavy	Many
Ap2	23 38	10 YR 5 4			sandy loam	Granular	Friable	Non sticky, non plastic	Many fine medim	-	Clear smooth	Many
C1	38 52	10 YR 3 3	10 R 3 3	M2D	sandy loam	Granular	Friable	Non sticky, non plastic	Few medium	-	Clear smooth	Many
C2	52 69	10 YR 4 6	10 YR 3 3	M2D	sandy loam	Granular	Friable	Non sticky, non plastic	Few medium	-	Clear smooth	Many
C3	69 83	10 YR 3 3			Loamy sand	Granular	Loose	Non sticky, non plastic	-	-	Clear smooth	Many
C4	83 200+	10 YR 6 3			Sand	Sinle grain	Loose	Non sticky, non plastic	-	-		Many

Abbreviations :Mottle pattern- The first letter denotes abundance (F=few; C=common; M=many); The centre number denotes size (1=fine; 2=medium; 3=coarse); The second letter denotes contrast (D distinct; P- prominent).

Plate 7: The Trofani 1 (TFN1) Profile Pit
{Soil classification: Aquic Dystrudepts (USDA) and Fluvic cambisol (RSG-WRB)}

TFN2 pedon, in each year was subject to alternate wetting and drying with change in season from rainy to dry. Due to hydromorphic influence, mottles occurred from the fourth to the bottom soil layer. From the fourth layer, common, medium distinct yellowish red (5 YR 5/6) mottles were obvious which graded into many, coarse, distinct, yellowish red (5 YR 4/6) mottles in the succeeding layer. The layer that followed was occupied by many, coarse, prominent, dark reddish brown (5 YR 3/3) mottles. The structure of the surface soil layer was crumbly while that of the subsurface layers was sub angular blocky. Consistence of surface soil layer was very friable when moist and non-sticky and non-plastic when wet. In the subsurface layers, consistence was slightly firm when moist and slightly sticky and slightly plastic when wet. Medium to coarse oil palm roots occurred all through the profile. Black concretions were noticed on the second layer of the profile. Mica flakes were common to many all through the profile. Clear smooth boundaries separated soil layers.

The TFN3 soils like ELM3, were located on the channel of the present actively flowing Forcados river, forming a point bar by Trofani (Plate 9), covering over 148 hectares of land (Table 4.3). Continuous yearly deposition of alluvium during the annual floods, occurring over a long period of time formed this soil. The sequential arrangement of the horizons in this profile followed the order A-Ap1-Ap2-C1-C2-C3-C4 (Plate 8). Alluvial deposits of the immediate past flood in 2014 formed the surface soil layer. Surface soil texture was fine loamy sand while the subsurface soil texture varied from loamy sand through sandy loam to sand. Surface soil colour (moist) was dark brown (10 YR 3/3). In the subsurface layers, soil colour was dark yellowish brown (10 YR 3/4), yellowish brown (10 YR 5/4), dark brown (10 YR 3/3), light yellowish brown (10 YR 4/6), dark brown (10 YR 3/3) and pale brown (10 YR 6/3). Similar to ELM 3 formed from very recent alluvial deposits at the centre of the Niger River. TFN3 drainage was good but many, medium, distinct.

Plate 8: The Trofani 3 (TFN3) Profile Pit
{Soil classification: Aquic Udifluvents (USDA) and Haplic Fluvisol (RSG-WRB)}

Plate 9: The Trofani 3 (TFN3) Landscape
{Soil classification: Aquic Udifluvents (USDA) and Haplic Fluvisol (RSG-WRB)}

dark brown (10 YR 3/3) mottles occurred on the 38-52 cm and 52-69 cm depths from the mineral soil surface of the profile while no mottles occurred in the succeeding two horizons. Surface soil structure was massive due to the fresh alluvial deposit from the most recent flood while subsurface structure was granular to single grained. Differences in structure of the various layers were ascribed to differences in the parent materials of the deposits and stratification. Consistence of soil in the surface layer was slightly firm when moist and slightly sticky and slightly plastic when wet. In the subsurface layers, consistence varied from friable to loose when moist and non-sticky and non-plastic when wet. Many mica flakes were found in all the layers of the soil profile. Horizons were separated by diffuse wavy boundaries in the surface while subsurface horizons were separated by clear smooth boundaries

4.1.1.4 The soils of Odi

The ODI1 soils (Figure 4.4) occurred on the levee crest or upper slope, on the western bank of the River Nun, developed on the alluvial plain of the Nun River. The soils were deep, with no lithic contact, free of redoximorphic influence to a depth of 135cm from the mineral soil surface (Table 4.4). The relief was flat with slopes ranging between 0 and 1%. The sequential arrangement of horizons in the ODI1 profile was Ap-A-B1-B2-B3-C1-C2-C3. The surface soil texture soil was silt loam while the structure was crumbly. In the subsurface layers, texture varied between silt loam, loam and silty clay loam while the structure was weak sub angular blocky, destroyed under slight pressure. The colour of the surface soil layer (moist) was dark brown (10 YR 3/3) while subsurface soil colour was dark yellowish brown (10 YR 4/4). Like the ODN1 soils, the three lowest soil layers were subject to hydromorphic influence with common, medium, distinct, dark brown mottles (7.5 YR ¾), medium, coarse, distinct, dark reddish brown mottles (2.5 YR ¾) and medium, coarse, prominent, reddish brown (5 YR 4/4) mottles. Consistence of the surface soil layer was friable when moist but slightly sticky and slightly plastic when wet. In the subsurface layers, consistence varied between friable through slightly firm to moderately firm when moist. In terms of stickiness and plasticity, the soils were slightly to moderately sticky and plastic when wet. Medium to fine roots were well distributed in the upper layers of the profile. Many mica flakes were present throughout the profile.

Table 4.4: Morphological Characteristics of Odi Soils

Horizon Desig.	Depth (cm)	Soil Colour Moist	Mottles		Texture	Structure	Consistence		Roots	Concret.	Boundary	Mica flakes
			Clour Moist	pattern			Moist	Wet				
							ODI1					
Ap	0 – 26	10 YR 3/3			Fine silt loam	Crumbly	Friable	Slightly sticky slightly plastic	Many fine medium	-	Clear smooth	Many
A	26 – 60	10 YR 4/4			Silt loam to loam	Weak subangular blocky	Friable	Slightly sticky slightly plastic	Common medium	-	Clear wavy	Many
B1	60 – 78	10 YR 4/4			Silt loam to loam	subangular blocky	Moderately firm	Moderatelysticky, moderately plastic	Common medium	-	Clear wavy	Many
B2	78 – 120	10 YR 4/4			Silt loam	subangular blocky	Slightly firm	Slightly sticky slightly plastic	Few medium	-	Clear wavy	Many
B3	120 – 135	10 YR 4/4			Loam	subangular blocky	Slightly firm	Slightly sticky slightly plastic	Few medium	-	Clear wavy	Many
C1	135 – 163	10 YR 4/4	7.5 YR 3/4	C2D	Silty clay loam	subangular blocky	Moderately firm	Moderatelysticky, moderately plastic		-	Clear wavy	Many
C2	163 – 186	10 YR 4/4	2.5 YR 3/4	M3D	Silt loam	subangular blocky	Moderately firm	Moderatelysticky, moderately plastic		-	Clear wavy	Many
C3	186 – 200+	10 YR 4/4	5 YR 4/4	M3P	Silt loam	subangular blocky	Moderately firm	Moderatelysticky, moderately plastic		-		Many
							ODI2					
Ap	0 – 20	10 YR 3/4			Fine silt loam	Crumbly	Friable	Non sticky, non plastic	Many medium fine		Gradual smooth	Many
A	20 – 40	10 YR 5/4			Loam	Weak subangular blocky	Slightly firm	Slightly sticky, slightly plastic	Many medium fine		Clear smooth	Common
B1	40 - 110	10 YR 5/3	5 YR 6/4	F2D	Silt loam	subangular blocky	Slightly firm	Slightly sticky, slightly plastic	Common medium		gradual smooth	Common
B2	110- 141	7.5 YR 5/4	5 YR 4/4	M3D	Silt loam	subangular blocky	Slightly firm	Slightly sticky, slightly plastic	Few medium		gradual smooth	Common
B3	141 – 180	7.5YR 5/2	5 YR 3/4	M3P	Silt loam	subangular blocky	Slightly firm	Slightly sticky, slightly plastic			gradual smooth	Common
C	180 – 200+	10 YR 5/1	5 YR 3/4	M3P	Silt loam	subangular blocky	Slightly firm	Slightly sticky, slightly plastic			Many carbon	Many

Table 4.4: Cont.

Horizon Design.	Depth (cm)	Soil Colour Moist	Mottles		Texture	Structure	Consistence		Roots	Concret.	Boundary	Mica flakes
			Clour Moist	pattern			moist	Wet				
							ODI3					
Ah	0 3	10 YR 2/2			Fine silt loam	crumbly	very friable	Non sticky non plastic	Many large medium fine		gradual smooth	Common
Ap1	3 20	10 YR 6/4	5 YR 5/3	C2D	Silt loam	very weak subangular blocky	Friable	Non sticky non plastic	Many large medium fine		gradual smooth	Many
Ap2	20 46	10 YR 6/3	5 YR 5/4	C2D	Silt loam	weak subangular blocky	slightly firm	Slightly sticky, slightly plastic	Common large		gradual smooth	Many
B1	46 – 60	10 YR 5/3	5 YR 4/6	C2D	Silt loam	subangular blocky	slightly firm	Slightly sticky, slightly plastic	Few large		gradual smooth	Many
B2	60 94	7.5 YR 4/4	5 YR 4/4	M2D	Silt loam	subangular blocky	slightly firm	Slightly sticky, slightly plastic	Few large		gradual smooth	Many
B3	94 145	10 YR 4/6	5 YR 4/6	M3D	Silt loam	subangular blocky	slightly firm	Slightly sticky, slightly plastic			gradual smooth	Many
C1	145 158	10 YR 5/4	2.5 YR 5/2	M3P	Silt loam	subangular blocky	slightly firm	Slightly sticky, slightly plastic		Many carbon	gradual smooth	Many
C2	158 200+	10 YR 5/4	5 YR 5/3	M3P	Silt loam	Sabk	sfi	Slightly sticky, slightly plastic		Many carbon		Many

Abbreviations :Mottle pattern- The first letter denotes abundance (F=few; C=common; M=many); The centre number denotes size (1=fine; 2=medium; 3=coarse); The second letter denotes contrast (D=distinct; P- prominent).

The soils of ODI2 sampling unit (4.4) found on the levee slope or middle slopes of the terraces on the western bank of Nun River, developed on the alluvial plain of the Nun River. The soils were deep, stratified, with no lithic contact and the horizons were sequential arranged in the order Ap-A-B1-B2-B3-C. The relief was nearly flat with slopes ranging between 0 and 3%. Surface soil texture was silt loam while subsurface texture varied from loam to silt loam. The surface soil coloration (moist) was dark yellowish brown (10 YR 3/4) while subsurface colours graded between yellowish brown (10 YR 5/4), brown (10 YR 5/3; 7.5 YR 5/4; 7.5 YR 5/2) to grayish brown (10 YR 5/1). Due to seasonal changes resulting in alternate wetting and drying, many, medium, distinct, light reddish brown (5 YR 6/4), many, coarse, distinct, reddish brown (5 YR 4/4), many, coarse, prominent, dark reddish brown (5 YR ¾), and many, coarse, prominent, dark reddish (5 YR 3/4) mottles occurred on the third, fourth, fifth and sixth layers, respectively. Structure of the surface soil was crumbly while subsurface structure was sub angular blocky through weak sub angular blocky to sub angular blocky. Consistence of surface soil layer was friable when moist and non-sticky and non-plastic when wet. Consistence of the subsurface soil layers was slightly firm when moist and slightly sticky and slightly plastic when wet. Fine to medium roots occurred in the surface to middle layers of the profile. Also, concretions of carbon occurred on the bottom layer of the profile. Common to many mica flakes occurred throughout the soil profile. Surface soil layer was separated from the rest by a gradual smooth boundary while clear smooth boundary separated the subsurface soil layers.

Plate 10: The Odi 3 (ODI3) Profile Pit
{Soil classification: Aeric Epiaquepts (USDA) and Fluvic Cambisol (RSG-WRB)}

Like the other flood plain soils, ODI3 soils occurred on the flood plain or lower slopes of the Nun River. They occurred in between the levee slope and the freshwater swamps or drainage basins of alluvial plain on the western bank of the Nun River. Also, galloping terrain with drift alluvium formed the parent materials. The relief was almost flat with slopes ranging between 0 and 4% and the arrangement of the horizons was Ah-Ap1-Ap2-B1-B2-B3-C1-C2 (Plate 10). The 0-3 cm surface layer (Ah) of ODI3 was humified by organic matter. Soil texture in the surface and subsurface layers was silt loam. The surface soil colour (moist) was very dark brown (10 YR 2/2) while colour of the succeeding layers were light yellowish brown (10 YR 6/4), pale brown (10 YR 6/3), brown (10 YR 5/3), brown (10 YR 4/4), dark yellowish brown (10 YR 4/6), yellowish brown (10 YR 5/4) and yellowish brown (10 YR 5/4) for the second, third, fourth, fifth, sixth, seventh and eighth layers, respectively (Table 4.4). Structure of the surface soil layer was crumbly while subsurface structure graded from very weak sub angular blocky in the second horizon to sub angular blocky in the succeeding horizons. Consistence of the surface layer was very friable and the second layer, friable when moist and non-sticky and non-plastic when wet. Consistence of all the subsequent horizons were slightly firm to moderately firm when moist and slightly sticky and plastic to moderately sticky and moderately plastic when wet. Many mica flakes were present in all the layers of the soil. Root presence was noticed from the surface to the fifth horizon while many dark concretions occurred in the seventh and eighth layers.

4.1.1.5 The soils of Koroama

The soils of Koroama (Figure 4.5) were represented by pedons KRM1, KRM2 and KRM3 and the morphological properties are as presented in table 4.5. The KRM1 soils were located on the levee crest or upper slope of the old terraces, fringing Taylor Creek, having A1-A2-B1-B2-BC-C as the sequential arrangement of the horizons (Plate 11). There were no redoximorphic characteristics to a depth of 115cm from the mineral soil surface (Table 4.5). The soil profile was deep; no lithic contact with a flat relief and slope ranging between 0 and 1%. The texture of surface and subsurface soils was silt loam. Structure of the surface soil was crumbly to weak sub angular blocky while the subsurface layers had sub angular blocky structure. The colour (moist) of the surface soil layer was dark yellowish brown (10 YR ¾) while subsurface soil colours varied from brown (10 YR 4/3) through very dark grayish brown (10 YR 3/2), dark grayish brown (10 YR 4/2) to brown (10 YR 4/3) down the profile. Hydromorphic influence was noticed in KRM1 as in the Elemebiri, Odoni, Trofani and Odi soils. Common, medium, distinct, brown (7.5 YR 4/4) and many, medium, distinct, brown (7.5 YR 4/4) mottles were present on the immediate two layers above the bottom layer. At the bottom layer of the profile, many, coarse prominent, dark yellowish brown mottles (10 YR 4/6) occurred. Consistence of the surface soil layer was very friable when moist and non-sticky and non-plastic under wet condition. In the subsurface layers, consistence varied from slightly firm to moderately firm when moist and slightly sticky and slightly plastic when wet. Black concretions (2.5/N) were prominent in the third horizon from the mineral soil surface. At the layer before the bottom layer, yellowish brown concretions (10 YR 5/6) were common. Also, many mica flakes occurred in the profile. Large, medium and fine roots were well distributed in the three topmost horizons from the mineral soil surface.

Table 4.5: Morphological Characteristics of Koroama Soils

Horizon Design.	Depth (cm)	Soil Colour Moist	Mottles		Texture	Structure	Consistence		Roots	Concret.	Boundary	Mica flakes
			Clour Moist	pattern			Moist	Wet				
						KRM1						
A1	0 – 7	10 YR ¾			Fine silt loam	crumb to weak subangular blocky	Friable	non sticky, non plastic	Many large medium fine	-	Clear smooth	Many
A2	7 – 43	10 YR 4/3			Silt loam	weak subangular blocky	Friable	Slightly sticky, Slightly plastic	Many large medium fine	-	Clear smooth	Many
B1	43 – 86	10 YR 3/2			Silt loam	subangular blocky	slightly firm	Slightly sticky, Slightly plastic	Common large	carbon	Clear smooth	Many
B2	86 – 115	10 YR 3/2			Silt loam	subangular blocky	slightly firm	Slightly sticky, Slightly plastic	Few large	-	Clear smooth	Many
BC	115 – 130	10 YR 4/2	7.5 YR 4/4	M2D	Silt loam	subangular blocky	slightly firm	Slightly sticky, Slightly plastic		Fe-Mn	Clear smooth	Many
C	130 – 200+	10 YR 4/3	10 YR 4/6	M3P	silt loam	subangular blocky	slightly firm	Slightly sticky, Slightly plastic		-	Clear smooth	Many
						KRM2						
Ap	0 -15	10 YR 3/2			silt loam	weak subangular blocky	slightly firm	non sticky, non plastic	Many lerge medium fine	-	wavy	Few
Ap2	15 – 23	10 YR 5/3			silt loam	subangular blocky	slightly firm	Slightly sticky, Slightly plastic	Many lerge medium fine	-	Clear smooth	Many
B1	23 – 40	10 YR 5/3			silty clay loam	subangular blocky	moderately firm	moderately sticky, moderately plastic	Common lerge medium fine	-	Clear smooth	Many
B2	40 – 64	10 YR 4/3	5 YR 4/3	C2D	silty clay loam	subangular blocky	moderately firm	moderately sticky, moderately plastic	Common lerge medium fine	-	Clear smooth	Many
B3	64 – 78	10 YR 5/3	5 YR ¾	M3D	silt loam	subangular blocky	slightly firm	Slightly sticky, Slightly plastic	Few large	-	diffuse wavy	Many
C1	78 – 140	10 YR 5/2	5 YR ¾	M3P	silt loam	subangular blocky	slightly firm	Slightly sticky, Slightly plastic	-	-	Clear smooth	Many
C2	140 – 194+	10 YR 5/1	7.5 YR 2.5/3	M3P	silt loam	subangular blocky	slightly firm	Slightly sticky, Slightly plastic	-	-		Common

Table 4.5: Cont.

Horizon	Depth (cm)	Soil Colour	Mottles		Texture	Structure	Consistence		Roots	Concret.	Boundary	Mica flakes
			Clour	pattern			Moist	Wet				
							KRM3					
Ap	0 12	10 YR 3.2			fine silt loam	weak subangular blocky	Friable	non sticky, non plastic	many large medium fine	-	Wavy	Few
Ap2	12 39	10 YR 5/2	5 YR 4/3	F2D	silty clay loam	weak subangular blocky	slightly firm	Slightly sticky, Slightly plastic	many large medium fine	-	wavy	Few
B1	39 59	10 YR 2/2	5 YR 3/4	M2D	silt loam	subangular blocky	moderately firm	Slightly sticky, Slightly plastic	many large medium	-	Clear smooth	Few
B2	59 96	10 YR 5/2	7.5 YR 4/6	M3D	silty clay loam	subangular blocky	moderately firm	Slightly sticky, Slightly plastic	common large	-	Clear smooth	Few
B3	96 135	10 YR 5/2	7.5 YR 4/6	M3P	silty clay loam	subangular blocky	moderately firm	Slightly sticky, Slightly plastic	Few large	-	Clear smooth	Few
C	135 190+	10 YR 5/2	7.5 YR 4/6	M3P	silty clay loam	subangular blocky	slightly firm	Slightly sticky, Slightly plastic	-	-		Few

Abbreviations :Mottle pattern- The first letter denotes abundance (F=few; C=common; M=many); The centre number denotes size (1=fine; 2=medium; 3=coarse); The second letter denotes contrast (D=distinct; P- prominent).

Plate 11: The Koroama 1 (KRM1) Profile Pit
{Soil classification: Udic Dysrtropepts (USDA) and Humic-Fluvic Cambisol 9rsg-WRB)]

The KRM2 soils occurred on the levee slope or middle slope of the terraces of the Taylor Creek developed on the alluvial plain of the creek. The soils were deep, no lithic contact with relief that was nearly flat, and slopes ranging between 0 and 3%. The horizon differentiation was Ap-Ap2-B1-B2-B3-C1-C2 (Plate 12). Surface soil texture was silt loam while subsurface texture varied from silt loam through silty clay loam to silt loam (Table 4.5). The surface soil clour (moist) was very dark grayish brown (10 YR 3/2) while subsurface colours were brown (10 YR 5/3), (10 YR 4/3), (10 YR 5/3), through grayish brown (5 YR 5/2) to gray (5 YR 5/1). Common, medium, distinct, reddish brown (5 YR 4/3), many, coarse, distinct, dark reddish brown (5 YR ¾), many, coarse, prominent, reddish brown (5 YR ¾) and many, coarse, prominent, very dark brown (7.5 YR2.5/3) mottles from the fourth to the bottom horizons.

Plate 12: The Koroama 2 (KRM2) Profile Pit
{Soil classification: Aquic Dystrudepts (USDA) and Fluvic Cambisol (RSG-WRB)}

Coarse to medium continuous pores were common in the profile which helped in draining water during the dry season and the profile was free of water at the time of sampling. Many large, medium and fine roots were distributed in the profile up to 78 cm depth from the mineral soil surface. Structure of the surface soil was weak sub angular blocky while the subsurface soil layers structure was sub-angular blocky. Consistence of surface soil layer was slightly firm when moist and slightly sticky and slightly plastic when wet. The subsurface soil layers consistence varied between moderately firm and slightly firm when moist and moderately to slightly sticky and plastic when wet. Fine, medium to large roots were common in the profile. Many mica flakes were observed throughout the profile. The surface layer was separated from others by a wavy boundary while subsurface horizons were separated by clear smooth boundary.

The KRM3 soils were found on the flood plains or lower slopes bordering the middle slope and the freshwater swamps or drainage basins of the alluvial plain of Taylor Creek. As with other floodplain soils, they formed galloping terrain and drift alluvium was the parent material. Also the relief was almost flat with slope ranging between 0 and 4%. The sequential arrangement of the horizons was Ap-Ap2-B1-B3-B3-C. Texture of soil was silt loam in the surface horizon, grading from silty clay loam to silt loam and to silty clay loam in the subsurface horizons. The surface soil colour (moist) was very dark grayish brown (10 YR 3/2) while colour of the remaining layers were grayish brown (10 YR 5/2), very dark brown (10 YR 2/2), and grayish brown (10 YR 5/2) for the remaining layers (Table 4.1). Many, medium, distinct, dark reddish brown (5 YR ¾), many, coarse, distinct, strong brown (7.5 YR 4/6), many, coarse, prominent, strong brown (7.5 YR 4/6) and many, coarse, prominent, strong brown (7.5 YR 4/6) were noticed in the third, fourth, fifth and sixth layers, respectively (Table 4.5). Structure in the surface horizon was very weak sub angular blocky while in the subsurface horizons, structure graded from weak sub angular blocky to sub angular blocky. Consistence of the surface soil layer was friable when moist and non-sticky and non-plastic when wet. In the subsurface layers, consistence varied between slightly firm to moderately firm when moist and slightly sticky to moderately sticky and plastic when wet. Root activities occurred from the surface to the fourth layer. Mica flakes occurred in few quantities in this pedon. At the upper part of the profile, horizons were separated by wavy boundaries while the lower parts of the profile had clear smooth boundary separating layers.

4.1.1.6 The soils of Niger Delta University Farm (NDU)

Table 4.6 presents the morphological properties of the soils of the Niger Delta University Teaching and Research Farm (Figure 4.6). The soils of NDU1 occurred on the old terraces of Igbedi River close to Tabogha creek. The soils were deep, without lithic contact to a depth of 195cm from the mineral soil surface, free of redoximorphic influence to a depth of about 138 cm (Table 4.6). It has a flat relief with slopes ranging between 0 and 1% while the horizon differentiation in the profile was Ap-B1-B2-B3-C1-C2 (Plate 13). The texture of the surface soil was silt loam while subsurface soil texture varied from silty clay loam to silt loam at the bottom. Surface layer soil colour (moist) was dark brown (10 YR 3/3) while the subsurface soil colours varied from dark yellowish brown (10 YR 4/4) through yellowish brown (10 YR 5/4), brown (10

YR 5/3) to light brownish gray (10 YR 6/2). Many, coarse, distinct, reddish brown (5 YR 4/4) mottles and many, coarse, prominent, reddish brown (5 YR 4/4) mottles occurred on the two bottom layers of the soil profile. Many, coarse to medium continuous pores occurred in this profile. Fine pores on the mottled layers were few while common to many medium to large continuous pores occurred in the profile. The structure of the soil was weak sub angular blocky at the surface layer while in the subsurface layers sub angular blocky to weak sub angular blocky occurred. Consistence of the surface layer was slightly firm when moist and slightly sticky and slightly plastic when wet. In the subsurface layers, consistence varied from moderately firm to slightly firm when moist and slightly sticky and slightly plastic when wet. Medium to fine roots occurred in the upper layers of the soil. Common and sometimes many mica flakes occurred in the various layers of the profile. The soil layers were separated by clear smooth boundaries.

Plate 13: The Niger Delta University 1 (NDU1)
{Soil classification: Udic Dystropepts (USDA) and Fluvic Cambisol (RSG-WRB)}

The NDU2 soils occurred on the levee slope or middle slope of the terraces of Igbedi River. The soils were deep, no lithic contact with nearly flat relief, slopes ranging between 0 and 2% (Plate 14). The soil profile's horizonization sequence was Ap-Ap2-B1-B2-B3-C. The surface soil texture was silty clay loam while subsurface soil layers texture varied from silty clay loam through clay loam to loam. The surface soil clour (moist) was dark yellowish brown (10 YR 4/4) while subsurface colours were dark yellowish brown (10 YR 4/4), brown (10 YR 5/3), dark yellowish brown (10 YR 3/4), yellowish brown (10 YR 5/4) and light brownish gray (10 YR 6/2) (Table 4.6).

Plate 14: The Niger Delta University 2 (NDU2) Landscape
{Soil classification: Aquic Dystrudepts (USDA) and Fluvic Cambisol (RSG-WRB)}

As observed earlier in soils from the levee slope of the other river systems, hydromorphic influence was obvious from the fourth soil layer being indicated by many, coarse, distinct, dark reddish brown mottles (5 YR 3/3), many coarse, prominent, reddish brown mottles (5 YR 5/3) and many, coarse, prominent dark brown mottles (7.5 YR ¾) on the fourth, fifth and sixth layers, respectively. Structure of the surface soil layer was weak sub-angular blocky and in the subsurface layers sub angular blocky. Consistence of surface soil was friable to slightly firm when moist while in the subsurface layers, consistence was slightly firm when moist and slightly sticky and slightly plastic when wet. Root activity was more prominent in the upper horizons while mica flakes occurrence in the first four layers was few but many in the two bottom layers. Clear smooth boundary separated the horizons.

Table 4.6: Morphological Characteristics of Niger Delta University Soils

Horizon Design.	Depth (cm)	Soil Colour Moist	Mottles		Texture	Structure	Consistence		Roots	Concret.	Boundary	Mica flakes
			Clour moist	Pattern			Moist	Wet				
							NDU1					
Ap	0 19	10 YR 3/3			Fine silt loam	Weak subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	Many medium fine	-	Clear smooth	Many
B1	19 39	10 YR 4/4			Silt clay loam	subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	Many medium fine	-	Clear smooth	Common
B2	39 71	10 YR ¾			Silt clay loam	subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	Common medium fine	-	Clear smooth	Many
B3	71 – 81	10 YR 5/4			Silt clay loam	subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	Few medium	-	Clear smooth	Many
C1	81 138	10 YR 5/3	5 YR 4/4	M3D	Fine silt loam	Weak subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	-	-	Clear smooth	Many
C2	138 195+	10 YR 6/2	5 YR 4/4	M3P	Fine silt loam	Weak subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	-	-		Many
							NDU2					
Ap	0 12	10 YR 4/4			Fine silty clay loam	Weak subangular blocky	Friable to slightly firm	Slightly sticky, Slightly plastic	Many medium fine	-	Clear smooth	Few
Ap2	12 – 26	10 YR 4/4			Silty clay loam	subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	Common medium fine	-	Clear smooth	Few
B1	26 36	10 YR 5/3			Silty clay loam	subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	Few medium	-	Clear smooth	Few
B2	36 53	10 YR ¾	5 YR 3/3	M3D	Silty clay loam	subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	Very Few medium	-	Clear smooth	Few
B3	53 – 116	10 YR 5/4	5 YR 5/3	M3P	Clay loam	subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	-	-	Clear smooth	Many
C	116 190+	10 YR 6/2	7.5 YR ¾	M3P	Loam	subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	-	-		Many

Table 4.6: Cont.

Horizon Desig n.	Depth (cm)	Soil Colour Moist	Mottles		Texture	Structure	Consistence		Roots	Concret.	Boundary	Mica flakes
			Clour moist	Pattern			Moist	Wet				
							NDU3					
A1	0 – 5	10 YR 3/3			Fine silt loam	Weak subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	Many medium fine	-	Clear smooth	Common
A2	5 – 13	10 YR 4/1	5 YR 5/3	M3D	silt loam	Weak subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	Many medium	-	Clear smooth	Common
AB	13 – 20	10 YR 4/4	5 YR 5/4	M3P	silt loam	weak subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	Few medium	-	Clear smooth	Many
B1	20 – 75	10 YR 5/4	5 YR 4/3	M3P	silt loam	subangular blocky	Slightly firm	Slightly sticky, Slightly plastic	-	-	Clear smooth	Many
B2	75 – 140	10 YR 5/4	5 YR 6/2	M3P	silt loam	subangular blocky	Moderately firm	Slightly sticky, Slightly plastic	-	-	Clear smooth	Many
C	140 – 196+	10 YR 6/3	5 YR 6/1	M3P	silt loam	subangular blocky	Moderately firm	Slightly sticky, Slightly plastic	-	-		Many

Abbreviations :Mottle pattern- The first letter denotes abundance (F=few; C=common; M=many); The centre number denotes size (1=fine; 2=medium; 3=coarse); The second letter denotes contrast (D=distinct; P- prominent).

The NDU3 soils were found on the flood plain or lower slopes bordering the levee slope and the freshwater swamps of the alluvial plain of Igbedi River. They form galloping terrain with drift alluvium as the parent materials. The relief was almost flat with slope ranging between 0 and 4% and the sequential arrangement of horizons down the profile was A1-A2-AB-B1-B2-C. The surface soil colour (moist) was dark brown (10 YR 3/3) while subsurface soil colours were dark gray (10 YR 4/1), dark yellowish brown (10 YR 4/4), yellowish brown (10 YR 5/4), yellowish brown (10 YR 5/4) and pale brown (10 YR 6/3) (Table 4.6). In the second soil layer, many, coarse, distinct, reddish brown (5 YR 5/3) mottles occurred while many, coarse, prominent, reddish brown (5 YR 5/4), many, coarse, prominent, reddish brown (5 YR 4/3), many, coarse, prominent, pinkish gray (5 YR 6/2), and many, coarse, prominent, gray (5 YR 6/1) mottles were present in the third, fourth, fifth and sixth layers, respectively (Table 4.6). Texture was silt loam both in the surface and subsurface horizons. Structure of the surface soil was weak sub angular blocky while subsurface horizons had sub angular blocky structure. Consistence of the surface soil layer was slightly firm when moist and slightly sticky and plastic when wet. Consistence of the subsurface horizons varied from slightly firm to moderately firm when moist and slightly sticky and plastic when wet. Mica flakes were common in the first two top layers and many in the remaining part of the profile. Root activity was limited to the first 20 cm and layers were separated by clear smooth boundary.

4.1.2 Physical Properties of the Soils

4.1.2.1 Texture

The results of soil textural class determination in the field (feel method) and in the laboratory were most times similar. The results of particle size distribution and soil texture determination using the hydrometer method for Elemebiri soils are presented in Table 4.7. Particle size distribution showed that silt-sized particles dominating in ELM1 and ELM2 profiles of Elemebiri followed by sand and then clay while sand dominated ELM3 (Table 4.7). For instance, silt content in the surface 40 cm of the soils varied from 54 to 67% (61%, mean) in ELM1, 57 to 68% (64%, mean) in ELM2 and 18 to 28% (23%, mean) in ELM3. In the subsurface horizons, silt content varied from 56 to 73% (65%, mean) in ELM1, 58 to 72% (65%, mean) and 10 to 21% (18%, mean) in ELM3. Sand content varied from 15 to 23% (19%, mean) in the surface 40 cm of ELM1, 18 to 31% (23%, mean) in ELM2 and 68 to 78% (73%, mean) in ELM3. In the subsurface horizons, sand varied from 12 to 24% (18%, mean) in ELM1, 12 to 28% (21%, mean) in ELM2 and 66 to 88% (74%, mean) in ELM3. On the other hand, clay in the surface 40 cm of ELM1 varied from 10 to 31% (20%, mean), 12 to 16% (14%, mean) in ELM2) and 4% (4%, mean) in ELM3. In the subsurface horizons, clay varied from 10 to 30% (17%, mean) in ELM1, 12 to 18% (15%, mean) in ELM2 and 2 to 15% (8%, mean) in ELM3 (Annexures 2 to 4).

Table 4.7: Some Physical Properties of Elemebiri Soils

Horizon Design.	Depth (cm)	Percent			Silt/clay ratio	Textural Class
		Sand	Silt	Clay		
			ELM1			
Ap	0-8	23.0	67.0	10.0	6.7	Silt loam
Ap2	8-21	20.0	62.0	18.0	3.4	Silt Loam
B1	24-34	15.0	54.0	31.0	1.7	Silty clay loam
B2	34-65	14.0	56.0	30.0	1.9	Silty clay loam
C1	65-90	20.0	70.0	10.0	7.0	Silt loam
C2	90-118	21.0	69.0	10.0	6.9	Silt loam
C3	118-150	12.0	73.0	15.0	4.9	Silt loam
C4	150-200+	24.0	56.0	20.0	2.8	Silt loam
			ELM2			
Ap	0-11	18.0	66.0	16.0	4.1	Silt loam
Ap2	11-19	22.0	64.0	14.0	4.6	Silt loam
B1	19-32	19.0	68.0	13.0	5.2	Silt loam
B2	32-42	31.0	57.0	12.0	4.8	Silt loam
B3	42-57	28.0	58.0	14.0	4.1	Silt loam
B4	57-88	18.0	64.0	18.0	3.6	Silt loam
C1	88-106	12.0	72.0	16.0	4.5	Silt loam
C2	160-190+	24.0	64.0	12.0	5.3	Silt loam
			ELM3			
A	0-18	78.0	18.0	4.0	4.5	Loamy sand
Ap	18-31	72.0	24.0	4.0	6	Loamy sand
Ap2	31-44	68.0	28.0	4.0	7	Sandy loam
C1	44-68	88.0	10.0	2.0	5	Loamy sand
C2	68-81	78.0	20.0	2.0	10	Loamy sand
C3	81-123	72.0	18.0	10.0	1.8	Sandy loam
C4	123-160	67.0	21.0	12.0	1.8	Sandy loam
C5	160-200+	66.0	19.0	15.0	1.3	Sandy loam

Silt/clay ratios of the surface 40 cm of Elemebiri soils varied from 1.9 to 6.7 (3.9, mean) in ELM1, 4.1 to 5.2 (4.7, mean) in ELM2 and 4.5 to 7.0 (5.8, mean) in ELM3 (Tables 4.7 and Annexures 2 to 4). In the subsurface horizons, silt/clay ratio varied from 1.9 to 7.0 (4.7, mean) in ELM1, 3.6 to 5.3 (4.4, mean) in ELM2 and 1.3 to 10.0 (4.0, mean) in ELM3.

In the Odoni soils, the percentage of sand in the surface 40 cm varied from 19 in ODN3 soil to 35 in ODN1, silt from 53 in ODN2 to 65 ODN1 and clay from 12 in ODN1 to 22 in ODN3

Table 4.8: Some Physical Properties of the Odoni Soils

Horizon Design.	Depth (cm)	Percent			Silt/clay ratio	Textural Class
		Sand	Silt	Clay		
			ODN1			
Ap	0-23	25.0	65.0	12.0	5.4	Silt loam
Ap2	23-30	22.0	65.0	13.0	5	Silt loam
B1	30-63	31.0	55.0	14.0	3.9	Silt loam
B2	63-117	41.0	53.0	6.0	8.8	Silt loam
B3	117-160	29.0	53.0	18.0	2.9	Silt loam
C	160-200+	32.0	52.0	16.0	3.3	Silt loam
			ODN2			
Ap	0-10	21.0	60.0	19.0	3.2	Silt loam
Ah	10-20	35.0	53.0	12.0	4.4	Silt loam
B1	20-40	31.0	55.0	14.0	3.9	Silt loam
B2	40-110	27.0	58.0	15.0	3.9	Silt loam
BC	110-141	35.0	53.0	12.0	4.4	Silt loam
C1	141-180	47.0	39.0	14.0	2.8	Loam
C2	180-200+	48.0	38.0	14.0	2.7	Loam
			ODN3			
A	0-5	19.0	63.0	18.0	3.5	Silt loam
Ap1	5-11	23.0	65.0	12.0	5.4	Silt loam
Ap2	11-25	21.0	61.0	18.0	3.4	Silt loam
B1	25-41	25.0	53.0	22.0	2.4	Silt loam
B2	41-48	21.0	51.0	28.0	1.8	Silty clay loam
B3	48-56	22.0	49.0	29.0	1.7	Silty clay loam
C1	56-122	29.0	49.0	22.0	2.2	Loam
C2	122-200+	33.0	48.0	19.0	2.5	Loam

(Table 4.8). In the subsurface horizons, sand varied from 21 in ODN3 to 48 in ODN2, silt, 38 in ODN2 to 55 in ODN1 and clay, 6 in ODN1 to 29 in ODN3 (Table 4.7). Surface and subsurface textures were predominantly silt loam followed by loam. Silt/clay ratio of the surface soil horizons varied from 5.0 to 5.4 in ODN1 (mean, 5.2), 3.2 to 4.4 in ODN2 (mean, 3.8) and 2.4 to 5.4 in ODN3 (mean, 3.7) while in the subsurface layers, it varied from 2.9 to 8.8 in ODN1 (mean, 4.7), 2.7 to 4.4 in ODN2 (mean, 3.5) and 1.7 to 2.5 in ODN3 (mean, 2.1) (Annexures 5 to 7).

As was observed in the Odoni soils, silt sized particles dominated the particle size distribution of Trofani soils except in TFN3 where sand dominated (Table 4.9). Sand in the surface horizons

Table 4.9: Some Physical Properties of the Trofani Soils

Horizon Design.	Depth (cm)	Percent			Silt/clay ratio	Textural Class
		Sand	Silt	Clay		
			TFN1			
Ap	0-14	21.0	60.0	19.0	3.2	Silt loam
A	14-31	21.0	62.0	17.0	3.6	Silt loam
B1	31-55	39.0	50.0	11.0	4.5	Silt loam
B2	55-140	17.0	66.0	17.0	3.9	Silt loam
B3	140-150	11.0	60.0	29.0	2.1	Silty clay loam
C	150-200+	13.0	66.0	21.0	3.1	Silt loam
			TFN2			
Ap	0-11	79.0	17.0	4.0	4.3	Loamy sand
Ap2	11-35	15.0	60.0	25.0	2.4	Silt loam
B1	35-44	15.0	57.0	28.0	2	Silty clay loam
B2	44-70	17.0	60.0	23.0	2.6	Silt loam
C1	70-126	31.0	58.0	11.0	5.3	Silt loam
C2	126-200+	41.0	49.0	10.0	4.9	Loam
			TFN3			
A	0-13	71.0	25.0	4.0	6.3	Sandy loam
Ap1	13-23	71.0	27.0	2.0	14	Sandy loam
Ap2	23-38	68.0	25.0	7.0	3.6	Sandy loam
C1	38-52	67.0	25.0	8.0	3.1	Sandy loam
C2	52-69	54.0	36.0	10.0	3.6	Sandy loam
C3	69-83	71.0	17.0	12.0	1.4	Sandy loam
C4	83-200+	91.0	8.0	1.0	8	Sand

of the SMUs varied from 15 in TFN2 to 79 in TFN2, silt, 17 in TFN2 to 62 in TFN1 and clay, 2 in TFN3 to 28 in TFN2. In the subsurface horizons, sand varied from 11 in TFN1 to 91 in TFN3, silt, 8 in TFN3 to 66 in TFN1 and clay, 1 in TFN3 to 29 in TFN1 (Annexures 7 to 10). Texture of the soils showed silt loam texture dominating in TFN1 and TFN2 while sandy loam dominated TFN3. Textural classification of subsurface layers in the TFN1 mapping unit (Table 4.9) showed that four out of the five horizons were silt loam while the horizon before the last layer was silty clay loam. In the TFN2 mapping unit, textural classes of three out of the five subsurface horizons were silt loam, one was silty clay loam and the other was loam. For TFN3, six out of the seven layers from the surface were sandy loam while the bottom layer was sand.

The soils of ODI, just like Odoni (ODN) and Trofani (TFN) soils, were dominated by silt sized particles followed by sand and then clay (Table 4.10). In the surface 40 cm, percentage silt ranged from 45 in ODI2 to 57 in ODI3 (mean, 53), sand, 31 in ODI1 to 41 in ODI2 (mean, 36) and clay, 8 in ODI3 to 14 in ODI2 (mean, 12). In the subsurface horizons, percentage silt ranged from 41 in ODI1 to 67 in ODI1 (mean, 59), sand, 11 in ODI1 to 42 in ODI2 (mean, 26) and clay, 10 in ODI3 to 22 in ODI1 (mean, 16). The silt/clay ratio of surface soil layers was 4.3 in ODI1 (mean, 4.3), 3.2 to 4.3 in ODI2 (mean, 3.8) and 3.9 to 7.1 in ODI3 (mean, 5.0) while in the subsurface layers, silt/clay ratio varied from 2.1 to 5.3 in ODI1 (mean 3.6), 3.4 to 4.8 in ODI2 (mean, 4.0) and 3.3 to 5.3 in ODI3 (mean, 4.3) (Annexures 11 to 13).

Table 4.10: Some Physical Properties of Odi Soils

Horizon Design.	Depth (cm)	Percent			Silt/Clay Ratio	Textural Class
		Sand	Silt	Clay		
ODI1						
Ap	0-26	31.0	56.0	13.0	4.3	Silt loam
A	26-60	41.0	44.0	15.0	2.9	Loam
B1	60-78	31.0	49.0	20.0	2.5	Loam
B2	78-120	17.0	67.0	16.0	4.2	Silt loam
B3	120-135	39.0	41.0	20.0	2.1	Loam
C1	135-163	25.0	63.0	12.0	5.3	Silt loam
C2	163-186	11.0	67.0	22.0	3	Silt loam
C3	186-200+	23.0	65.0	12.0	5.4	Silt loam
ODI2						
Ap	0-20	41.0	45.0	14.0	3.2	Loam
A	20-40	42.0	47.0	11.0	4.3	Loam
B1	40-110	31.0	57.0	12.0	4.8	Silt loam
B2	110-141	35.0	51.0	14.0	3.6	Silt loam
B3	141-180	21.0	61.0	18.0	4.4	Silt loam
C	180-200+	15.0	69.0	16.0	4.3	Silt loam
ODI3						
Ah	0-3	35.0	57.0	8.0	7.1	Silt loam
Ap	3-20	21.0	63.0	16.0	3.9	Silt loam
Ap2	20-46	27.0	58.0	15.0	3.9	Silt loam
B1	46-60	37.0	53.0	10.0	5.3	Silt loam
B2	60-94	21.0	65.0	14.0	4.6	Silt loam
B3	94-145	21.0	65.0	14.0	4.6	Silt loam
C1	145-158	17.0	65.0	18.0	3.6	Silt loam
C2	158-200+	15.0	65.0	20.0	3.3	Silt loam

The results on the physical properties of soils from the Koroama study location are presented in Table 4.11. Again, silt-sized particles dominated the particle size distribution of Koroama soils followed by sand and then clay.

Table 4.11: Some Physical Properties of the Koroama Soils

Horizon	Depth (cm)	Percent Sand	 Silt	 Clay	Silt/clay ratio	Textural Class
			KRM1			
A1	0-7	24.0	61.0	15.0	4.1	Silt loam
A2	7-43	20.0	64.0	14.0	4.6	Silt loam
B1	43-86	21.0	60.0	19.0	3.2	Silt loam
B2	86-115	16.0	69.0	15.0	4.6	Silt loam
BC	115-130	16.0	67.0	17.0	3.9	Silt loam
C	130-200+	20.0	60.0	19.0	3.2	Silt loam
			KRM2			
	0-15	24.0	67.0	9.0	7.4	Silt loam
Ap2	15-23	27.0	63.0	10.0	6.3	Silt loam
B1	23-40	19.0	53.0	28.0	1.9	Silty clay loam
B2	40-64	18.0	53.0	29.0	1.8	Silty clay loam
B3	64-78	19.0	67.0	14.0	4.8	Silt loam
C1	78-140	18.0	69.0	13.0	5.3	Silt loam
C2	140-194+	18.0	70.0	12.0	5.8	Silt loam
			KRM3			
Ap	0-12	30.0	61.0	9.0	6.8	Silt loam
Ap2	12-39	20.0	64.0	16.0	4	Silt loam
B1	39-59	10.0	60.0	30.0	2	Silty clay loam
B2	59-96	17.0	64.0	29.0	2.2	Silty clay loam
B3	96-135	16.0	54.0	30.0	1.8	Silty clay loam
C	135-190+	18.0	67.0	25.0	2.3	Silt loam

In the surface 40 cm, sand varied from 20 to 24% (22%, mean) in KRM1, 19 to 27% (23%, mean) for KRM2 and 10 to 30% (20%, mean) for KRM3 and in the subsurface layers, 16 to 21% (18%, mean), 18 to 19% (18%, mean) and 16 to 20% (18%, mean), respectively. Silt content in the surface 40 cm varied from 61 to 64% (63%, mean), 53 to 67% (61%, mean) and 60 to 61% (61%, mean) and in the subsurface, 60 to 69% (64%, mean) 53 to 70% (65%, mean) and 54 to 67% (61%, mean) in KRM1, KRM2 and KRM3, respectively. Clay on the other hand, varied from 14 to 15% (15%, mean), 9 to 28% (16%, mean) and 9 to 16% (13%, mean) in the surface 40 cm and subsurface, 15 to 19% (18%, mean), 12 to 29% (17%, mean) and 16 to 30% (29%, mean) in KRM1, KRM2 and KRM3, respectively (Annexures 14 to 16).

Silt/clay ratio in the Koroama soils varied from 4.1 to 4.6 with mean as 4.4 for KRM1, 1.9 to 7.4 with 5.4 as mean for KRM2 and 4 to 6 with 5.4 as mean for KRM3.

For the soils of the Niger Delta University (NDU) Teaching and Research Farm, silt-sized particles also dominated the particle size distribution followed by clay and then, sand (Table 4.12). The content of silt in the surface 40 cm were 61-73 (67 mean) in NDU1, 59-61 (60%, mean) in NDU2 and 69 (69 mean) in NDU3 and in the subsurface horizons 59-72 (64 mean), 57-70 (61 mean) and 66-69 (67 mean), repectively (Annexures 17-19).

Table 4.12: Some Physical Properties of the Niger Delta University Farm Soils

Horizon Design.	Depth (cm)	Percent Sand	Percent Silt	Percent Clay	Silt/clay ratio	Textural Class
			NDU1			
Ap	0-19	20.0	73.0	7.0	10.4	Silt loam
B1	19-39	10.0	61.0	29.0	2.1	Silty clay loam
B2	39-71	10.0	62.0	28.0	2.2	Silty clay loam
B3	71-81	11.0	59.0	30.0	2	Silty clay loam
C1	81-138	18.0	72.0	10.0	7.2	Silt loam
C2	138-195+	21.0	64.0	15.0	4.3	Silt loam
			NDU2			
Ap	0-12	20.0	61.0	19.0	3.2	Silt loam
Ap2	12-26	22.0	60.0	18.0	3.3	Silt loam
B1	26-36	13.0	59.0	28.0	2.1	Silty clay loam
B2	36-53	15.0	57.0	28.0	2	Silty clay loam
B3	53-116	19.0	57.0	24.0	1.9	Silt loam
C	116-190+	16.0	70.0	14.0	5	Silt loam
			NDU3			
A1	0-5	16.0	69.0	15.0	4.6	Silt loam
A2	5-13	17.0	69.0	14.0	4.9	Silt loam
AB	13-20	16.0	69.0	15.0	4.6	Silt loam
B1	20-75	14.0	67.0	19.0	3.5	Silt loam
B2	75-140	15.0	66.0	19.0	3.5	Silt loam
C	140-190+	15.0	69.0	16.0	4.3	Silt loam

Clay content varied from 7 to 29% (18%, mean) in the surface 40 cm and 10 to 30% (21%, mean) in the sub surface horizons of NDU1, 18 to 28% (22%, mean) in the surface 40 cm, and 14 to 28% (22%, mean) in the subsurface of NDU2 and 14 to 15% (15%, mean) in the surface 40 cm and 16 to 19% (18%, mean) in the sub surface horizons of NDU3. Sand in the surface 40 cm of NDU1 was 10 to 20% (15%, mean) and 13 to 17% (15%, mean) in the sub surface horizons, 13 to 22% (18%, mean) in the surface 40 cm and 15 to 19% (17%, mean) in the sub surface of NDU2, and 16 to 17% (16%, mean) in the surface 40 cm and 14 to 15% (15%, mean) in the sub surface of NDU3. Silt/clay ratio varied from 2.1 to 10.4 with 6.3 as mean for NDU1, 2.1 to 3.3 with 2.9 as mean for NDU2 and 4.6 to 4.9 with 4.7 as mean for NDU3.

4.1.3 Chemical Properties of the Soils

4.1.3.1 The Soils of Elemebiri

The results of chemical properties and micronutrient composition of Elemebiri soils are presented in Tables 4.13 to 4.18 and Annexures 2 to 19. The chemical composition of Elemebiri soils are presented in Table 4.13. The pH (H_2O) of the top 40 cm of the Elemebiri soils ranged from 5.62 (ELM1) to 6.22 (ELM3) with an average of 5.93 while in the subsurface horizons, pH ranged from 5.78 (ELM3) to 6.04 (ELM2) with 5.92 as mean for Elemebiri soils (Annexures 2 to 4)..

Table 4.13: Chemical properties /Micronutrient concentration of Elemebiri Soils

Horizon Des	Depth (cm)	pH		ΔpH	EC dS/M	Percent				Avail P (mg Kg)	Exchangable (cmol/kg)				TEB (cmol/kg)	Exchange (cmol/kg)		ECEC (cmol/kg)	Percent		Micronutrients (mg/kg)			
		H_2O	$CaCl_2$			Total N	Org C	Org Mat	C N ratio		Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}		Acid	Al		Al sat	BS	Fe	Mn	Zn	Cu
											ELM 1													
Ap	0-8	5.46	5.25	0.21	0.06	0.25	2.25	3.88	9	18	0.74	0.64	1.65	0.09	3.12	2.5	0.8	5.62	14	61	50	3.05	15.57	3.00
Ap2	8-21	5.62	5.36	0.26	0.21	0.11	2.24	3.87	20	16	1.26	0.59	0.55	0.09	2.49	1.5	1.1	3.99	28	62	57	2.90	14.28	3.00
B1	21-34	5.77	5.17	0.6	0.09	0.08	1.52	2.62	19	9	0.78	0.43	0.53	0.06	1.8	2.4	1	4.2	24	43	48	1.81	9.61	3.20
B2	34-65	5.73	5.15	0.58	0.11	0.09	1.5	2.59	17	10	0.76	0.49	1.42	0.07	2.74	2.0	0.7	4.74	15	58	68	1.91	8.47	3.10
C1	65-90	6.55	5.37	1.18	0.12	0.08	1.22	2.10	15	6	0.75	1.22	0.47	0.07	2.51	1.8	1	4.31	23	58	41	1.35	12.94	1.55
C2	90-118	5.72	4.94	0.78	0.12	0.04	0.7	1.21	18	6	1.2	0.10	0.21	0.08	1.59	1.8	1	3.39	29	47	57	1.30	6.70	3.40
C3	118-150	5.85	5.36	0.49	0.08	0.06	0.71	1.23	12	5	1.22	0.16	0.18	0.08	1.64	2.4	1.8	4.04	46	41	63	1.42	8.48	1.65
C4	150-200+	5.86	5.22	0.64	0.23	0.05	1.07	1.85	21	3	0.71	0.49	0.72	0.07	1.99	1.4	1.1	3.39	32	59	62	1.57	7.23	3.60
											ELM 2													
Ap	0-11	5.44	5.31	0.09	0.06	0.09	1.03	1.77	11	16	1.95	0.09	0.43	0.10	2.57	1.7	1.2	4.27	28	69	41	3.56	11.95	2.30
Ap2	11-19	5.71	5.23	0.51	0.09	0.01	0.21	0.37	21	17	0.80	0.09	0.62	0.03	1.54	0.9	0.6	2.44	25	63	60	2.50	9.54	3.20
B1	19-32	6.61	5.37	1.24	0.31	0.02	0.26	0.44	13	14	0.80	0.76	0.58	0.07	2.21	2.1	0.9	4.31	21	52	64	2.39	14.85	3.65
B2	32-42	6.04	5.20	0.84	0.01	0.02	0.16	0.27	8	10	0.85	0.79	0.66	0.07	2.37	2.7	0.8	5.07	16	52	65	1.69	16.17	2.95
B3	42-57	6.07	5.22	0.85	0.21	0.01	0.11	0.19	11	7	0.84	0.13	0.44	0.06	1.47	2.3	1.3	3.77	34	47	42	1.80	13.39	1.25
B4	57-88	5.71	5.20	0.54	0.08	0.02	0.12	0.21	6	8	0.90	0.48	0.70	0.08	2.16	1.5	1.0	3.66	27	65	53	1.94	16.56	4.70
C1	88-106	6.15	5.32	0.83	0.06	0.03	0.16	0.28	5	6	0.63	0.43	0.18	0.05	1.29	1.7	0.9	2.99	30	51	51	1.72	8.74	2.90
C2	106-190+	6.18	5.17	1.01	0.07	0.03	0.14	0.24	5	7	0.85	0.36	0.26	0.04	1.51	0.7	0.5	2.21	23	73	55	1.60	8.66	3.00
											ELM 3													
A	0-18	5.52	5.42	0.10	0.04	0.03	0.84	1.45	28	15	0.73	0.45	0.45	0.07	1.70	1.2	1	2.90	34	66	62	4.25	11.34	1.90
Ap1	18-31	7.00	5.30	1.70	0.07	0.06	0.78	1.35	13	18	0.84	0.97	0.58	0.08	2.47	1.9	1.2	4.37	27	62	42	3.01	6.75	4.80
Ap2	31-44	6.15	5.31	0.84	0.06	0.04	0.82	1.41	21	9	0.72	0.76	0.18	0.06	1.72	1.2	0.7	2.92	24	65	53	2.22	4.09	2.25
C1	44-68	5.95	5.64	0.31	0.09	0.02	0.53	0.91	27	9	0.72	0.08	0.12	0.07	0.99	0.5	0.3	1.49	20	76	42	1.80	6.42	3.10
C2	68-81	5.98	5.30	0.68	0.07	0.04	0.56	0.97	14	10	0.56	0.22	0.33	0.03	1.14	1.0	0.6	2.14	28	59	78	2.41	3.48	250
C3	81-123	5.79	5.19	0.60	0.22	0.07	0.56	0.97	8	6	0.87	0.08	0.27	0.08	1.30	1.8	1.0	3.10	32	53	53	2.00	9.66	4.95
C4	123-160	5.86	5.33	0.53	0.09	0.05	0.59	1.02	12	7	1.20	0.43	0.52	0.08	2.23	2.8	1.9	5.63	34	46	91	1.56	17.98	4.20
C5	160-200+	5.31	5.27	0.04	0.04	0.04	0.57	0.98	14	5	1.28	0.74	1.81	0.08	3.91	2.2	1.0	6.11	16	68	62	1.60	12.72	5.30

Organic C and organic matter in the surface 40 cm of the Elemebiri soils ranged from 1.52 to 2.25% (2.00%, mean) in ELM1, 0.16 to 1.03% (0.42%, mean) in ELM2, and 0.78 to 0.84% (0.81%, mean) in ELM3, while in the subsurface, organic C ranged from 0.70 to 1.50% (1.04% mean) in ELM1, 0.11 to 0.16% (0.13%, mean) in ELM2, 0.53 to 0.59% (0.56%, mean) in ELM3. The mean values of organic matter in the surface 40 cm of the SMUs were ELM1 (2.00%), ELM2 (0.71%), ELM3 (1.4%). Total N values generally, were higher in the surface soil layers than in the subsurface layers. The percent total N in the surface 40cm of Elemebiri soils (Annexures 2 to 4) varied from 0.08-0.25 (0.15 mean), 0.01-0.09 (0.04 mean) and 0.03-0.06 (0.04 mean) for ELM1, ELM2 and ELM3 but in the subsurface of the respective soils, total N was 0.02-0.09 (0.06 mean), 0.01-0.03 (0.02 mean) and 0.02-0.07 (0.04 mean). Using the rating by FPDD (2012) for Bayelsa soils, available P in the surface layers of the Elemebiri soils were generally moderate. The available P (mg/kg) in the surface 40 cm of the soils was 9-18 (14, mean) for ELM1, 10-17 (14, mean) for ELM2, 9-18 (14, mean) for ELM3, while in the subsurface of the soils, available P was 3-10 (6, mean) for ELM1, 6-8 (7, mean) for ELM2, 5-10 (7, mean) for ELM3.

The relative abundance of the cations in the surface 40 cm and subsurface horizons of the Elemebiri soils was in a decreasing order of $Ca^{++} > K^{+} > Mg^{++} > Na^{+}$ (surface) and $Ca^{++} > K^{+} > Mg^{++} > Na^{+}$, (subsurface) in ELM1; $Ca^{++} > K^{+} > Mg^{++} > Na^{+}$ (surface) and $Ca^{++} > K^{+} > Mg^{++} > Na^{+}$ (subsurface) in ELM2; $Ca^{++} > Mg^{++} > K^{+} > Na^{+}$ (surface) and $Ca^{++} > K^{+} > Mg^{++} > Na^{+}$ (subsurface) in ELM3. Cation ratios are helpful in identifying soil structural problems. In this regard, computation of the calcium/magnesium ratios of surface 40 cm and subsurface horizons from the SMUs gave the following results: ELM1 (1.69, surface) and (1.9 subsurface); ELM2 (2.56, surface) and (2.4 subsurface); ELM3 (1.04, surface) and (3 subsurface). The average exchangeable K values (cmol/kg) for the surface 40 cm and the subsurface horizons were: ELM1 0.91 (surface) and 0.60 subsurface, ELM2 0.57 (surface) and 0.40 subsurface, ELM3 0.4 (surface) and 0.61 (subsurface).

Across the pedons, the lowest exchange acidity (0.50cmolkg^{-1}) was recorded in pedon ELM. Exchange acidity in the surface 40 cm and the sub surface horizons of various pedons as summarized in annexures 2 to 4 were 1.5-2.5 (mean 2.13) surface and 1.4-2.4 (mean 1.88) subsurface for ELM1, 0.9-2.7 (mean 1.85) surface and 0.7-2.3 (mean 1.55) subsurface for

ELM2, 1.20-1.90 (mean 1.43) surface and 0.50-3.40 (mean 1.78) subsurface for ELM3. In the surface 40 cm and the subsurface of the SMUs, ECEC values above 4cmolkg^{-1} were recorded in ELM1 (4.60 cmolkg^{-1}, surface), and ELM2 (4.02 cmolkg^{-1}, surface). Exchangeable Al and exchangeable H make up exchange acidity in soils. Exchangeable Al (cmol/kg) in the surface 40 cm of Elemebiri soils (Tables 4.16 and Annexures 2 to 4) were 0.8-1.1 (1.0 mean), 0.6-1.2 (0.9 mean) and 0.7-1.2 (1.1 mean) for ELM1, ELM2 and ELM3 and in the subsurface, 0.7-1.8 (1.1 mean), 0.5-1.3 (0.9 mean) and 0.3-1.9 (1.0 mean), in the respective soils. In the surface 40 cm of all the soil sampling units, the lowest exchangeable Al (0.6cmol/kg) was recorded in the levee slope of Elemebiri (ELM2) while the lowest in subsurface horizons was in the soil profile located at the centre of the active Niger River at Elemebiri (ELM3) and that in the middle slope of Koroama (KRM2). The saturation of Al in the surface 40cm of Elemebiri SMUs ranged from 14-24, 16-28 and 24-34 in ELM1, ELM2 and ELM3 and in the subsurface layers, 15-46, 23-34 and 16-34 in the respective SMUs. Base saturation in the surface 40cm ranged from 43-63, 52-69 and 62-66 in ELM1, ELM2 and ELM and in the subsurface layers, 41-59, 47-73 and 46-76, respectively.

According to Brady and Weil (2005) micronutrient cations are most soluble and available under acid conditions except Mo which is rendered unavailable in acid soils. Whereas, the availability of Mo is high in soils high in pH, deficiencies of the other trace elements are very common. Generally, the desirability of a slightly acid soil (between pH 6 and 7) largely stems from the fact that for most plants, this pH condition allows micronutrient cations to be soluble enough to satisfy plants needs without becoming toxic to plants.

Certain plants, especially those that are native to very acid soils, have only a poor ability to take up iron and other micronutrients unless the soil is quite acid (pH 5). Such acid-loving plants therefore become deficient in these elements when the soil pH is such that their solubility is lowered (usually above pH 5.5). In this study, the concentration of iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) in the soils were as presented in Table 4.13 and summarized in Annexures 2 to 19. The results showed that the soils generally, were not deficient in micronutrient elements. The distribution of Fe in the profiles did not take any definite pattern. The highest (99 mg/kg) and lowest (26 mg/kg) values were recorded in the subsurface horizons of ODI2 and ODN2, respectively. The mean values of Fe in the surface 40 cm of the Elemebiri pedons were 52, 58 and 52 for ELM1, ELM2 and ELM3 and in the subsurface, Fe values were 58, 50 and 65mg/kg, respectively. In the Elemebiri soils, the mean concentration of Mn in the surface 40 cm and the subsurface horizons were 2.58 and 1.51, 2.54 and 1.77, and 3.16 and 1.87mg/kg for ELM1, ELM2 and ELM3, respectively. Similarly, the mean concentration of Zn in the surface 40 cm and subsurface horizons were 13.15 and 8.76, 13.13 and 11.84, and 7.39 and 10.05mg/kg for ELM1, ELM2 and ELM3, respectively. The concentration of Cu in the surface 40 cm and subsurface horizons of Elemebiri soils were 3.07 and 2.66, 3.03 and 2.96, and 2.98 and 4.01mg/kg for ELM1, ELM2 and ELM3, respectively.

4.1.3.2 The Soils of Odoni

In the Odoni soils, pH (H_2O) of the top 40 cm (Table 4.14) ranged from 5.76 (ODN1) to 6.04 (ODN3) with an average of 5.88 and in the subsurface horizons, 6.04 (ODN1) to 6.30 (ODN3) with 6.20 as mean (Annexures 5 to 7). Organic C in the top 40 cm of Odoni soils varied from 0.58 to 1.07% (0.83%, mean) in ODN1, 0.20 to 2.13% (1.22%, mean) in ODN2, 0.31 to 2.33% (1.36%, mean) in ODN3, and in the subsurface, 0.01 to 0.41% (0.19%, mean) in ODN1, 0.37 to 0.73% (0.61%, mean) in ODN2, and 0.31 to 0.99% (0.71%, mean) in ODN3. The mean values of organic matter in the surface 40 cm of Odoni soils were 1.42% (ODN1), 2.1% (ODN2), and 2.35% (ODN3). Total N values for the surface 40cm were 0.05 (0.05 mean), 0.04-0.21 (0.11 mean) and 0.03-0.20 (0.12 mean) and in the subsurface, 0.01-0.04 (0.02 mean), 0.03-0.06 (0.05 mean) and 0.03-0.09 (0.06 mean) for ODN1, ODN2 and ODN3, respectively (Annexures 5 to 7).

Available P in the top 40 cm of the soils varied from 12-15 (14, mean) in ODN1, 8-16 (13, mean) in ODN2, 14-22 (17, mean) in ODN3) and in the subsurface, 3-9 (7, mean) in ODN1, 2-4 (3, mean) in ODN2, and 1-5 (3, mean) in ODN3. The relative abundance of exchangeable cations in the top 40 cm and in the subsurface were in the decreasing order of Ca^{++} › Mg^{++} › K^{+} › Na^{+} (surface) and Ca^{++} › K^{+} › Mg^{++} › Na^{+} (subsurface) in ODN1; Ca^{++} › Mg^{++} › K^{+} › Na^{+} (surface) and Ca++ › Mg++ › K+ › Na^{+} (subsurface) in ODN2; Ca++ › K+ › Mg++ › Na^{+} (surface) and K+ › Ca^{++} › Na^{+} › Mg^{++} (subsurface) in ODN3. Calcium/magnesium ratios of surface 40 cm and subsurface horizons gave the following results: 1.27 (surface) and 1.88 (subsurface) in ODN1; 1.4 (surface) and 1.37 (subsurface) in ODN2 and 2.35 (surface) and 1.83 (subsurface) in ODN3. Potassium concentration (cmol/kg) in the soils was 0.39 (surface) and 0.56 (subsurface) in ODN1, 0.33(surface) and 0.43 (subsurface) in ODN2, and 0.53 (surface) and

1.22 (subsurface) in ODN3. ECEC values of 4 cmolkg^{-1} and above were recorded in ODN1 (4.30 cmolkg^{-1}, surface), ODN2 (4.66 cmolkg^{-1}, subsurface), ODN3 (4.15 cmolkg^{-1}, surface) and (5.29 cmolkg^{-1}, subsurface).

Table 4.14: Chemical properties/Micronutrient concentration of Odoni Soils

Horizon Des.	Depth (cm)	pH		ΔpH	EC dS/M	Percent			C/N ratio	Avail P (mg/Kg)	Exchangable (cmol/kg)				TEB (cmol/kg)	Exchange (cmol/kg)		ECEC (cmol/kg)	Percent		Micronutrients (mg/kg)			
		H_2O	$CaCl_2$			Total N	Org. C	Org. Mat			Ca^{2+}	Mg^{2+}	K	Na		Acid	Al		Al sat	BS	Fe	Mn	Zn	Cu
											ODN 1													
Ap	0-23	5.76	5.33	0.43	0.12	0.05	1.07	1.84	21	12.0	0.75	0.99	0.24	0.07	2.05	2.2	1.4	4.25	33	55	46	2.80	18.00	3.65
Ap2	23-30	5.75	5.17	0.42	0.19	0.05	0.58	1.00	12	15.0	1.25	0.58	0.53	0.09	2.45	1.9	1.0	4.35	23	63	36	1.62	15.20	2.05
B1	30-63	6.01	5.27	0.74	0.11	0.04	0.41	0.71	10	8.0	0.75	0.20	0.43	0.07	1.45	2.1	1.6	3.55	45	50	95	0.83	10.14	4.00
B2	63-117	6.32	5.30	1.02	0.00	0.02	0.2	0.35	10	7.0	0.85	0.93	1.12	0.09	2.99	1.1	0.7	4.09	17	77	75	0.53	11.67	0.95
B3	117-160	5.33	5.17	0.16	0.16	0.01	0.1	0.13	10	9.0	0.91	0.43	0.52	0.09	1.95	2.8	1.8	4.75	38	49	47	1.16	4.99	4.20
C	160-200+	6.48	5.72	0.76	0.17	0.01	0.12	0.20	12	3.0	0.72	0.15	0.17	0.03	1.07	1.4	0.8	2.47	32	48	49	1.21	10.51	5.95
											ODN 2													
Ap	0-10	5.64	5.22	0.42	0.12	0.09	1.32	2.28	15	16.0	0.74	0.86	0.10	0.07	1.77	2.2	1.6	3.97	40	45	63	5.70	18.99	4.35
Ah	10-21	6.70	5.32	1.38	0.14	0.21	2.13	3.68	10	16.0	0.79	0.46	0.48	0.08	1.81	2.9	1.9	4.71	40	38	41	3.72	12.45	3.00
B1	21-37	5.38	5.18	0.20	0.14	0.04	0.2	0.35	5	8.0	0.7	0.28	0.42	0.07	1.47	1.5	0.9	2.97	30	49	43	1.51	8.12	3.50
B2	37-46	6.11	5.30	0.81	0.06	0.03	0.37	0.63	12	4.0	0.78	0.89	0.15	0.08	1.9	1.8	0.9	3.7	24	51	55	1.11	17.19	3.15
BC	46-79	6.41	6.19	0.22	0.07	0.06	0.67	1.16	11	2.0	0.83	0.54	0.44	0.05	1.86	6.2	3.6	8.06	45	23	37	5.80	6.61	5.10
C1	79-149	6.19	5.38	0.81	0.08	0.06	0.73	1.26	12	3.0	0.75	0.38	0.82	0.07	2.02	1.4	0.7	3.42	20	59	52	1.40	11.95	2.30
C2	149-200+	6.37	5.27	1.10	0.20	0.06	0.66	1.13	11	2.0	0.74	0.45	0.29	0.07	1.55	1.9	1	3.45	29	45	26	1.64	10.53	2.80
											ODN 3													
A	0-5	5.67	5.37	0.30	0.67	0.2	2.33	4.02	12	19.0	1.95	0.70	0.61	0.13	3.39	1.6	0.8	4.99	16	68	35	1.14	11.80	3.40
Ap1	5-11	6.45	5.51	0.94	0.10	0.17	1.97	3.39	12	22.0	0.69	0.45	0.18	0.04	1.36	2.3	1.5	3.66	41	37	54	2.78	5.08	4.10
Ap2	11-25	5.97	5.18	0.79	0.01	0.07	0.84	1.44	12	14.0	1.2	0.32	0.68	0.09	2.29	1.7	1	3.99	25	57	74	3.10	7.95	2.40
B1	25-41	6.07	5.31	0.76	0.00	0.03	0.31	0.53	10	14.0	0.75	0.47	0.65	0.07	1.94	2.0	1.2	3.94	30	49	67	1.45	4.45	3.60
B2	41-48	6.45	5.70	0.75	0.00	0.09	0.99	1.7	11	3.0	0.73	0.40	1.40	0.07	2.6	2.0	1.2	4.6	26	57	45	1.58	9.79	2.50
B3	48-56	5.91	5.36	0.55	0.00	0.03	0.31	0.53	10	1.0	1.22	0.92	2.13	0.07	4.34	2.5	1.6	6.84	23	63	55	2.29	4.10	2.80
C1	56-122	6.20	5.27	0.93	0.05	0.06	0.64	1.1	11	1.0	1.2	0.39	0.58	0.08	2.25	3.4	2	5.65	35	40	74	2.86	9.88	2.70
C2	122-200+	6.62	5.32	1.30	0.25	0.08	0.89	1.54	11	5.0	0.73	0.39	0.77	0.08	1.97	2.1	1.3	4.07	32	48	39	2.05	7.39	4.10

In this study, the highest ECEC value (6.2cmolkg^{-1}) was recorded in pedon ODN2. Exchange acidity values varied from 1.9-2.2 (mean 2.1) surface and 1.1-2.8 subsurface (mean 1.9) in ODN1, 1.5-2.9 (mean 1.7) surface and 1.4-6.2 (mean 2.8) subsurface in ODN2, and 1.6-2.3 (mean 1.9) surface and 2.0-3.4 (mean 2.5) subsurface in ODN3. The highest exchangeable Al value (3.6cmol/kg) was also recorded in the levee slope soils of Odoni (ODN2). In the surface 40 cm of the soils (Tables 4.14), exchangeable Al (cmol/kg) ranged from 1.0-1.4 (1.2 mean) for ODN1, 0.9-1.9 (1.2 mean) for ODN2 and 0.8-1.5 (1.1 mean) for ODN3 and in the subsurface, 0.7-1.8 (1.2 mean), 0.7-3.6 (1.6 mean) and 1.2-2.0 (1.5 mean) for the respective soils. Al saturation in the surface 40cm of Elemebiri SMUs was 23-33 ODN1, 30-40 in ODN2 and 16-41 in ODN3 and in the subsurface layers, 17-45, 20-45 and 23-35 in the respective layers. Base saturation in the surface 40cm was 55-63 in ODN1, 38-49 in ODN2 and 37-68 in ODN3 and in the subsurface layers, 48-77, 23-59 and 40-63, respectively.

The mean values Fe in the surface 40 cm were 41, 49 and 58 for ODN1, ODN2, and ODN3 and in the subsurface, 67, 43 and 53mg/kg, respectively (Annextures 5 to 7). The mean concentration of Mn in the surface 40 cm and the subsurface layers were 2.21 and 0.93, 2.98 and 1.99, and 2.12 and 2.20mg/kg for ODN1, ODN2 and ODN3, respectively and for Zn 16.60 and 9.33, 13.19 and 11.57, 7.32 and 7.79mg/kg for ODN1, ODN2, and ODN3, respectively. The mean concentration of Cu in the surface 40 cm and subsurface layers of Odoni soils were 2.85 and 3.78, 3.62 and 3.34, and 3.38 and 3.03mg/kg for ODN1, ODN2 and ODN3, respectively.

4.1.3.3 The Soils of Trofani

In the Trofani soils, pH (H_2O) of the top 40 cm (Table 4.15) varied from 5.70 (TFN1) to 6.16 (TFN2) with an average of 5.87 and in the subsurface, from 5.82 (TFN1) to 6.45 (TFN2) with 6.57 as mean (Annexures 8 to 10). Organic C varied from 0.45 to 1.60% (1.03%, mean) in TFN1, 0.35 to 1.28% (0.74%, mean) in TFN2, 0.55 to 1.2% (0.82%, mean) in TFN3, and in the subsurface, from 0.21 to 1.04% (0.54%, mean) in TFN1, 0.19 to 0.31% (0.24%, mean) in TFN2, 0.08 to 0.68% (0.35%, mean) in TFN3. The mean values of organic matter in the surface 40 cm of the Trofani soils were TFN1 (1.77%), TFN2 (1.27%), TFN3 (1.42%). Percent total N in the surface 40cm were 0.06-0.13 (0.10 mean), 0.05-0.06 (0.06 mean) and 0.05-0.10 (0.07 mean) for TFN1, TFN2 and TFN3 (Annexures 8 to 10). The corresponding values in the subsurface horizons were 0.02-0.04 (0.03 mean), 0.02-0.03 (mean 0.03) and 0.01-0.06 (0.03 mean), respectively. Available P (mg/Kg) in the surface 40 cm varied from 8-12 (10, mean) in TFN1, 10-17 (14, mean) in TFN2, 3-15 (9, mean) in TFN3 and 4-16 (9, mean) in TFN1, 2-15 (7, mean) in TFN2, and 4-10 (7, mean) in TFN3 in the subsurface horizons. Exchangeable bases abundance in the surface 40 cm and in the subsurface horizons were in the decreasing order of Ca^{++} › K^{+} › Mg^{++} › Na^{+} (surface) and Ca^{++} › Mg^{++} › K^{+} › Na^{+} (subsurface) in TFN1; Ca^{++} › Mg^{++} › K^{+} › Na^{+} (surface) and Ca^{++} › K^{+} › Mg^{++} › Na^{+} (subsurface) in TFN2; Ca^{++} › Mg^{++} › K^{+} › Na^{+} (surface) and Ca^{++} › K^{+} › Mg^{++} › Na^{+} (subsurface) in TFN3. The calcium/magnesium ratios of surface 40 cm and subsurface horizons were 2.85 (surface) and 1.67 (subsurface) in TFN1, 2.89 (surface) and 2.94 (subsurface) in TFN2, and 1.43 (surface) and 1.63 (subsurface) in TFN3. Potassium concentration (cmol/kg) in the soils were 0.35 (surface) and) 0.41 (subsurface) in TFN1, 0.31 (surface) and 0.81 (subsurface) in TFN2, and 0.64(surface) and 0.55 (subsurface) in TFN3. ECEC values above 4cmol/kg were recorded in TFN1 (4.71 cmolkg^{-1}, subsurface), TFN2 (4.62 cmolkg^{-1}, surface), and TFN3 (4.34 cmolkg^{-1}, subsurface). Exchange acidity values were 1.7-1.8 (mean 1.75) surface and 1.9- 5.4 (mean 3.1) subsurface in TFN1, 1.8-3.3 (mean 2.57) surface and 0.8-1.8 (mean 1.2) subsurface in TFN2, and 1.6-1.8 (mean 1.7) surface and 1.4-4.6 (mean 2.43) subsurface in TFN3. Exchangeable Al (cmol/kg) values in the surface 40 cm (Tables 4.18 and Annexures 9 to 11) were 1.0-1.4 (1.2 mean), 1.0-1.9 (1.5 mean) and 0.9-1.2 (1.0 mean) in TFN1, TFN2 and TFN3 and in subsurface horizons 0.8-2.4 (1.4 mean), 0.5-1.1 (0.7 mean) and 0.7-2.2 (1.2 mean), respectively.

Table 4.15: Chemical Properties/Micronutrient Concentration of Trofani Soils

Horizon Des.	Depth (cm)	pH		ΔpH	EC dS/M	Percent				Avail P (mg/Kg)	Exchangable (cmol/kg)				TEB (cmol/kg)	Exchange (cmol/kg)		ECEC (cmol/kg)	Percent		Micronutrients (mg/kg)			
		H_2O	$CaCl_2$			Total N	Org. C	Org. Mat.	C/N ratio		Ca^{2+}	Mg^{2+}	K^+	Na		Acid	Al		Al sat	BS	Fe	Mn	Zn	Cu
											TFN 1													
Ap	0-14	5.64	5.12	0.52	0.09	0.13	1.6	2.76	12	12	0.75	0.12	0.15	0.07	1.09	1.8	1	2.89	35	38	54	2.39	5.41	2.80
A	14-31	5.75	5.25	0.50	0.07	0.06	0.45	0.78	8	8	0.78	0.42	0.65	0.07	1.92	2.1	1.4	3.62	39	53	49	3.42	15.86	2.40
B1	31-55	5.88	5.14	0.74	0.10	0.03	0.24	0.42	8	4	0.78	0.98	0.26	0.05	2.07	2.3	1.5	4.37	34	47	34	0.58	6.52	3.80
B2	55-140	5.95	5.39	0.56	0.00	0.02	0.21	0.37	11	11	0.75	0.32	0.62	0.07	1.76	1.9	0.9	3.66	25	48	79	0.86	9.17	5.70
B3	140-150	5.86	5.29	0.57	0.11	0.04	0.68	1.17	17	5	0.56	0.22	0.16	0.03	0.97	5.4	2.4	6.37	38	15	77	0.49	9.55	3.40
C	150-200+	5.30	5.09	0.21	0.04	0.04	1.04	1.8	26	16	0.77	0.20	0.61	0.07	1.65	2.0	0.8	4.45	18	37	76	0.63	14.26	2.55
											TFN 2													
Ap	0-11	6.16	5.35	0.81	0.01	0.06	1.28	2.20	21	17	0.75	0.12	0.15	0.07	1.09	1.8	1	2.89	35	38	45	1.53	6.33	2.60
A2p	11-35	6.15	5.06	1.09	0.09	0.05	0.59	1.02	12	10	1.83	0.89	0.14	0.08	2.91	3.3	1.9	6.21	31	47	40	0.74	11.84	0.75
B1	35-44	5.98	5.17	0.81	0.01	0.03	0.35	0.60	12	15	1.22	0.32	0.53	0.08	2.15	2.6	1.1	4.75	23	45	61	0.65	8.79	3.10
B2	44-70	6.80	5.25	1.55	0.00	0.03	0.31	0.54	10	5	0.89	0.40	1.88	0.07	3.24	1.8	0.7	5.04	14	64	39	0.80	6.43	4.80
C1	70-126	6.40	4.90	1.50	0.00	0.02	0.19	0.32	10	15	0.78	0.66	0.28	0.07	1.79	1.0	0.6	2.79	22	64	46	0.45	7.90	5.30
C2	126-200+	6.15	5.06	1.09	0.03	0.02	0.21	0.36	11	2	1.83	0.48	0.28	0.05	2.64	0.8	0.5	3.44	15	77	60	0.34	8.74	2.40
											TFN 3													
A	0-13	5.74	5.24	0.50	0.00	0.10	1.20	2.07	12	15	1.24	0.93	0.46	0.09	2.72	1.8	1.2	4.52	27	60	49	3.80	11.34	5.10
Ap1	13-23	5.98	5.16	0.82	0.05	0.06	0.72	1.24	12	10	0.8	0.68	0.51	0.07	2.06	1.6	0.9	3.66	26	56	55	2.26	7.20	5.30
Ap2	23-38	5.55	4.98	0.57	0.00	0.05	0.55	0.94	11	3	0.75	0.34	0.94	0.07	2.1	1.7	1	3.8	26	55	92	1.20	9.53	4.10
C1	38-52	6.06	5.28	0.78	0.00	0.03	0.30	0.51	10	9	0.74	0.34	0.50	0.07	1.65	1.4	0.7	3.05	23	54	75	0.92	8.88	3.90
C2	52-69	5.98	5.33	0.65	0.00	0.06	0.68	1.18	11	5	0.95	1.01	0.63	0.08	2.67	2.0	1	4.67	21	57	66	1.29	15.99	2.59
C3	69-83	6.11	5.15	0.96	0.13	0.03	0.32	0.55	11	4	0.78	0.06	0.19	0.07	1.1	4.6	2.2	5.7	39	19	83	1.21	0.87	3.40
C4	83-200+	5.79	5.28	0.51	0.00	0.01	0.08	0.14	8	10	0.74	0.53	0.88	0.07	2.22	1.0	0.8	3.92	20	57	30	0.95	18.52	0.85

The percentage Al saturation in the surface 40cm of Trofani SMUs was 35-39 in TFN1, 23-35 in TFN2 and 26-27 in TFN3 and in the subsurface layers, 18-38, 14-22 and 21-39, respectively. Base saturation in the surface 40cm was 38-53 in TFN1, 38-47 in TFN2 and 55-60 in TFN3 and in the subsurface layers, 15-48, 64-77 and 19-57, respectively.

Iron in the surface 40 cm of the Trofani pedons were 46, 49, and 65 for TFN1, TFN2 and TFN3 and in the subsurface, 77, 48 and 85mg/kg, respectively (Annexures 8 to 10). Mn in the surface 40 cm and subsurface layers were 2.91 and 0.56, 0.97 and 0.53, and 2.42 and 1.09mg/kg for TFN1, TFN2 and TFN3, respectively. Similarly, Zn in the surface 40 cm and subsurface layers were 10.64 and 9.88, 8.99 and 7.69, and 9.36 and 11.07mg/kg, respectively and Cu in the respective layers were 2.60 and 3.86, 2.15 and 4.17, and 4.83 and 2.78mg/kg for TFN1, TFN2 and TFN3.

4.1.3.4 The Soils of Odi

The chemical properties and micronutrient concentration of Odi soils are presented in table 16 and annextures 11 to 13. For the Odi soils, pH ranged from 5.83 (ODI 3) to 6.30 (ODI 1) with an average of 6.01 in the surface 40 cm and in the subsurface horizons, from 6.00 (ODI 1) to 6.03 (ODI 3) with 6.02 as mean (Annexures 11 to 13). Organic C was 0.95% in ODI1, varied from 0.46 to 1.58% (1.02, mean) in ODI2, 0.38 to 5.25% (2.27%, mean) in ODI3 in the surface 40cm and in the subsurface layers, 0.11 to 0.93% (0.34%, mean) in ODI1, 0.11 to 0.20% (0.17%, mean) in ODI2, 0.21 to 0.34% (0.25%, mean) in ODI3. The mean organic matter values in the surface 40 cm of the Odi soils were 1.64% (ODI1), 1.76% (ODI2), and 3.92% (ODI3). Total N in the surface 40cm in ODI1, ODI2 and ODI3 were 0.04 (0.04 mean), 0.04-0.14 (0.04 mean) and 0.03-0.45 (0.18 mean) and in the sub surface layers, 0.01-0.04 (0.02 mean), 0.01-0.02 (0.02 mean) and 0.02-0.03 (0.02 mean), respectively (Annexures 11 to 13). Available P (mg/Kg) in the surface 40 cm were 13 (13, mean) in ODI1, 16-19 (18, mean) in ODI2 and 7-21 (12, mean) in ODI3 and in the subsurface layers, 6-19 (11, mean) in ODI1, 6-13 (9, mean) in ODI2 and 2-12 (7, mean) in ODI3.

Exchangeable bases relative abundance in the surface 40 cm and in the subsurface layers were in the decreasing order of $K^+ > Ca^{++} > Mg^{++} > Na^+$ (surface) and $Ca^{++} > K^+ > Mg^{++} > Na^+$ (subsurface)

Table 4.16: Chemical Properties/Micronutrient Concentration of Odi Soils

Horizon Des	Depth (cm)	pH		ΔpH	EC dS^{-1} M	Percent				Avail P	Exchangable (cmol/kg)				TEB(cmol/kg)	Exchange (cmol/kg)		ECEC	Percent		Micronutrients (mg/kg)			
		H_2O	$CaCl_2$			Total N	Org C	Org Mat	C:N ratio	(mg Kg)	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}		Acid	Al	(cmol/kg)	Al sat	BS	Fe	Mn	Zn	Cu
ODI 1																								
Ap	0-26	6.30	5.24	1.06	0.08	0.04	0.95	1.64	24	13	0.77	0.28	1.51	0.07	2.63	1.8	1	4.43	23	59	14	3.05	18.00	3.65
A	26-60	6.03	5.07	0.96	0.07	0.04	0.93	1.60	23	8	0.63	0.43	0.27	0.05	1.38	2.5	1.3	3.88	34	36	73	1.17	6.21	3.70
B1	60-78	6.40	5.23	1.17	0.26	0.03	0.30	0.51	10	8	0.66	0.48	0.22	0.03	1.39	1.5	0.8	2.89	28	48	89	3.23	10.06	2.70
B2	78-120	5.79	5.36	0.43	0.16	0.02	0.20	0.35	10	15	0.72	0.73	1.44	0.07	2.96	1.6	0.9	4.56	20	65	72	1.65	4.53	3.10
B3	120-135	6.02	5.55	0.47	0.17	0.02	0.11	0.19	6	6	0.72	0.42	0.89	0.06	2.09	1.7	0.8	3.79	21	55	58	1.61	6.66	3.15
C1	135-163	6.39	5.31	1.08	0.26	0.02	0.26	0.45	13	13	0.74	0.23	0.78	0.07	1.82	1.8	0.8	3.62	22	50	68	2.05	12.38	2.85
C2	163-186	5.77	5.34	0.43	0.07	0.01	0.28	0.48	28	9	0.75	0.25	0.11	0.03	1.14	1.6	0.8	2.74	29	42	79	1.39	10.60	4.10
C3	186-200+	5.60	5.22	0.38	0.06	0.02	0.34	0.58	17	19	0.75	1.26	0.45	0.07	2.53	2.0	1.2	4.53	26	56	37	2.98	11.34	2.20
ODI 2																								
Ap	0-20	5.70	5.31	0.39	0.02	0.14	1.58	2.72	11	19.0	0.78	0.22	0.73	0.08	1.81	2.5	1.3	4.31	30	42	70	4.23	4.21	5.20
A	20-40	6.08	4.78	1.30	0.05	0.04	0.46	0.80	12	16.0	0.74	0.25	0.77	0.07	1.83	1.7	0.9	3.53	25	52	99	2.66	3.24	2.70
B1	40-110	6.00	5.31	0.69	0.04	0.02	0.20	0.34	10	8.0	0.44	0.88	0.10	0.06	1.48	0.9	0.4	2.38	17	62	86	2.44	7.38	5.55
B2	110-141	6.01	5.44	0.57	0.04	0.01	0.17	0.29	17	6.0	0.74	0.62	0.53	0.08	1.97	1.9	0.8	3.87	21	51	74	1.80	8.47	3.10
B3	141-180	6.10	5.13	0.97	0.11	0.02	0.20	0.35	10	13.0	0.73	0.48	0.71	0.07	1.99	2.7	1.4	4.69	30	42	59	1.59	9.86	3.30
C	180-200+	6.02	5.47	0.55	0.22	0.01	0.11	0.19	11	9.0	1.13	1.12	1.44	0.08	3.77	2.1	1.4	5.87	24	64	76	2.24	7.62	3.50
ODI 3																								
Ah	0-3	5.67	5.37	0.30	0.33	0.45	5.25	9.05	12	21.0	0.83	0.52	0.19	0.08	1.62	2.8	1.7	4.42	38	37	44	2.80	15.70	6.30
Ap1	3-20	5.89	5.40	0.89	0.11	0.05	1.19	2.05	24	8.0	0.77	0.17	0.23	0.07	1.24	2.4	1.3	3.64	36	34	63	1.99	5.69	4.40
Ap2	20-46	6.30	5.40	0.90	0.07	0.03	0.38	0.65	13	7.0	0.71	0.25	0.19	0.07	1.22	2.0	1	3.22	31	38	79	1.63	7.64	2.50
B1	46-60	6.20	5.23	0.97	0.05	0.03	0.34	0.58	11	12.0	0.85	0.46	0.48	0.08	1.87	1.8	1	3.67	27	51	65	1.62	7.99	3.30
B2	60-94	6.04	5.11	0.93	0.10	0.02	0.21	0.37	11	7.0	0.65	0.02	0.11	0.04	0.82	5.0	3	5.82	51	14	52	1.01	9.00	3.60
B3	94-145	6.00	5.21	0.89	0.03	0.02	0.26	0.44	13	4.0	0.77	0.1	0.58	0.07	1.52	1.8	0.9	3.32	27	46	51	2.42	9.45	9.00
C1	145-158	5.90	5.23	0.67	0.15	0.02	0.21	0.36	11	9.0	0.73	0.87	0.58	0.07	2.25	2.2	0.9	4.45	20	51	35	0.84	9.73	2.80
C2	158-200+	6.01	5.32	0.69	0.16	0.02	0.23	0.39	12	2.0	0.74	0.06	0.73	0.07	1.6	2.0	0.9	3.6	25	44	39	1.51	7.65	3.90

in ODI1: Ca^{++} › K^{+} › Mg^{++} › Na^{+} (surface) and Mg^{++} › Ca^{++} › K^{+} › Na^{+} (subsurface) in ODI2: Ca^{++} › Mg^{++} › K^{+} › Na^{+} (surface) and Ca^{++} › K^{+} › Mg^{++} › Na^{+} (subsurface) in ODI3. Calcium/magnesium ratios in the surface 40 cm and in the subsurface horizons were ODI1 (2.75, surface) and (0.26, subsurface), ODI2 (3.17, surface) and (0.97, subsurface) ODI3 (2.48, surface) and (2.5, subsurface). Mean K concentration (cmol/kg) in the soils were ODI1 (1.51, surface) and (0.59, subsurface), ODI2 (0.73, surface) and (0.70, subsurface), and ODI3 (0.20, surface) and (0.50, subsurface). ECEC values higher than 4cmol/kg were recorded in ODI1 (4.43, cmolkg^{-1}, surface), ODI2 (4.20 cmolkg^{-1}, subsurface) and ODI3 (4.17 cmolkg^{-1}, subsurface). Exchange acidity values were 1.8 (mean 1.8) surface and 1.5-2.5 (mean 1.81) subsurface in ODI1, 1.7-2.5 (mean 2.1) surface and 0.9-2.7 (mean 1.9) subsurface in ODI2 and 2.0-2.8 (mean 2.4) surface and 1.8-5.0 (mean 2.6) subsurface in ODI3. Similarly exchangeable Al (cmol/kg) values in the surface 40cm were 1 (1 mean) in ODI1, 0.9-1.3 (1.1 mean) in ODI2 and 1.0-1.7 (1.3 mean) in ODI3 and in the sub surface horizons, 0.8-1.2 (0.9 mean), 0.4-1.4 (1.0 mean) and 0.9-3.0 (1.3 mean), respectively (Annexures 2 to 19). Al saturation (Fig. 27) in the surface 40 cm of Odi SMUs was 23 in ODI, 23-30 in ODI2 and 31-38 in ODI3 and in the subsurface, 21-34, 17-30 and 20-51, respectively. Base saturation in the surface 40 was 59 in ODI1, 42-52 in OD2 and 21-25 in ODI3 and the subsurface layers, 36-65, 42-64 and 14-51, respectively.

The mean values of Fe in the surface 40 cm were 41, 85 and 62 for ODI1, ODI2 and ODI3 and in the subsurface layers, 68, 74 and 48mg/kg, respectively. The mean concentration of Mn in the surface 40 cm and subsurface layers were 3.05 and 2.01, 3.45 and 2.02, and 2.14 and 1.48mg/kg for ODI1, ODI2, and ODI3, respectively. The concentration of Zn in the surface 40 cm and subsurface layers were 18.00 and 8.83, 3.73 and 8.33, 9.68 and 8.76mg/kg for ODI1, ODI2 and ODI3, respectively while Cu in the surface 40 cm and subsurface layers were 3.65 and 3.11, 3.95 and 3.86, and 4.40 and 3.32 for ODI1, ODI2, and ODI3, respectively.

4.1.3.5 The Soils of Koroama

In Table 4.17 is presented the chemical properties and micronutrient concentration of Koroama soils while the summaries are in annextures 14 to 16. In the surface 40 cm, pH varied from 5.64 (KRM1) to 6.01 (KRM2) with 5.84 as average and in the subsurface layers, 5.99 (KRM1) to 6.30 (KRM2) with 6.13 as mean (Annexures 14 to 16). Organic C ranged from 1.76 to 1.84% (1.80%, mean) in KRM1, 0.43 to 1.30% (0.76%, mean) in KRM2, 0.31 to 1.29% (0.80%, mean) in KRM3 and 0.37 to 1.03% (0.75%, mean) in KRM1, 0.23 to 0.45% (0.36%, mean) in KRM2, 0.14 to 0.45% (0.29%, mean) in KRM3 for the top 40 cm and subsurface layers, respectively. The mean organic matter values in the surface 40 cm was 3.15% (KRM1), 1.32% (KRM2) and 1.38% (KRM3). Total N values in the surface 40 cm varied from 0.10-0.11 (0.11 mean) in KRM1, 0.03-0.06 (0.04 mean) in KRM2 and 0.02-0.06 (0.04 mean) in KRM3 and in the subsurface layers, 0.02-0.05 (0.04 mean), 0.02-0.03 (0.03 mean) and 0.01-0.02 (0.02 mean), respectively. Available P (mg/Kg) in the surface 40 cm varied from 20-21 (21, mean) for KRM1, 16-22 (19, mean) for KRM2, and 18-20 (19, mean) for KRM3 and in the subsurface layers, 5-14 (9, mean) for KRM1, 4-15 (9, mean) for KRM2, 6-14 (10, mean) for KRM3.

The relative abundance of exchangeable bases in the surface 40 cm and in the subsurface layers were in the decreasing order of $Ca^{++} > Mg^{++} > K^{+} > Na^{+}$ (surface) and $K^{+} > Ca^{++} > Mg^{++} > Na^{+}$ (subsurface) in KRM1; $Ca^{++} > Mg^{++} > K^{+} > Na^{+}$ (surface) and $Ca^{++} > Mg^{++} > K^{+} > Na^{+}$ (subsurface) in KRM2; $Ca^{++} > Mg^{++} > K^{+} > Na^{+}$ (surface) and $Ca^{++} > Mg^{++} > K^{+} > Na^{+}$ (subsurface) in KRM3. Calcium/magnesium ratios of surface 40 cm and subsurface horizons were 11.6 (surface) and 1.25 (subsurface) for KRM1, 2.15 (surface) and 1.15 (subsurface) for KRM2 and 2.61 (surface) and 1.68 (subsurface) for KRM3. The mean K concentration (cmol/kg) was 0.53 (surface) and 0.66 (subsurface) for KRM1, 0.24 (surface) and 0.21 (subsurface) for KRM2 and 0.18 (surface) and 0.35 (subsurface) for KRM3.

Table 4.17: Chemical Properties/Micronutrient Concentration of Koroama Soils

Horizon Des.	Depth (cm)	pH		ΔpH	EC dS/M	Percent				Avail P (mg/Kg)	Exchangable (cmol/kg)				TEB (cmol/kg)	Exchange (cmol/kg)		ECEC (cmol/kg)	Percent		Micronutrients (mg/kg)			
		H_2O	$CaCL_2$			Total N	Org. C	Org. Mat.	C/N ratio		Ca^{2+}	Mg^{2+}	K^+	Na^+		Acid	Al		Al sat	BS	Fe	Mn	Zn	Cu
											KRM 1													
A1	0-7	5.79	5.02	0.77	0.09	0.11	1.84	3.18	17	20	1.35	0.15	0.33	0.12	1.95	1.5	0.7	3.45	20	57	53	2.00	7.21	2.40
A2	7-43	5.48	5.30	0.18	0.30	0.10	1.76	3.03	18	21	0.75	0.02	0.73	0.07	1.57	1.3	0.7	2.87	24	55	42	3.20	7.65	2.30
B1	43-86	6.12	5.41	0.71	0.02	0.05	1.03	1.78	21	14	0.71	0.63	0.16	0.03	1.53	4.9	2.4	6.43	37	24	32	1.64	3.47	3.00
B2	86-115	5.84	5.51	0.33	0.23	0.04	0.84	1.45	21	8	0.85	0.51	0.53	0.04	1.93	1.0	0.6	2.93	20	66	59	1.89	6.51	3.10
BC	115-130	5.77	5.05	0.72	0.10	0.04	0.74	1.27	19	10	0.3	0.37	1.51	0.08	2.26	3.4	1.8	5.66	32	40	33	0.20	7.85	2.50
C	130-200+	6.18	5.45	0.73	0.00	0.02	0.37	0.64	19	5	0.75	1.02	0.45	0.07	2.29	2.0	1.1	4.29	26	53	37	2.89	3.50	0.80
											KRM 2													
Ap	0-15	5.55	4.66	0.89	0.09	0.06	1.30	2.24	22	22	0.9	0.07	0.09	0.08	1.14	1.7	0.8	2.84	28	40	31	1.92	10.76	1.70
Ap2	15-23	6.39	5.00	1.39	0.09	0.03	0.56	0.97	19	20	0.93	0.82	0.23	0.06	2.04	3.0	1.4	5.04	28	40	63	1.80	7.31	4.70
B1	23-40	6.10	4.27	1.83	0.02	0.03	0.43	0.74	14	16	0.81	0.35	0.41	0.04	1.4	5.4	3.8	6.8	59	21	95	2.01	8.41	3.70
B2	40-64	6.38	5.43	0.95	0.21	0.03	0.44	0.75	15	10	0.6	0.35	0.12	0.04	1.11	1.6	0.8	2.71	30	41	94	1.72	7.42	3.00
B3	64-78	6.49	5.04	1.45	0.09	0.03	0.45	0.78	15	15	0.66	0.51	0.25	0.04	1.46	1.6	0.9	3.06	29	48	73	1.86	6.75	3.20
C1	78-140	6.19	5.45	0.74	0.21	0.02	0.23	0.40	12	7	0.86	1.04	0.27	0.11	2.28	0.7	0.3	2.98	10	77	62	1.61	9.80	6.95
C2	140-194+	6.15	5.52	0.63	0.09	0.02	0.33	0.57	17	4	1.53	1.24	0.19	0.07	3.03	2.1	0.9	5.13	18	59	73	1.40	12.05	2.95
											KRM 3													
Ap	0-12	5.67	5.51	0.16	0.32	0.06	1.29	2.22	22	18.0	0.86	0.53	0.24	0.05	1.68	1.7	0.7	3.38	21	50	65	1.33	6.54	2.60
Ap2	12-39	6.09	5.52	0.57	0.08	0.02	0.31	0.54	16	20.0	0.75	0.09	0.12	0.07	1.03	1.8	0.7	2.83	25	36	42	1.20	8.55	4.30
B1	39-59	6.24	4.15	2.09	0.00	0.02	0.45	0.77	23	14.0	0.7	0.53	0.44	0.04	1.71	2.6	1	4.31	23	40	42	1.21	12.05	2.80
B2	59-96	5.72	5.40	0.32	0.00	0.02	0.35	0.61	18	10.0	0.73	0.55	0.52	0.06	1.86	2.1	1	3.96	25	47	63	1.30	11.51	7.05
B3	96-135	6.12	5.40	0.72	0.07	0.01	0.14	0.20	14	8.0	2.05	1.12	0.27	0.08	3.52	1	0.5	4.52	11	78	66	1.00	6.21	4.20
C	135-190+	6.35	5.32	1.03	0.03	0.01	0.21	0.37	21	6.0	1.61	0.85	0.18	0.08	2.72	1.3	0.6	4.02	15	68	64	0.97	4.45	2.80

As was the case in other soils from the study area. ECEC values higher than 4cmol/kg were recorded in KRM1 (4.83 cmolkg^{-1}. subsurface). KRM2 (4.89 cmolkg^{-1}. surface) and KRM3 (4.20 cmolkg^{-1}. surface). Exchange acidity values were 1.3-1.5 (mean 1.4) surface and 1.0-4.9 (mean 2.83) subsurface in KRM1. 1.7-5.4 (mean 3.37) surface and 0.7-2.1 (mean 1.5) subsurface in KRM2 and 1.7-1.8 (mean 1.8) surface and 1.0-2.1 (mean 1.8) subsurface in KRM3. Exchangeable Al (cmol/kg) in the surface 40 cm were 0.7 (0.7 mean) for KRM1. 0.8-3.8 (2.0 mean) for KRM2 and 0.7 (0.7 mean) for KRM3 and in the subsurface layers. 0.6-2.4 (1.5 mean). 0.3-0.9 (0.7 mean) and 0.5-1.0 (0.8 mean) for the respective soils.

The Al saturation in the surface 40cm of Koroama SMUs was 20-24 in KRM1. 28-59 in KRM2 and 21-25 in KRM2 and in the subsurface layers. 20-37. 10-30 and 11-25. respectively. Base saturation (F.g. 28) in the surface 40cm was 55-57 in KRM1. 21-40 in KRM2 and 36-50 in KRM3 and in the subsuraface. 24-66. 41-77 and 40-78. respectively.

The mean values of Fe in the surface 40 cm were 48. 63 and 54mg/kg for KRM1. KRM2 and KRM3 and in the subsurface layers. 40. 76 and 59mg/kg. respectively. The mean Mn concentration in the surface 40 cm and in the subsurface layers was 2.60 and 2.16. 1.91 and 1.65. and 1.27 and 1.12mg/kg for KRM1. KRM2 and KRM3. respectively. Similarly. the mean concentration of Zn in the surface 40 cm and in the subsurface layers was 7.43 and 5.33. 8.83 and 9.01. 7.55 and 8.56mg/kg for KRM1. KRM2 and KRM3. respectively. The concentration of Cu in the surface 40 cm and in the subsurface layers was 2.35 and 2.35 2.15 and 4.03. and 3.45 and 4.21 for KRM1. KRM2. and KRM3. respectively.

4.1.3.6 The Soils of Niger Delta University Farm

The pH (H_2O) of the surface 40 cm of the Niger Delta University Teaching and Research farm soils varied from 5.64 (NDU1) to 5 87 (NDU2) with an average of 5.73 and in the subsurface layers. 6.08 (NDU1) to 6.13 (NDU1) with 6.10 as mean (Table 4.18 and Annexures 17 to 19). Organic C in the surface 40 cm and in the subsurface layers were 1.48 to 1.51% (1.50%. mean) in NDU1. 0.93 to 2.06% (1.41%. mean) in NDU2 and 1.23 to 2.81% (2.22%. mean) in NDU3 and 0.29 to 0.5% (0.38%. mean) in NDU1. 0.23 to 0.59% (0.46%. mean) in NDU2 and 0.59 to 0.92% (0.75%. mean) in NDU3. respectively. Organic matter in the surface 40 cm was 2.58% in NDU1. 2.44% in NDU2 and 3.82% in NDU3.

Table 4.18: Chemical properties/Micronutrient Concentration of Niger Delta University Farm Soils

Horizon Des.	Depth (cm)	pH		ΔpH	EC dS/M	Percent				Avail P (mg/Kg)	Exchangable (cmol/kg)				TEB (cmol/kg)	Exchange (cmol/kg)		ECEC (cmol/kg)	Percent		Micronutrients (mg/kg)			
		H_2O	$CaCl_2$			Total N	Org. C	Org. Mat	C/N ratio		Ca^{2+}	Mg^{2+}	K^+	Na^+		Acid	Al		Al sat	BS	Fe	Mn	Zn	Cu
NDU 1																								
Ap	0-19	5.58	5.45	0.13	0.08	0.06	1.51	2.60	25	4.6	0.75	0.99	0.35	0.05	2.14	2.3	1	4.44	23	48	61	1.56	7.68	2.60
B1	19-39	5.69	4.53	1.16	0.29	0.06	1.48	2.56	25	11.4	1.25	1.63	0.16	0.09	3.13	4	2.3	7.14	32	44	64	1.49	1.97	3.80
B2	39-71	6.07	4.28	1.79	0.16	0.03	0.5	0.87	17	0.6	0.9	1.35	0.16	0.07	2.48	3.3	1.8	5.78	31	43	63	2.00	4.42	3.20
B3	71-81	5.92	5.49	0.43	0.09	0.03	0.42	0.73	14	1.0	0.91	0.45	0.43	0.04	1.83	2	1	3.83	26	48	73	2.1	3.85	4.30
C1	81-138	6.20	5.05	1.15	0.10	0.02	0.29	0.50	15	1.3	1.1	1.19	0.38	0.09	2.76	1.6	0.8	4.36	18	63	78	1.89	4.32	3.60
C2	138-195+	6.32	4.33	1.99	0.21	0.02	0.31	0.54	16	1.3	0.7	0.10	0.09	0.04	0.93	1.1	0.6	2.03	30	46	57	1.41	8.85	3.90
NDU 2																								
Ap	0-12	5.64	5.45	0.19	0.07	0.1	2.06	3.56	21	1.4	0.57	0.44	0.4	0.04	1.45	2.9	1.9	4.35	44	33	48	1.10	6.53	2.50
Ap2	12-26	5.92	5.49	0.43	0.11	0.06	1.25	2.15	21	1.9	0.77	0.55	0.43	0.06	1.81	3.4	2	5.21	38	35	64	1.71	12.08	1.60
B1	26-36	6.06	5.40	0.66	0.02	0.05	0.93	1.61	19	1.4	1.25	0.12	0.24	0.09	1.7	1.8	0.7	3.5	20	49	67	1.90	14.42	4.20
B2	36-53	6.01	4.92	1.09	0.07	0.03	0.59	1.01	20	1.7	0.58	0.90	0.15	0.07	1.7	4.5	2.4	6.2	39	27	60	2.51	3.00	3.70
B3	53-116	6.07	5.50	0.57	0.01	0.03	0.55	0.95	18	3.2	0.67	0.51	0.32	0.04	1.54	3.8	2.1	5.34	39	29	77	1.30	7.79	2.90
C	116-190+	6.15	4.22	1.93	0.00	0.01	0.23	0.40	23	1.4	0.75	0.60	0.16	0.07	1.58	0.9	0.4	2.48	16	64	83	1.30	8.02	3.40
NDU 3																								
A1	0-5	5.42	5.20	0.22	0.09	0.22	2.81	4.84	13	3.3	0.69	0.10	0.15	0.03	0.97	2.3	1	3.27	31	30	44	1.51	7.50	2.60
A2	5-13	5.72	5.44	0.28	0.43	0.13	2.61	4.50	20	2.1	0.5	0.39	0.28	0.03	1.2	1.7	0.9	2.9	28	41	34	1.39	13.91	5.70
AB	13-20	5.90	5.53	0.37	0.10	0.06	1.23	2.12	22	0.9	0.69	0.39	0.44	0.05	1.57	1.5	0.8	3.07	26	51	99	1.20	6.51	4.00
B1	20-75	6.03	5.45	0.58	0.13	0.04	0.92	1.58	23	4.3	0.88	0.13	0.44	0.08	1.53	1.7	0.8	3.23	25	47	81	2.70	9.74	3.70
B2	75-140	6.10	5.25	0.75	0.12	0.04	0.74	1.28	19	3.3	0.75	0.21	0.54	0.05	1.55	1.7	0.7	3.25	22	48	85	2.51	9.14	3.80
C	140-190+	6.14	5.55	0.59	0.11	0.03	0.59	1.02	20	3.5	0.92	0.32	0.60	0.06	1.9	1.8	0.8	3.7	22	51	88	2.80	9.00	3.60

Total N in the surface 40cm was 0.06 (0.06 mean) in NDU1, 0.05-0.10 (0.07 mean) in NDU2 and 0.06-0.22 (0.14 mean) in NDU3 and in the subsurface layers, 0.02-0.03 (0.03 mean), 0.01-0.03 (0.02 mean) and 0.03-0.04 (0.04 mean) for NDU1, NDU2 and NDU3, respectively. Available P (mg/Kg) in the surface 40 cm varied from 5-11 (8, mean) for NDU1, 1-2 (2, mean) for NDU2 and 0.9-3 (2, mean) for NDU3 and in the subsurface layers 0.6-1 (1, mean) for NDU1, 1-3 (2, mean) for NDU2 and 3-4 (4, mean) for NDU3. Relative abundance of exchangeable bases in the surface 40 cm and in the subsurface layers were in the decreasing order of Mg^{++} › Ca^{++} › K^{+} › Na^{+} (surface) and Ca^{++} › Mg^{++} › K^{+} › Na^{+} (subsurface) in NDU1, Ca^{++} › Mg^{++} › K^{+} › Na^{+} (surface) and Ca^{++} › Mg^{++} › K^{+} › Na^{+} (subsurface) in NDU2 and Ca^{++} › Mg^{++} = K^{+} › Na^{+} (surface) and Ca^{++} › K^{+} › Mg^{++} › Na^{+} in NDU3. Calcium/magnesium ratios of surface 40 cm and in the subsurface horizons were 0.76 (surface) and 1.17 (subsurface) in NDU1, 1.7 (surface) and 1.05 (subsurface) in NDU2 and 2.17 (surface) and 3.86 (subsurface) in NDU3. Mean potassium concentration (cmol/kg) in the soils were NDU1 0.26 (surface) and 0.27 (subsurface), NDU2 0.36 (surface) and 0.21 (subsurface) and NDU3 0.29 (surface) and 0.53 (subsurface). ECEC values higher than 4cmol/kg was recorded in NDU1 (5.79 cmolkg^{-1}, surface) and (4.00 cmolkg^{-1}, (subsurface), and in NDU2 (4.35 cmolkg^{-1}, surface) and (4.67 cmolkg^{-1}, subsurface). Exchange acidity was 2.3-4.0 (mean 3.2) surface and 1.1-3.3 (mean 2.0) subsurface in NDU1, 1.8-3.4 (mean 2.7) surface and 0.9-4.5 (mean 3.07) subsurface in NDU2, and 1.5-2.3 (mean 1.8) surface and 1.7-1.8 (mean 1.7) subsurface in NDU3. Exchangeable Al (cmol/kg) in the surface 40 cm was 1.0-2.3 (1.8 mean), 0.7-2.0 (1.5 mean) and 0.8-1.0 (0.9 mean) in NDU1, NDU2 and NDU3 and in the subsurface layers 0.6-1.8 (1.1 mean), 0.4-2.4 (1.6 mean) and 0.7-0.8 (0.8 mean) in the respective soils. The Al saturation in the surface 40cm of NDU SMUs was 23-32 in NDU1, 20-44 in NDU2 and 26-31 in NDU3 and in the subsurface layers, 18-31, 16-39 and 22-25, respectively. Base saturation in the surface 40cm was 44-48 in NDU1, 33-49 in NDU2 and 30-51 in NDU3 and in the subsurface layers, 43-63, 27-64 and 47-51, respectively.

The mean Fe in the surface 40 cm was 63, 60 and 59 mg/kg for NDU1, NDU2, and NDU3, and in the subsurface layers, mean 68, 73, and 85 mg/kg, respectively. The mean concentration of Mn in the surface 40 cm and in the subsurface layers was 1.53 and 1.86, 1.57 and 1.70, and 1.37 and 2.67 mg/kg for NDU1, NDU2, and NDU3, respectively. Similarly, mean Zn concentration in the surface 40 cm and in the subsurface layers was 4.83 and 5.36, 11.01 and 6.27, and 9.31 and 9.29 in NDU1, NDU2 and NDU3, respectively. The concentration of Cu in the surface 40 cm and in the subsurface layers was 3.15 and 3.75, 2.77 and 3.33, and 4.10 and 3.70 mg/kg for NDU1, NDU2 and NDU3, respectively.

4.1.4 Classification of the Soils

The soils generally belonged to the Entisols and Inceptisols soil orders of the USDA Soil Taxonomy and Fluvisol and Cambisol of the the World Reference Base (WRB) system (FAO/ISRIC, 2006). The ELM3 and TFN3 pedons belonged to the Entisols order of the USDA Soil Taxonomy while the remaining 16 pedons were of the Inceptisols order. In the RSG-WRB system, ELM3 and TFN3 belonged to the Fluvosol order while all the remaining 16 pedons were of the Cambisol order. Classification of soils using the two systems is summarized in Table 4.19.

Table 4.19: Classification of the Soils using Soil Taxonomy and Reference Soil Group of the World Reference Base

	Classification				
	Pedon	Drainage[1]	Soil Taxonomy		RSG-WRB
S/No			Sub group	Family[2]	
1	ELM1	MWD	Aquic Dystrudepts	fine loamy, mixed	Fluvic Cambisol (Eutric, siltic)
2	ELM2	IPD	Typic Epiaquepts	fine, loamy	Fluvic Cambisol (Eutric, siltic)
3	ELM3	WD	Eutric Udifluvents	loamy sand over sandy loam mixed	Haplic-Fluvic Fluvisol (Eutric, siltic)
4	ODN1	MWD	Humic Dystrudepts	fine, silt loam	Fluvic Cambisol (Eutric-siltic)
5	ODN2	IPD	Typic Epiaquepts	silt loam over loam	Fluvic Cambisol (Dystric-siltic)
6	ODN3	PD	Fluvaquentic Epiaquepts	silt loam over silty clayloam	Fluvic Cambisol (Dystric-siltic)
7	TFN1	WD	Aquic Dystrudepts	silt loam over silty clayloam	Fluvic Cambisol (Dystric-siltic)
8	TFN2	IPD	Typic Epiaquepts	silt loam over silty clayloam	Fluvic Cambisol (Eutric-siltic)
9	TFN3	WD	Aquic Udifluvents	fine, silt loam over loam, sand, Mixed	Haplic Fluvisol (Arenic-greyic)
10	ODI1	MWD	Humic Dystrudepts	fine, silt loam over loam	Fluvic Cambisol (Dystric-greyic)
11	ODI2	IPD	Aquic Dystrudepts	silt loam over loam	Fluvic Cambisol (Dystric-siltic)
12	ODI3	PD	Aeric Epiaquepts	fine, silt loam	Fluvic Cambisol (Dystric-siltic)
13	KRM1	MWD	Udic Dystropepts	fine, loam	Humic-fluvic Cambisol (Dystric-siltic)

Table 4.19: Cont.

			Classification		
	Pedon	Drainage[1]	Soil Taxonomy		RSG-WRB
S/No			Sub group	Family[2]	
14	KRM2	IPD	Aquic Dystrudepts	fine, silt loam over silty clayloam	Fluvic Cambisol (Dystric-greyic-siltic)
15	KRM3	PD	Typic Epiaquepts	fine, silt loam over silty clayloam	Fluvic Cambisol (Dystric-greyic-siltic)
16	NDU1	MWD	Udic Dystropepts	fine, silt loam over silty clayloam	Fluvic Cambisol (Dystric-greyic-siltic)
17	NDU2	IPD	Aquic Dystrudepts	fine, silt loam over silty clayloam	Fluvic Cambisol (Dystric-siltic)
18	NDU3	PD	Fluvaquentic Endoaquepts	fine, silt loam	Fluvic Cambisol (Dystric-greyic-siltic)

1 MWD= moderately well drained; WD well drained; IPP=imperfectly drain; PD poorly drained
2 All belong to the iso-hyperthermic temperature regime

4.1.5 Distribution of Clay Minerals in the Soil Mapping Units

Table 4.20 shows the variation in the composition of clay mineral assemblage found in the pedons at the eighteen locations. Quartz (SiO_2) and kaolinite ($Al_2Si_2O_5(OH)_4$ jointly constitute about 48 to 69% of the clay minerals assemblage in the soils, the highest value recorded in TFN2 and the lowest in KRM2.

Table 4.20: Percentage Distribution of Clay Mineral Types in the Soil Mapping Units

	Percentage Mineral in the soil									
SMU	Quartz	kaolinite	vermiculite	biotite	Muscovite	microline	albite	anorthite	chlorite	zeolite
ELM1	46.1	15.1	Nd	Nd	11.2	13.6	14	Nd	nd	nd
ELM2	41.2	20	Nd	Nd	11.3	18.3	9.2	Nd	nd	nd
ELM3	51.1	9.9	0.4	Nd	9.1	Nd	12.4	17.1	nd	nd
ODN1	57.6	8.3	0.1	Nd	5.8	13.5	6.7	8	nd	nd
ODN2	60.9	4	0.1	Nd	5.8	11.9	6.4	10.9	nd	nd
ODN3	48	15.4	Nd	Nd	8.6	14.4	7.2	6.4	nd	nd
TFN1	41.4	19.2	0.6	1.8	9.5	14.7	12.8	Nd	nd	nd
TFN2	46.2	22.6	0.4	1.1	8.7	12.9	8.2	Nd	nd	nd
TFN3	51.8	8	0.2	2.5	6	20.3	11.1	Nd	nd	nd
ODI1	65.3	2.5	0.2	Nd	3.1	19.8	9.1	Nd	nd	nd
ODI2	58.6	1.3	0.3	Nd	8	19	12.8	Nd	nd	nd
ODI3	54.5	2.5	0.2	Nd	16.4	17.9	8.5	Nd	nd	Nd
KRM1	60.2	2.5	0.2	1.5	3.3	18.8	13.5	Nd	nd	Nd
KRM2	46.4	1.3	0.3	Nd	14.4	11.4	24	Nd	2.2	Nd
KRM3	41.8	25.8	0.2	Nd	8.5	13.3	9.5	Nd	nd	0.8
NDU1	46.1	18.5	0.3	Nd	7.4	12.5	14.9	Nd	nd	0.2
NDU2	48.8	2.8	0.7	Nd	13.8	21.5	12.4	Nd	nd	Nd
NDU3	53.7	1	0.5	Nd	10.2	18.4	16.1	Nd	nd	nd

Nd not detected

Ten different mineral phases were identified in the eighteen locations. Kaolinite, quartz, muscovite ($KAl_2(AlSi_3O_{10})(OH,F)_2$ and albite ($NaAlSi_3O_8$) were identified in all the eighteen locations. Quartz was the dominant mineral in all the locations and silt-sized soil fraction dominated the textural classification of the soils. From Table 4.20 and the X-ray diffractograms in Figures 4.7 to 4.24, quartz and kaolinite were easily detectable and dominated the clay fraction.

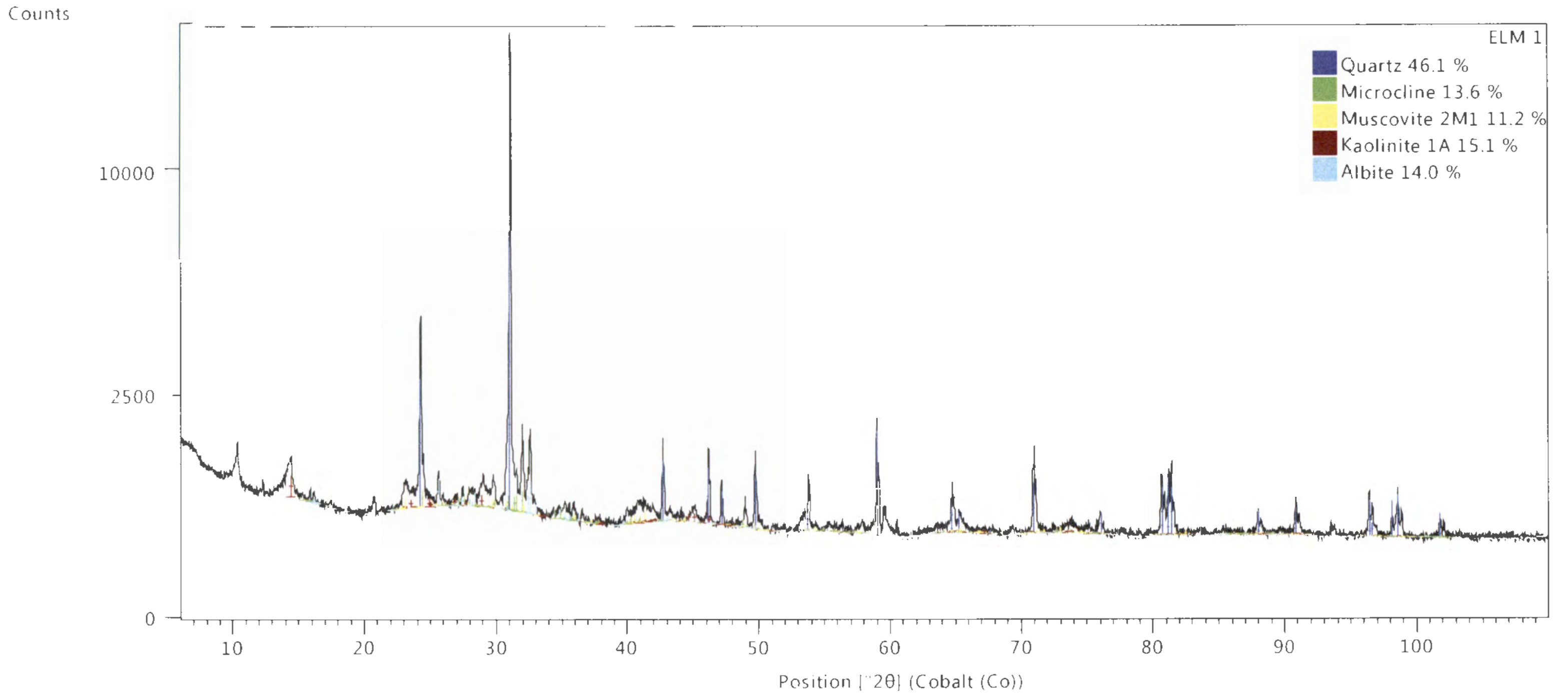


Figure 4.7: X-ray diffractogram for the clay fraction of ELM1

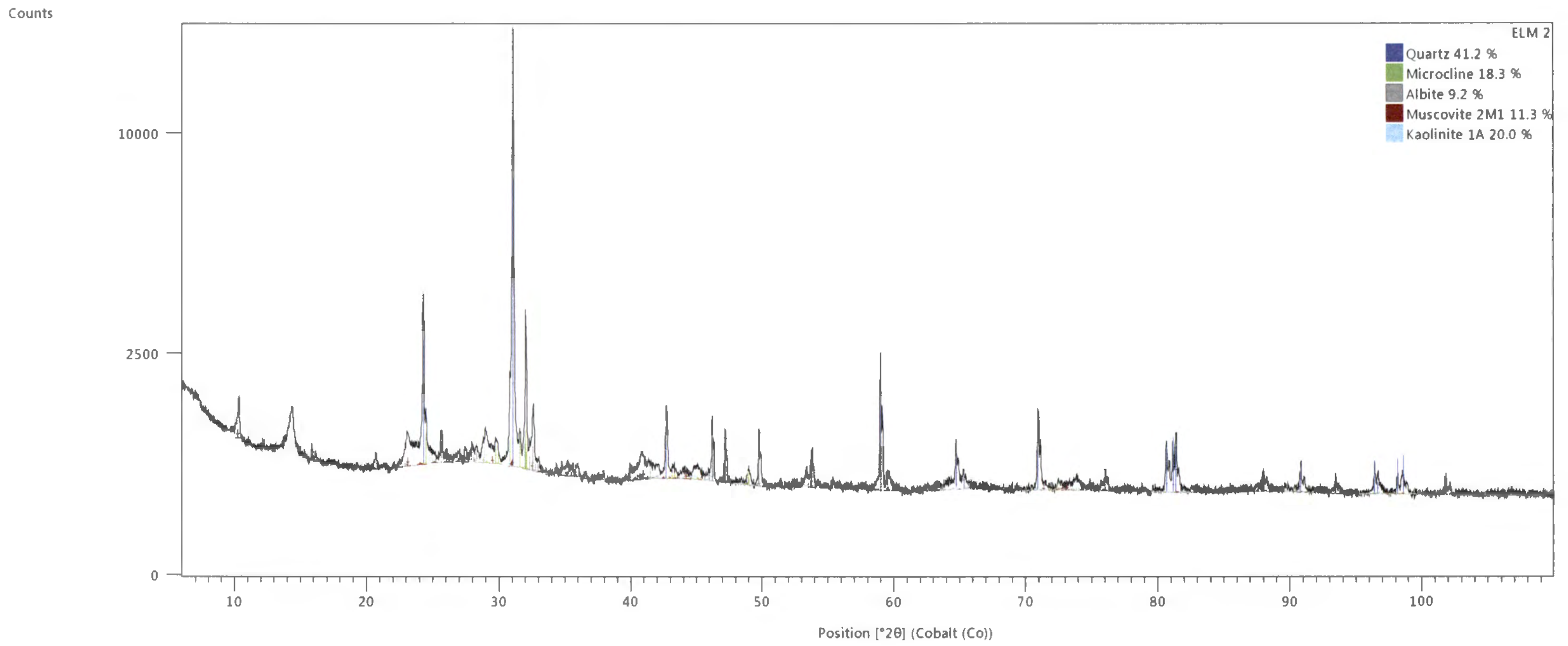
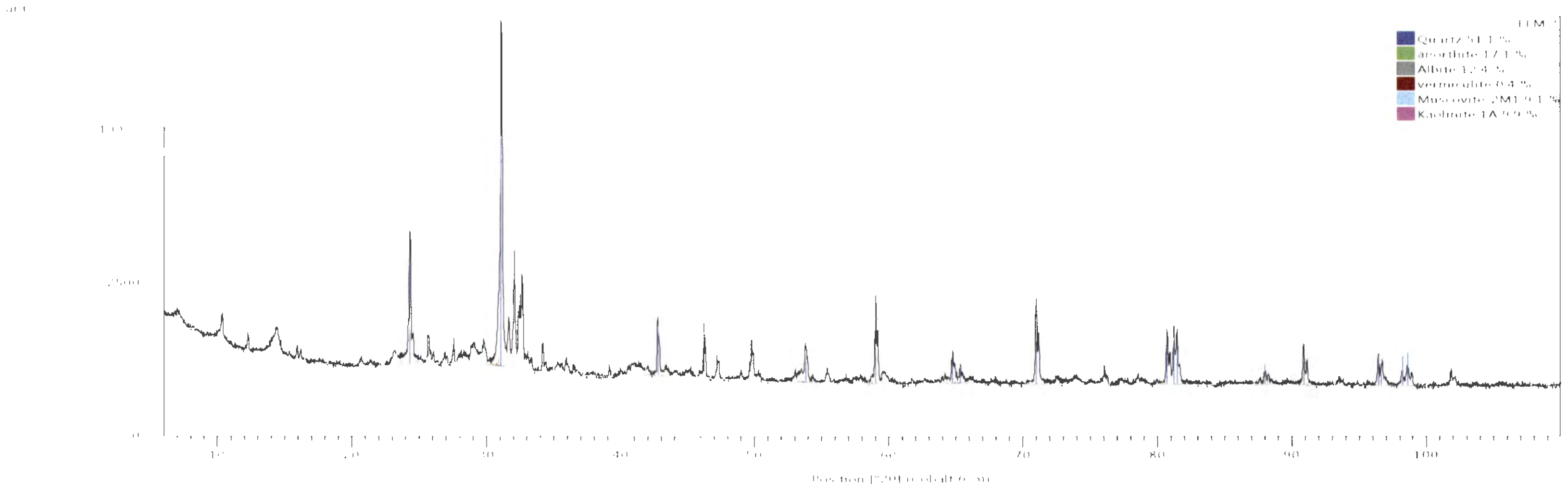


Figure 4.8: X-ray diffractogram for the clay fraction of ELM2



9Figure 4.31: X-ray diffractogram for the clay fraction of EML3

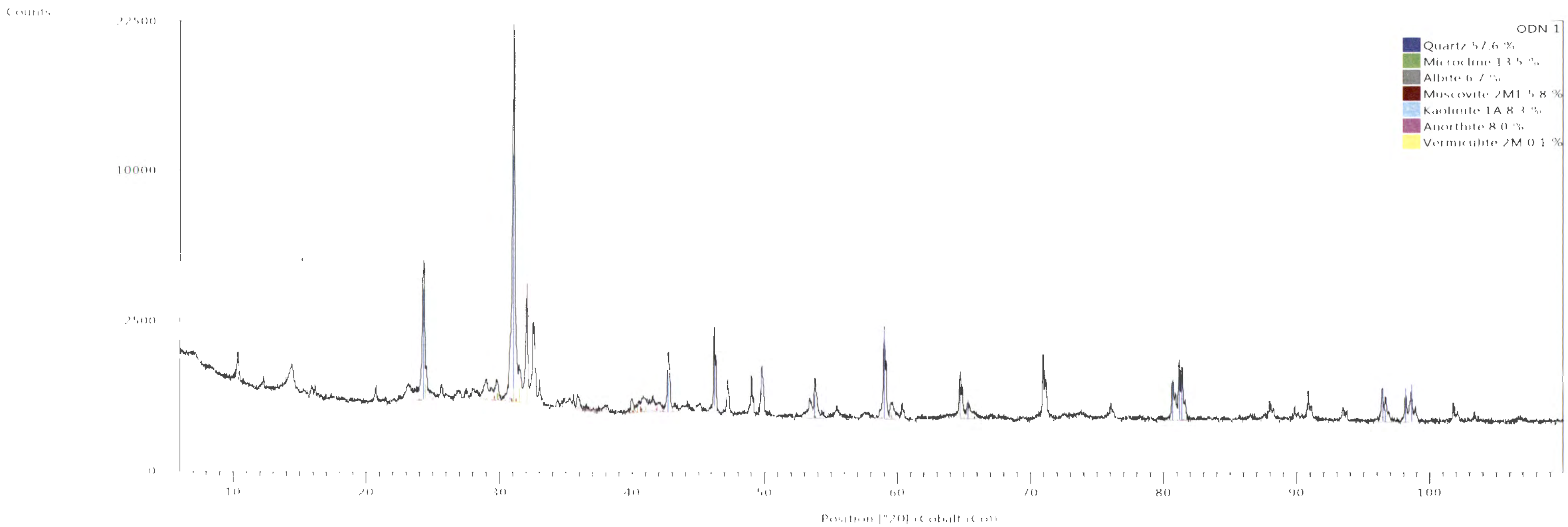


Figure 4.10: X-ray diffractogram for the clay fraction of ODN1

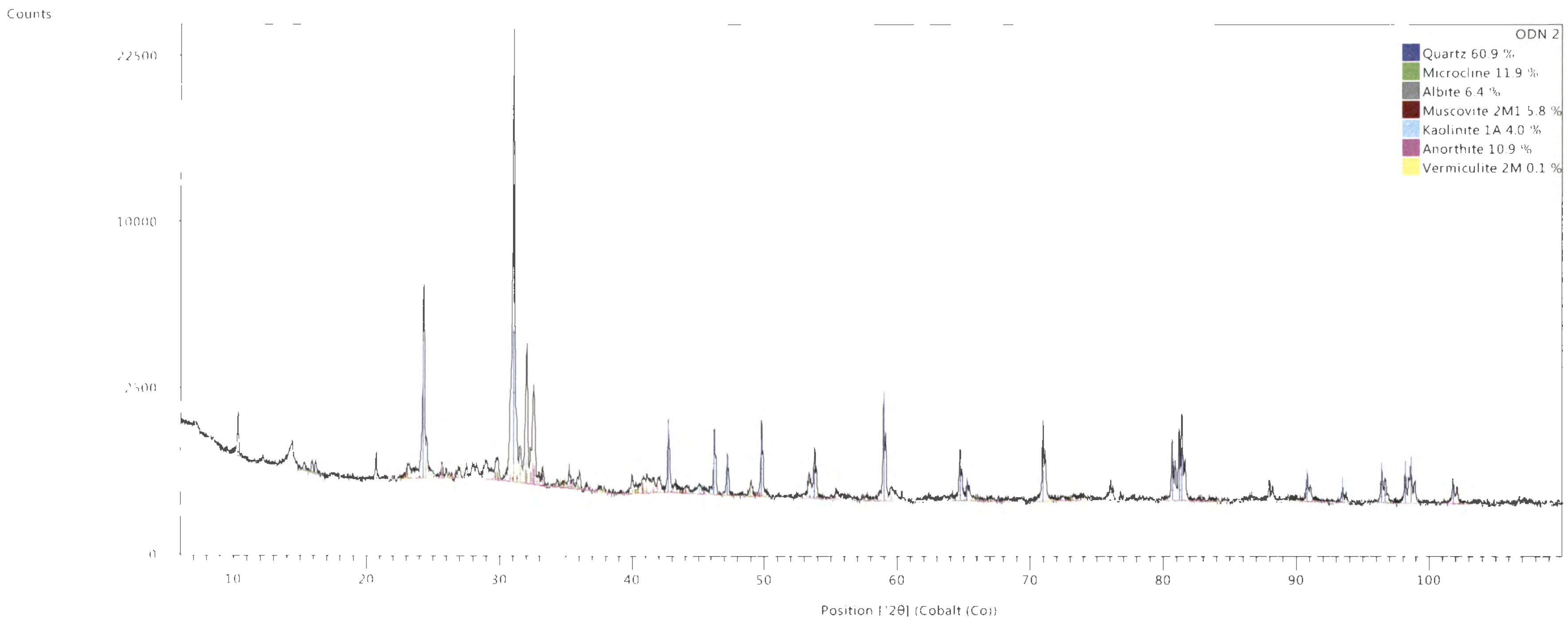


Figure 4.11: X-ray diffractogram for the clay fraction of ODN2

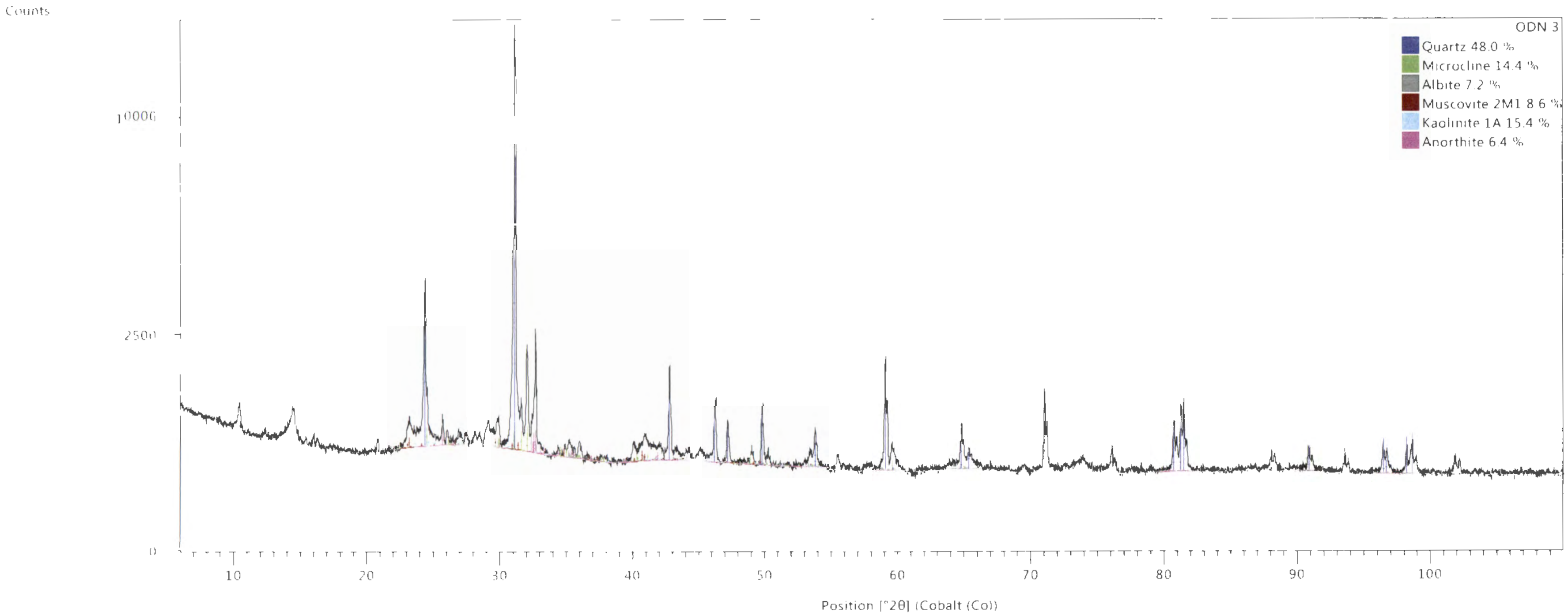


Figure 4.12: X-ray diffractogram for the clay fraction of OND3

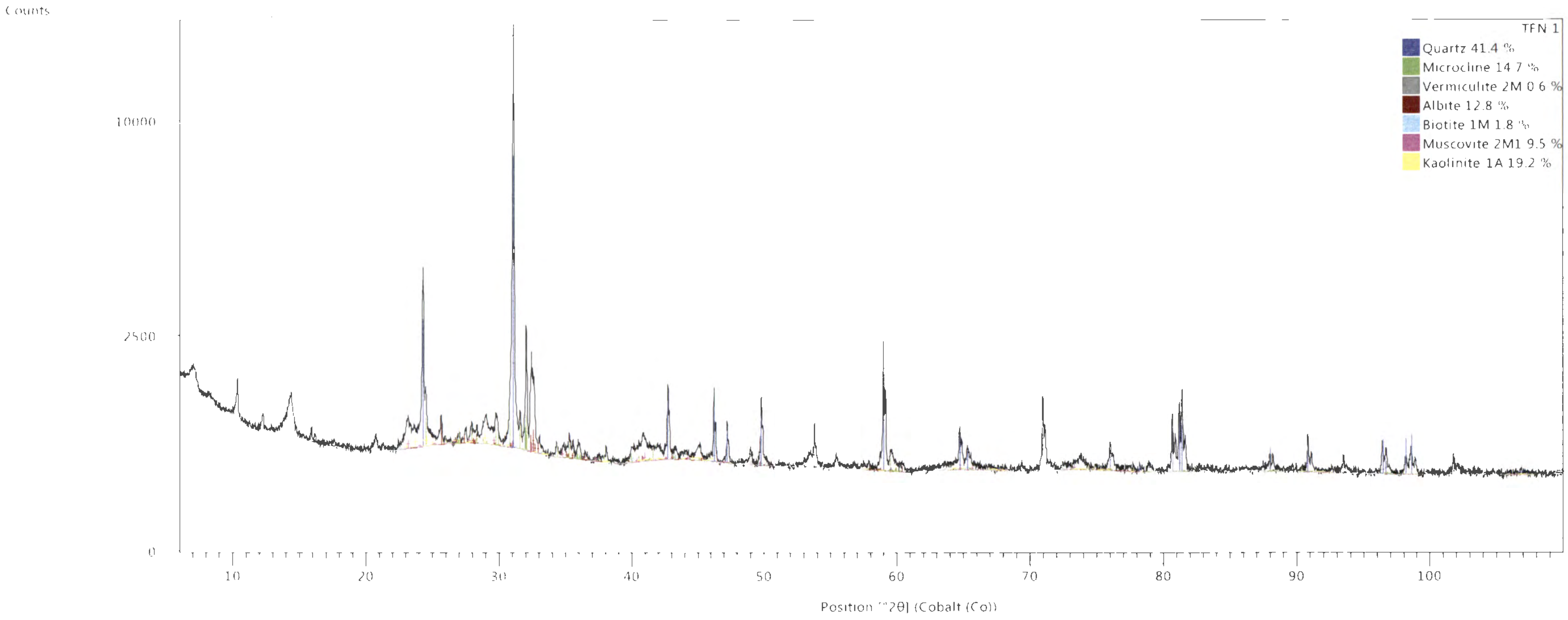


Figure 4.13: X-ray diffractogram for the clay fraction of TFN1

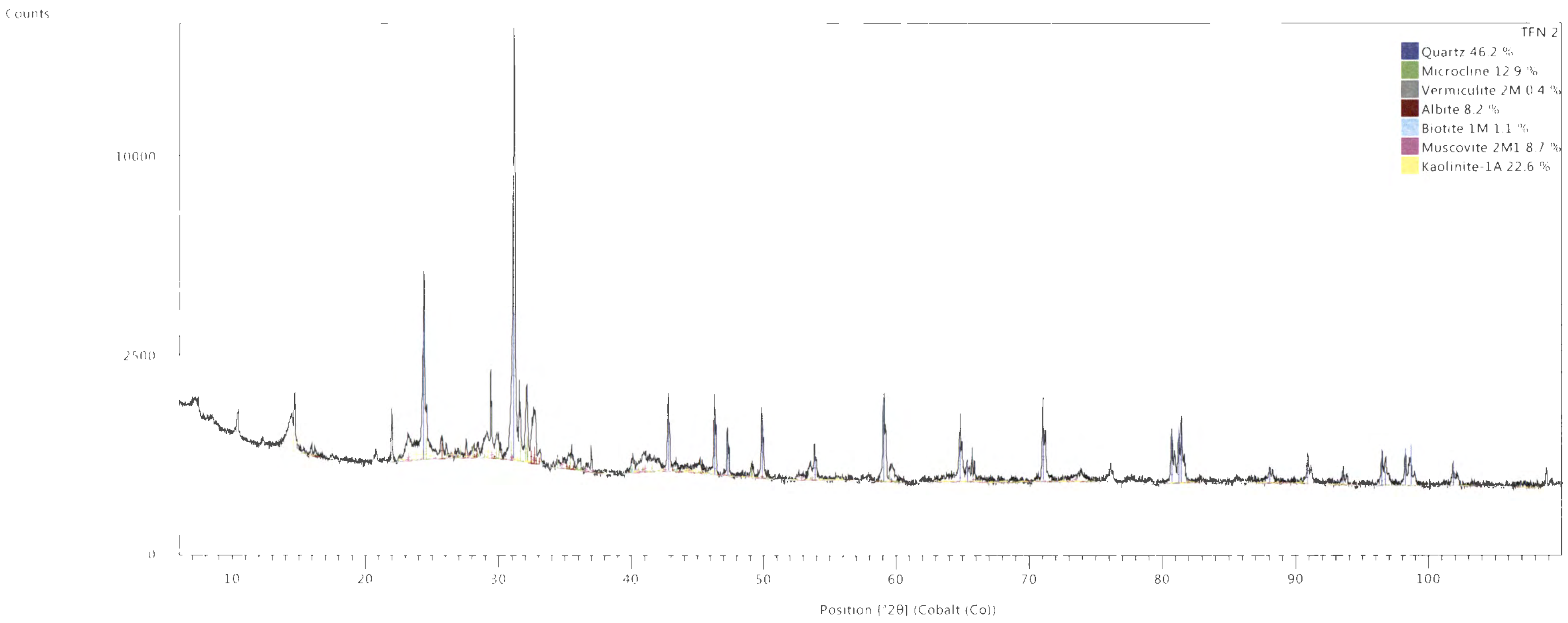


Figure 4.14: X-ray diffractogram for the clay fraction of TFN2

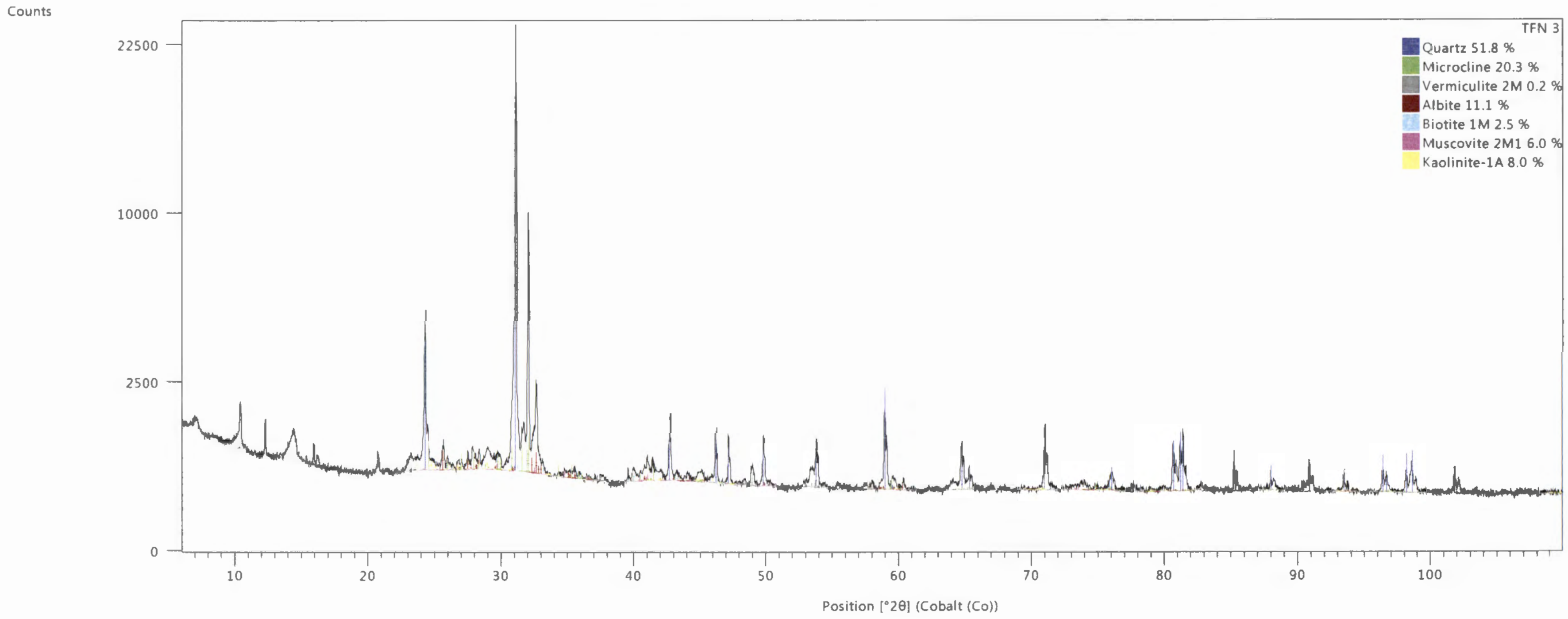


Figure 4.15: X-ray diffractogram for the clay fraction of TFN3

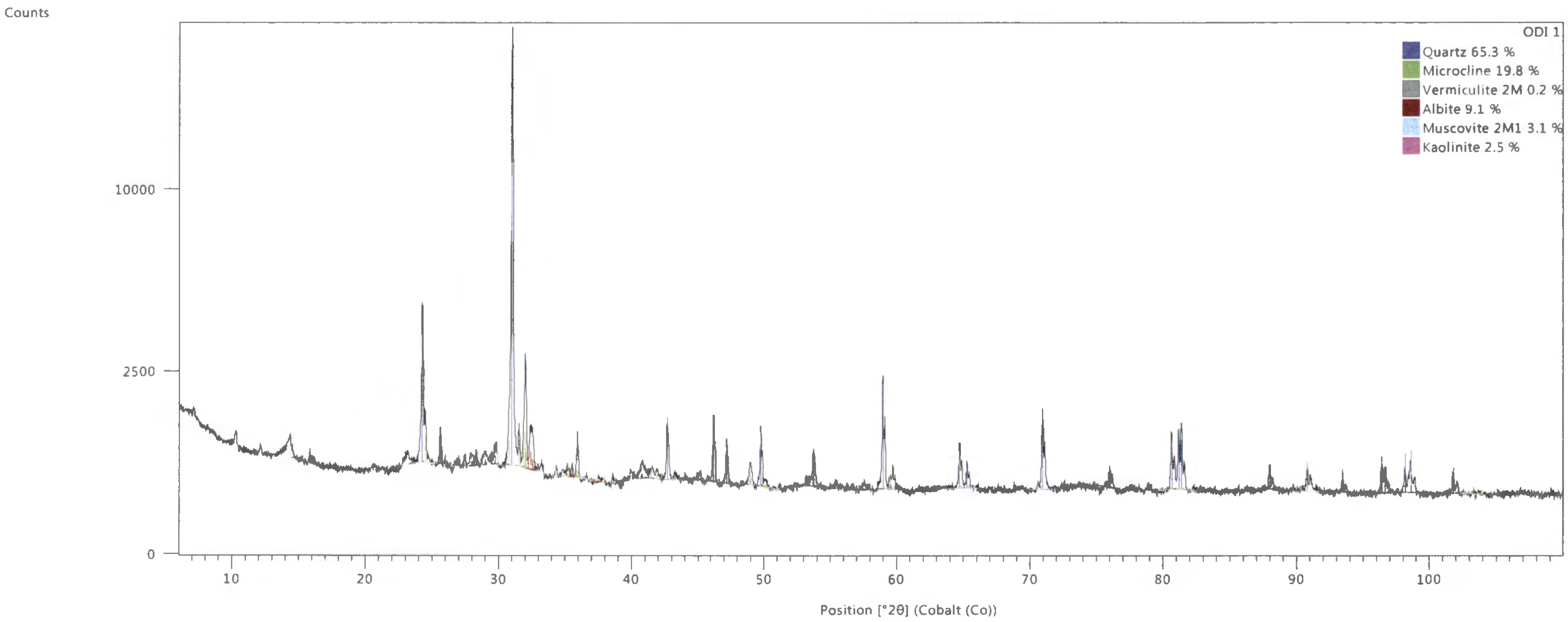


Figure 4.16: X-ray diffratogram for the clay fraction of ODI1

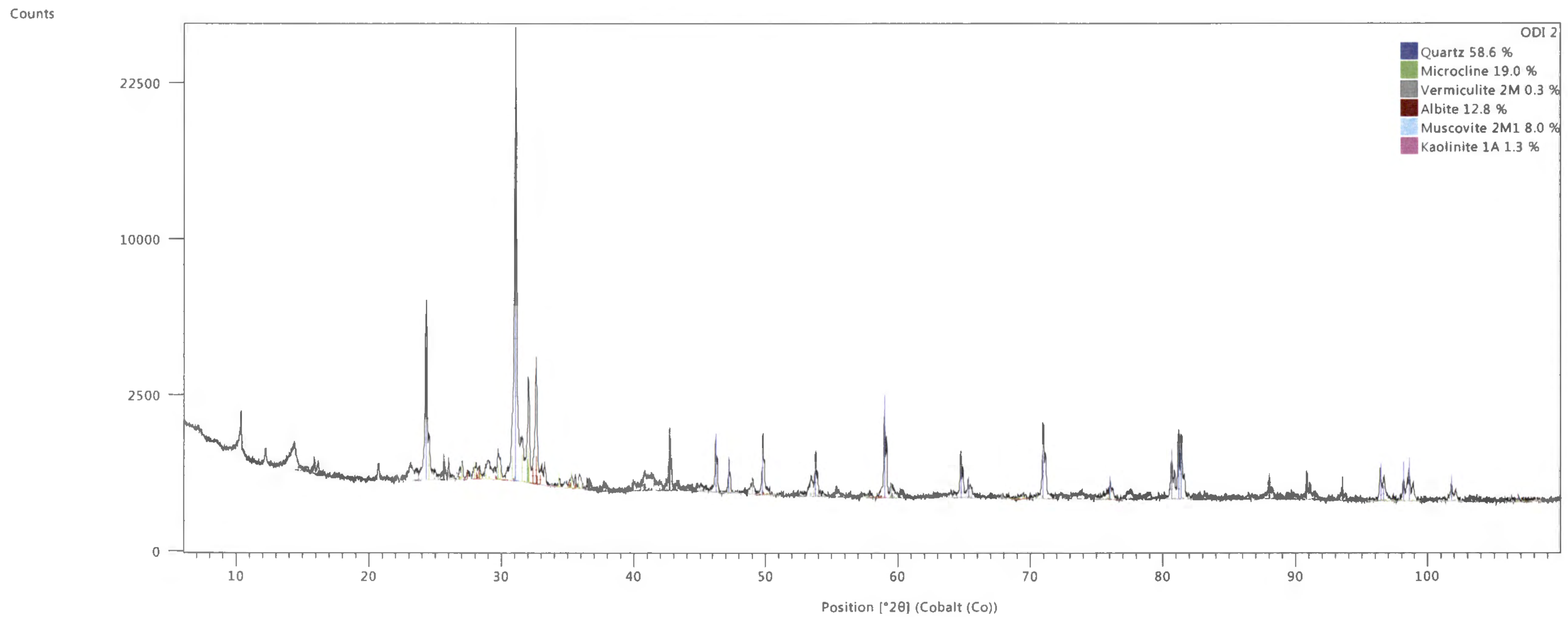


Figure 4.17: X-ray diffractogram for the clay fraction of ODI2

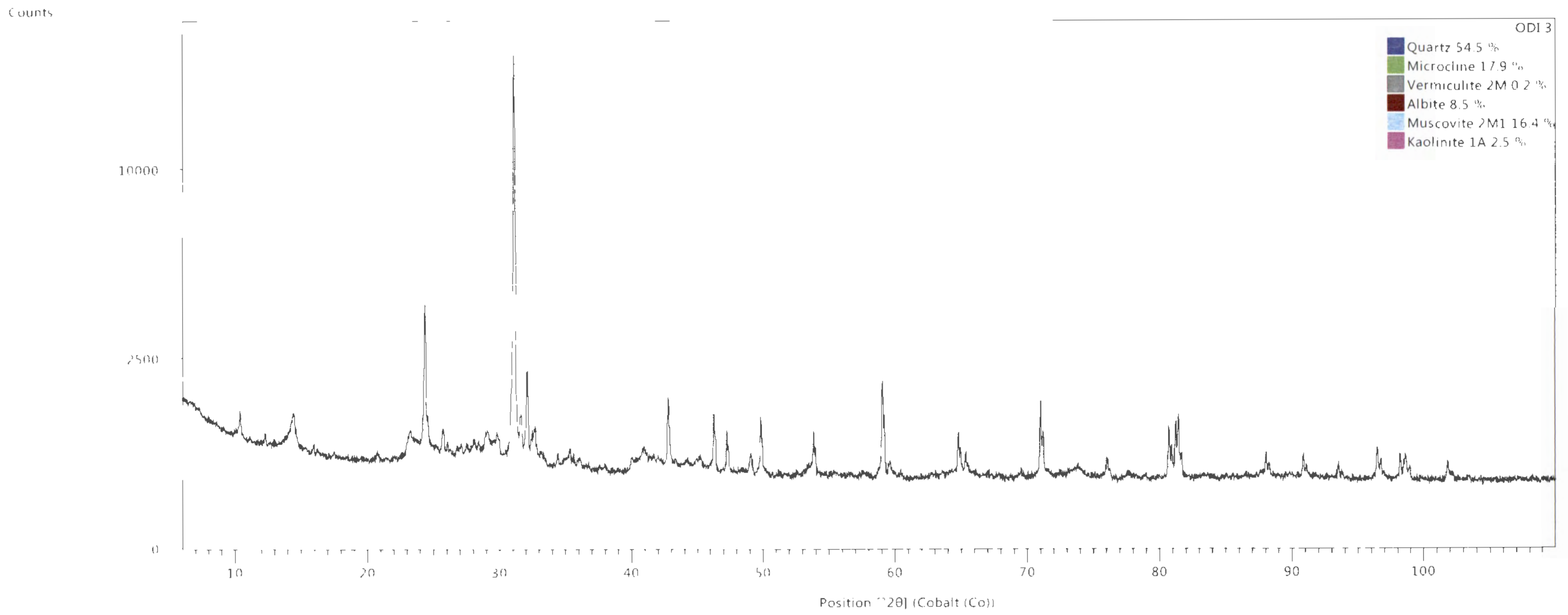


Figure 4.18: X-ray diffractogram for the clay fraction of ODI3

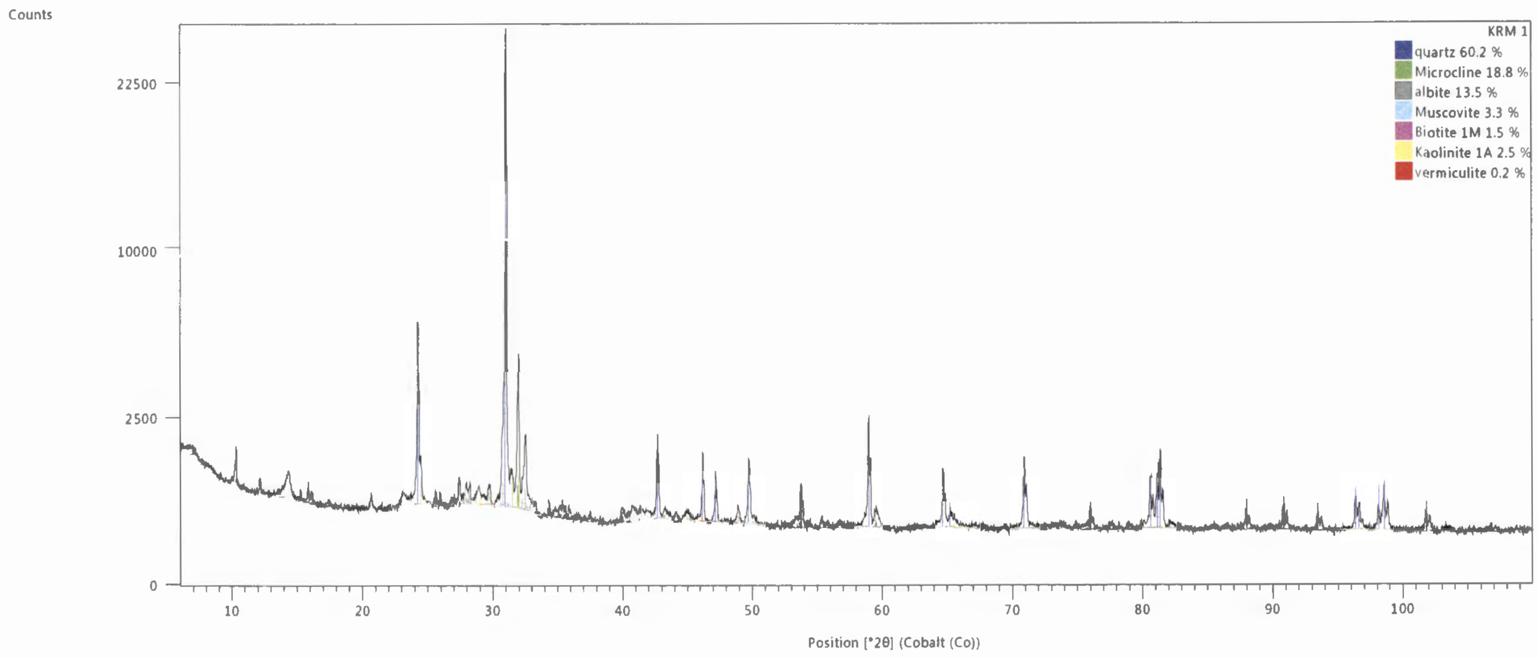


Figure 4.19: X-ray diffractogram for the clay fraction of KRM1

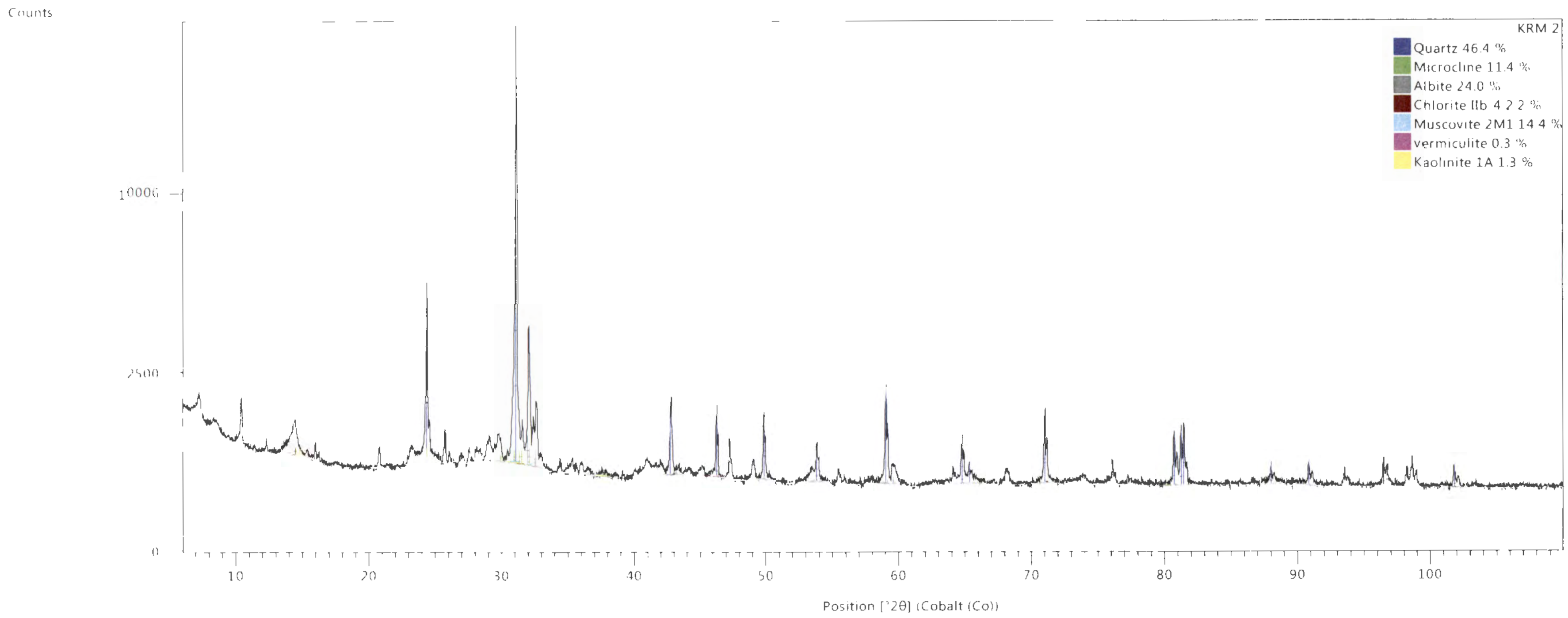


Figure 4.20: X-ray diffractogram for the clay fraction of KRM2

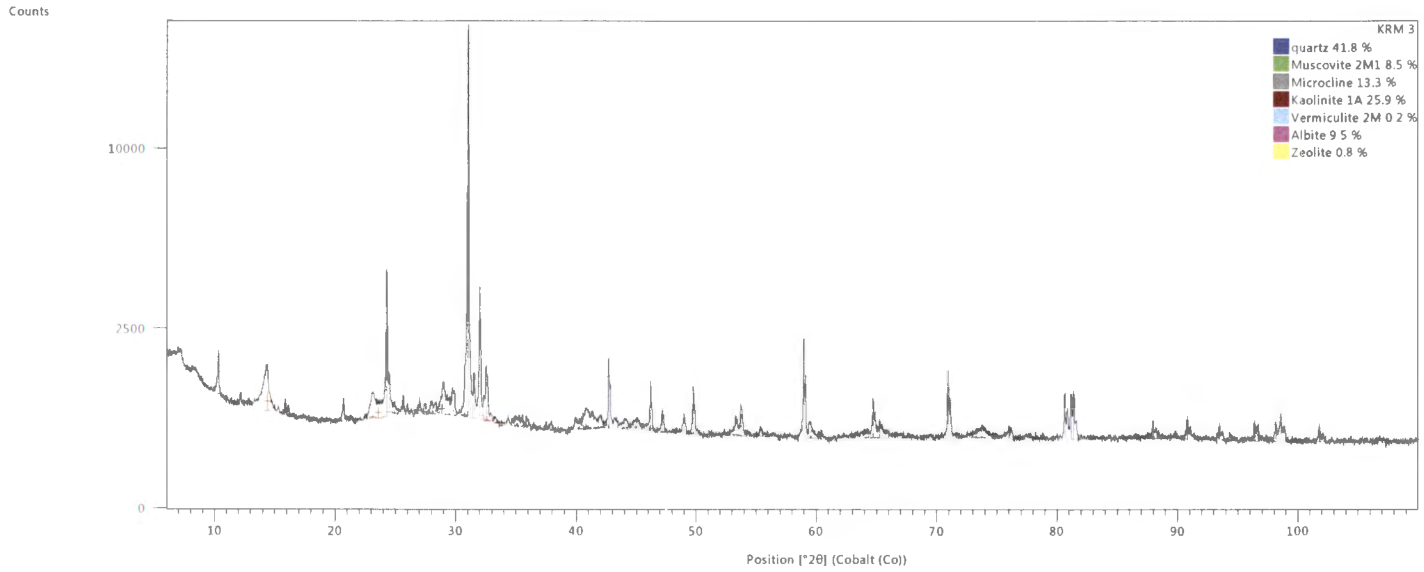


Figure 4.21: X-ray diffractogram for the clay fraction of KRM3

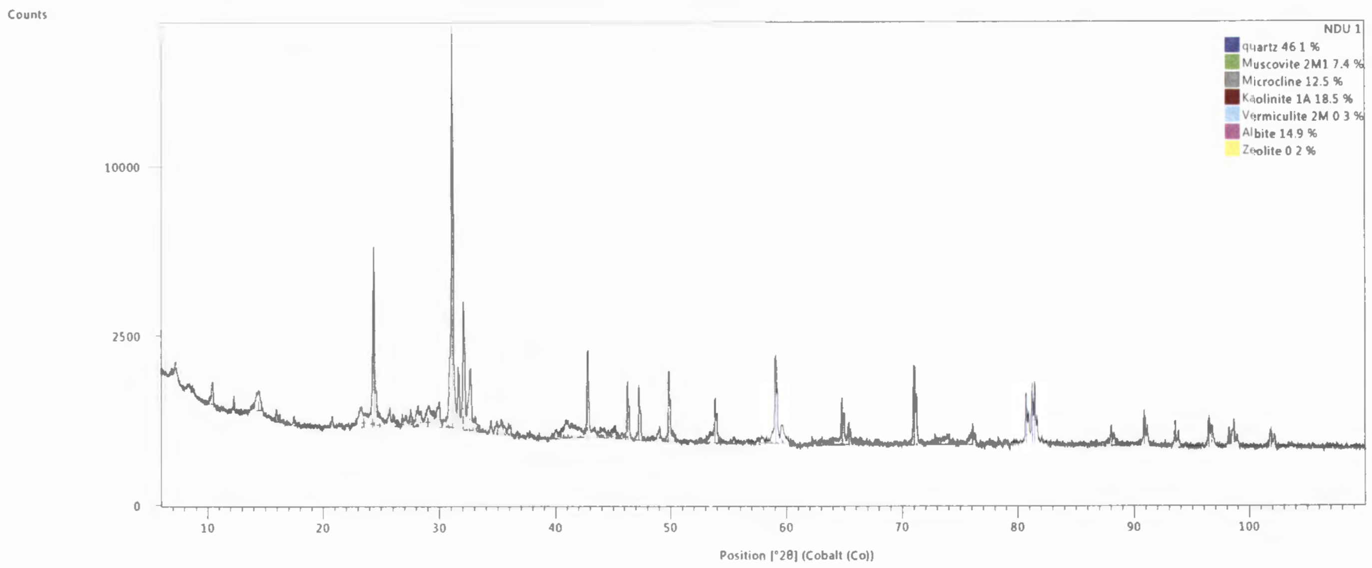


Figure 4.22: X-ray diffractogram for the clay fraction of NDU1

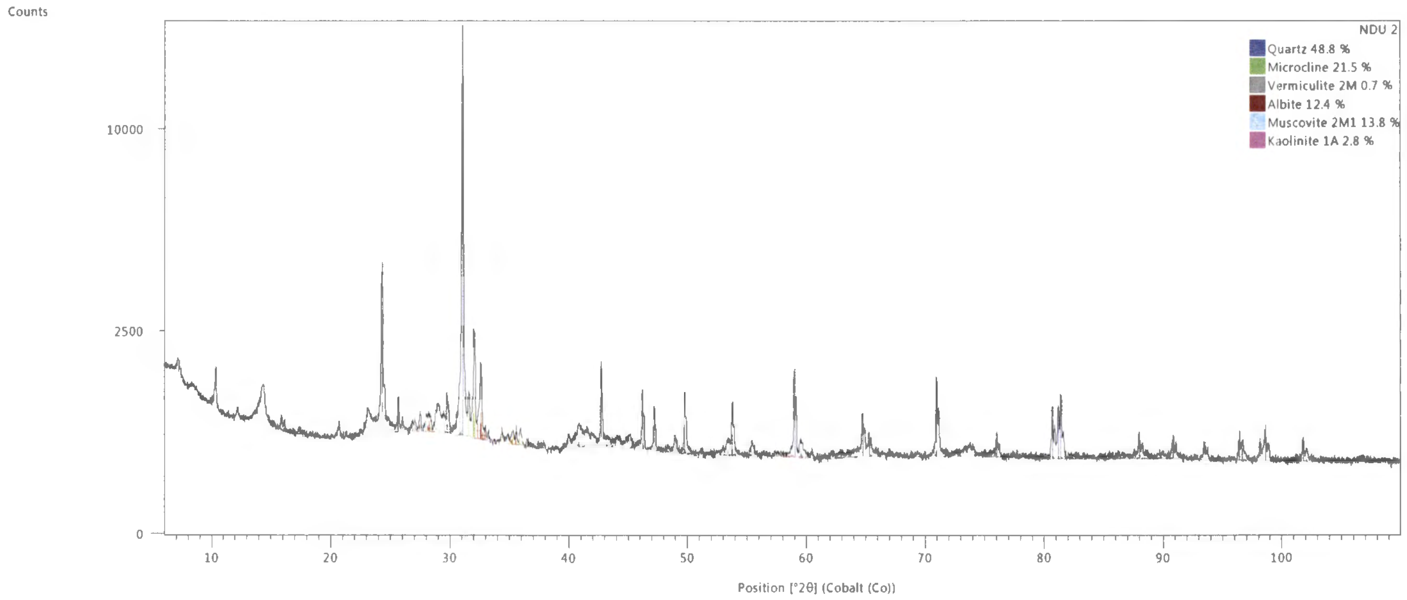


Figure 4.23: X-ray diffractogram for the clay fraction of NDU2

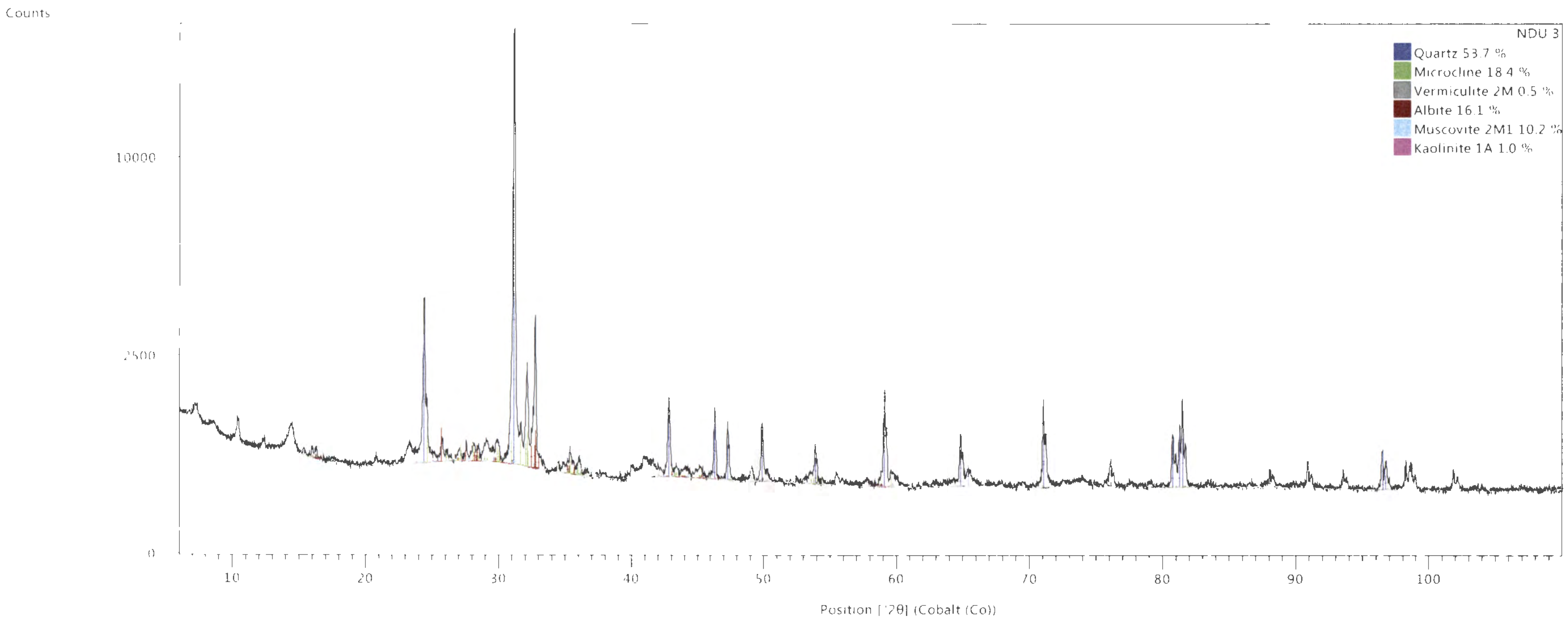


Figure 4.24: X-ray diffractogram for the clay fraction of NDU3

4.1.6 Capability Classification of the Soils

4.1.6.1 Land Capability Classification (LCC) of the Soils

Table 4.21 presents the Land Capability Classification (LCC) of the pedons encountered in this study while Annexure 20 presents the summary of criteria for Land Capability Classification (Adopted from Ogunkunle and Babalola, 1986). Presented in Table 4.22 is summary of Land Capability Index (LCI) or Soil Index (SI) of the Soil Mapping Units (SMUs) rated for annual and perennial crops while Annexures 29 to 46 showed Land Capability Index (LCI) or Soil Index (SI) of the SMUs rated for annual and perennial crops based on Van Ranst and Verdoodt (2005) modification.

Table 4.21: Interpretation of LCC units of the Soil Mapping Units

Soil Mapping Unit	LCC Uni	Interpretation
ELM1	IInf0	ELM1 belongs to class II, free from the annual seasonal floods but the soil is low in nutrient retentive capacity, exchangeable Ca^{2+} and Mg^{2+} and may require additional supplies through liming. Exchangeable Al^{3+} on the other hand is high. The area is good for planting wide variety of arable crops.
ELM2	IIwnf0	ELM1 belongs to class II, free from the annual seasonal floods but the soil is low in nutrient retentive capacity, exchangeable Ca^{2+} and Mg^{2+} and may require additional supplies through liming. Exchangeable Al^{3+} on the other hand is high. The area is good for planting wide variety of arable crops.
ELM3	IIwnf2	ELM3 belongs also to class II. Due to its location on the channel of the Niger River, it is subject to wetness during the flood season and flooding for a period of 1-2 months. Water retentive capacity is low during the dry period. Generally, nutrient retentive capacity level is a challenge and exchangeable Ca^{2+} and Mg^{2+} levels are low while exchangeable Al^{3+} is high. A wide variety of arable crops could be planted.
ODN1	IInf0	ODN1 belongs to class II, no flooding and can be plant with wide variety of crops but has low nutrient retentive capacity, low exchangeable Ca^{2+} and Mg^{2+} and moderately high exchangeable Al^{3+} level as limitations.
ODN2	IIwnf0	ODN2 belongs to class II, no flooding and can be planted to wide variety of crops but low nutrient retentive capacity, low exchangeable Ca^{2+} and g^{2+} as well as high exchangeable Al^{3+} are major limitations.
ODN3	IIwnf1	ODN3 also belongs to class II but with wetness and flooding for less than 1 month during the flood season. Low nutrient retentive capacity and low exchangeable Ca^{2+} and Mg^{2+} as well as high exchangeable Al^{3+} are limitations. The area could be planted to wide variety of crops

Table 4.21 cont.

Soil Mapping Unit	LCC Uni	Interpretation
TFN1	IIf0	TFN1belongs to class II free of flooding and can be used for a wide variety of crops. The major limitations are wetness in the rainy season.
TFN2	IIwnf0	TFN2 belongs to class II, free from flooding. The major limitations are wetness during the rainy season and low nutrient retentive capacity, low exchangeable Ca^{2+} and Mg^{2+} as well as high exchangeable Al^{3+}. Land suitable for the production of wide range of arable crops
TFN3	IIwnf2	TFN3 belong to class II, subject to the Niger River seasonal flood through the Forcados River. Apart from flooding, low water retentive capacity during the dry period, low nutrient retentive capacity, low exchangeable Ca and Mg as well as high exchangeable Al are major limitations
ODI1	IInf0	ODI1 belongs to class II, free from flooding. The major limitations are low nutrient retentive capacity, low exchangeable Ca^{2+} and Mg^{2+} and high exchangeable Al^{3+}. Land is suitable for cultivating wide variety of arable crops.
ODI2	IIwnf0	ODI2 belongs to class II, free from seasonal floods. The major limitations are wetness within 50 cm depth, low nutrient retentive capacity, low exchangeable Ca^{2+} and Mg^{2+} and high exchangeable Al^{3+}. Land is suitable for cultivating wide variety of arable crops.
ODI3	IIwnf1	ODI3 belongs to class II, with indications of wetness all through the profile. Apart from wetness, flooding for less than 1 month during the annual floods and low exchangeable Ca^{2+} and Mg^{2+} as well as high exchangeable Al^{3+} are major limitations. Land is suitable for cultivating arable crops when big mounds are raised.
KRM1	IInf0	KRM1 belongs to class II, free from annual flooding with low nutrient holding capacity, low exchangeable Ca^{2+} and Mg^{2+} as well as high exchangeable Al^{3+} as major limitations. Land is suitable for cultivating wide variety of arable crops.
KRM2	IIwnf0	KRM2 belongs to class II, free from flooding but wetness with 50cm depth, low nutrient retentive capacity; low exchangeable Ca^{2+} and Mg^{2+} as well as high exchangeable Al^{3+} are the limitations. Land is suitable for cultivating wide range of arable crops with improvement in nutrient holding capacity.
KRM3	IIwnf1	KRM3 belongs to class II. Flooding for less than 1 month, wetness with 50cm depth, low nutrient retentive capacity, low exchangeable Ca^{2+} and Mg^{2+} as well as high exchangeable Al^{3+} are the limitations. Land suitable for cultivating wide range of arable crops with improvement in nutrient holding capacity including liming.
NDU1	IInf0	NDU1 belongs to class II, free from flooding but wet, low in nutrient retentive capacity, low exchangeable Ca^{2+} and Mg^{2+} as well as high exchangeable Al^{3+} is the limitations. Land suitable for cultivating wide range of arable crops with improvement in nutrient holding capacity

Table 4.1 cont.

Soil Mapping Unit	LCC Uni	Interpretation
NDU2	IIwnf0	NDU II belongs to class II free of flooding but wet within 5o cm depth from soil surface. Other limitations are low nutrient retentive capacity, low exchangeable Ca and Mg as well as high exchangeable Al3+. Land is suitable for cultivating a wide variety of crops with improvement in nutrient retentive capacity by supplying additional nutrients
NDU3	VWnf3	NDU3 belongs to class VW due to high degree of wetness. The land is flooded for 3-6 months each year and there is serious wetness even during the dry months. Nutrient retentive capacity is low as well as exchangeable Ca^{2+} and Mg^{2+} while exchangeable Al^{3+} level is high which are the limitations. Land is suitable for low land rice production.

Table 4.22: Land Capability Index and Capability Classification of the Soil Mapping Units

Soil Mapping Unit	Annual Crops		Perennial Crops	
	Land Capability Index	Land Capability Class	Land Capability Index	Land Capability Class
ELM1	97	I	85	I
ELM2	56	III	45	IV
ELM3	59	III	59	III
ODN1	83	II	74	II
ODN2	68	III	54	III
ODN3	57	III	38	IV
TFN1	86	II	86	II
TFN2	63	III	51	III
TFN3	60	III	60	III
ODI1	72	II	64	III
ODI2	58	III	46	IV
ODI3	52	III	35	IV
KRM1	78	II	70	II
KRM2	69	III	55	III
KRM3	56	III	37	IV
NDU1	86	II	76	II
NDU2	69	III	55	III
NDU3	52	III	35	IV

4.1.6.2 Fertility Capability Classification (FCC) of the Soils

Presented in Tables 4.23 and 4.24 are the detailed interpretation of Fertility Capability Classification (FCC) of the soils and the summarized interpretation, respectively.

Table 4.23: Interpretation of FCC units of the Soil Mapping Units

Soil Mapping Unit	FCC Unit	Interpretation
ELM1	Lha-e	loamy textured soil with good water holding properties, having fertility constraints, especially Ca^{2+} and Mg^{2+}, moderate acidity, having more than 20% Al saturation (50cm), may require liming for Al-sensitive crops, N deficiency likely, require may additional supply during the growing season.
ELM2	Lha-e	loamy textured soil with good water holding characteristics, having fertility constraints, low ECEC of less than 4 Cmol/kg and moderate acidity with more than 20% Al saturation at 50cm depth, may require liming for Al-sensitive crops, N deficiency likely and may require supplies during the growing season
ELM3	Sha-ek	Loamy sand or sandy loam textured soil with high infiltration, low water holding capacity, low nutrient holding capacity (ECEC less than 4 Cmol/kg, low exchangeable K+ in some layers within 50cm depth, moderate acidity (Al saturation of more than 20% at 50cm depth), may require liming for Al-sensitive crops, N deficiency most likely, requiring supply during each planting season.
ODN1	Lha-	Loamy textured soil with good water holding characteristics, acidity between 5 and 6 in top layer, having Al saturation of more than 30% at 50cm depth, above the critical value of 20% (Ibanga and Udo 1996) requiring liming for Al-sensitive crops, N deficiency is most likely requiring supply for each planting season.
ODN2	Lgha-ek	loamy textured soil with gleying characteristics due to low Chroma of 2 for more than half the surface 50cm depth, moderate acidity (Al saturation more than 30% at 50cm depth), may require liming for Al-sensitive crops, low exchangeable K^{+} of less than 0.2 in the surface layer, N deficiency likely requiring supply for each planting season.
ODN3	Lgha-ek	loamy soil showing wetness with mottles all through the profile and gleying characteristics with mottles with chroma of 2 or less within 50cm depth, moderate acidity (Al saturation more than 20% at 50cm depth), may require liming for Al-sensitive crops, N deficiency most likely requiring supply for each planting season.

Table 4.23 cont.

Soil Mapping Unit	FCC Unit	Interpretation
TFN1	Lha-ek	loamy soil having good water holding characteristics, with fertility constraints, low ability to supply P, Ca^{2+} and Mg^{2+}, moderate acidity (Al saturation more than 30% at 50cm depth), may require liming for Al- sensitive crops. N deficiency most likely, requiring supply for each planting season.
TFN2	SLa-ek	sandy soil changing to loam with good water holding characteristics, moderate acidity (Al saturation more than 20% at 50cm depth), may require liming for Al- sensitive crops, low ability to supply K^+, Ca^{2+} and Mg^{2+}. N deficiency most likely, requiring supply for each planting season.
TFN3	Sha-e	Sandy textured soil with high infiltration rate and low water holding capacity, having moderate acidity (Al saturation more than 20% at 50cm depth), low ability to supply Ca^{2+} and Mg^{2+} may require liming for Al- sensitive crops, N deficiency most likely, requiring supply for each planting season.
ODI1	La-	loamy soil with good water holding characteristics, having fertility constraints, low ability to supply P, Ca^{2+} and Mg^{2+}, Al saturation more than 20% at 50cm depth, may require liming for Al- sensitive crops, N deficiency most likely, may require N supplies during each cropping season.
ODI2	Lha-	loam with good water holding characteristics, having fertility constraints with low ability to supply Ca^{2+} and Mg^{2+}, moderately acid, Al saturation of more than 20% at 50cm depth, may require liming for Al- sensitive crops. N deficiency most likely, requiring N supplies in each cropping season.
ODI3	Lga-eh	loam with good water holding characteristics, mottling all through the profile, soil saturated with water for more than 60 days in most years, moderate acidity, Al saturation of more than 20% at 50cm depth, may require liming for Al- sensitive crops. N deficiency most likely, requiring N supplies in each cropping season.
KRM1	Lha-e	loam with good water holding characteristics, having fertility constraints with low ability to supply Ca^{2+} and Mg^{2+}, moderately acid with Al saturation of more than 20% at 50cm depth, may require liming for Al- sensitive crops. N deficiency most likely, requiring N supplies in each cropping season.

Table 4.23 cont.

Soil Mapping Unit	FCC Unit	Interpretation
KRM2	Lgha-ek	loam with good water holding characteristics, soil is saturated with water for more than 60 days in most years, having fertility constraints with low ECEC and ability to supply K^+, Ca^{2+} and Mg^{2+}, moderately acid, Al saturation of more than 20% at 50cm depth, may require liming for Al-sensitive crops, N deficiency most likely, requiring N supply during each planting season.
KRM3	Lgha-ek	loam with good water holding characteristics, most likely saturated with Water for more than 60 days in most years, having fertility constraints with low ECEC and ability to supply Ca^{2+} and Mg^{2+}, moderately acid, Al saturation of more than 20% at 50cm depth, may require liming for Al-sensitive crops, N deficiency most likely, requiring N supply during each planting season.
NDU1	Lha-k	loamy soil with good water holding characteristics, with moderate acidity, Al saturation of more than 20% at 50cm depth, may require liming for Al- sensitive crops, low ability to supply P, Ca^{2+} and Mg^{2+}, N deficiency most likely, requiring N supply during each planting season.
NDU2	Lha-	loam with good water holding characteristics, with moderate acidity, Al saturation of more than 30% at 50cm depth, may require liming for Al- sensitive crops, low ability to supply P, Ca^{2+} and Mg^{2+}, N deficiency most likely, requiring N supply during each planting season.
NDU	Lgha-ek	loamy soil saturated with water for more than 60 days in most years, having fertility constraints, low ECEC, buffering capacity and ability to supply P, K^+, Ca^{2+} and Mg^{2+}, moderate acidity, Al saturation of more than 30% at 50cm depth, may require liming for Al- sensitive crops, N deficiency most likely, requiring N supply during each planting season.

Table 4.24: Summary of Interpretations of Fertility Capability Classification of the Soils

SMU	Type	Sub strat.	Condition Modifiers								FCC Unit
			g	E	h	i	x	k	b	a⁻	
ELM1	L		-	+	+	-	-	-	-	+	Lha-e
ELM2	L		-	+	+	-	-	-	-	+	Lha-e
ELM3	S		-	+	+	-	-	+	-	+	Sha-ek
ODN1	L		-	-	+	-	-	-	-	+	Lha⁻
ODN2	L		+	+	+	-	-	+	-	+	Lgha-ek
ODN3	L		+	+	+	-	-	+	-	+	Lgha-ek
TFN1	L		-	+	+	-	-	+	-	+	Lha-ek
TFN2	S	L	-	+	-	-	-	+	-	+	SLa-ek
TFN3	S		-	+	+	-	-	-	-	+	Sha-e
ODI1	L		-	-	-	-	-	-	-	+	La-
ODI2	L		+	-	+	-	-	-	-	+	Lha-
ODI3	L		+	+	+	-	-	-	-	+	Lgha-e
KRM1	L		-	+	+	-	-	-	-	+	Lha-e
KRM2	L		+	+	+	-	-	+	-	+	Lgha-ek
KRM3	L		+	+	+	-	-	+	-	+	Lgha-ek
NDU1	L		-	+	+	-	-	+	-	+	Lha-ek
NDU2	L		-	-	+	-	-	-	-	+	Lha-
NDU3	L		+	+	+	-	-	+	-	+	Lgha-ek

Key: S = Sandy; L = loamy; g = gley; e = low ECEC; h = acidic; i = high P fixation by iron; k = k deficient; a- = 10 to 60% Al saturation; b = basic reaction

4.1.7 Comparison of the various Capability Classification Systems

Table 4.25 presents a comparison of the evaluation of the capabilities of the Soil Mapping Units (SMUs) using Land capability Classification (LCC), Land Capability Index (LCI), Fertility Capability Classification (FCC) methods.

Table 4.25 Comparison of the various Capability Classification Systems

SMU	LCC	LCI		FCC
		Arable Crops	Permanent crops	
ELM1	IInf0	I	I	Lha-e
ELM2	IIwnf0	III	IV	Lha-e
ELM3	IIwnf2	III	III	Sha-ek
ODN1	IInf0	II	II	Lha-
ODN2	IIwnf0	III	III	Lgha-ek
ODN3	IIwnf1	III	IV	Lgha-ek
TFN1	IIf0	II	II	Lha-ek
TFN2	IIwnf0	III	III	SLa-ek
TFN3	IIwnf2	III	III	Sha-e
ODI1	IInf0	II	III	La-
ODI2	IIwnf0	III	IV	Lha-
ODI3	IIwnf1	III	IV	Lga-eh
KRM1	IInf0	II	II	Lha-e
KRM2	IIwnf0	III	III	Lgha-ek
KRM3	IIwnf1	III	IV	Lgha-ek
NDU1	IInf0	II	II	Lha-k
NDU2	IIwnf0	III	III	Lha-
NDU3	Vwnf3	III	IV	Lgha-ek

Keys: w = wetness: n = low nutrient retentive capacity: f0 = no flooding: f1 = flooding for less than 1 month: f2 = flooding for 1-2 months in a year: S = Sandy: L = loamy: g = gley: e = low ECEC: h = acidic: i = high P fixation by iron: k = k deficient: a- = 10 to 60% Al saturation:

4.1.8 Suitability Evaluation of the Soils for the Cultivation of Crops.

In Table 4.26 are the land characteristics of the pedons at 15 cm depth while in Table 4.27 is presented the land characteristics of the pedons at 40 cm depth. For maize and upland rice, the data in Table 4.26 was used while data in Table 4.27 was used for cassava, banana, oil palm, coconut and rubber.

Table 4.26: Land Characteristics of the Soil MappingUnits at 15cm Depth

	SMU																	
Land quality/characteristic	ELM 1	ELM 2	ELM 3	ODN 1	ODN 2	ODN 3	TFN 1	TFN 2	TFN 3	ODI 1	ODI 2	ODI 3	KRM 1	KRM 2	KRM 3	NDU 1	NDU 2	NDU 3
Climate (c)																		
Annual rainfall (mm)	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500
Length of dry season (days)	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120
Mean annual Temp. (c)	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
Relative humidity (%)	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78
Topography (t)																		
slope (%)	1	2	4	1	2	3	1	2	4	1	2	3	1	2	3	1	2	4
Wetness (w)																		
Flooding	f0	f	f1	f0	f0	f1	f0	f0	f1	f0	f0	f1	f0	f0	f1	f0	f0	f2
Drainage	Good	Mod.	Good	Good	Mod.	Poor	Good	Mod.	Good	Good	Mod.	Poor	Good	Mod.	Poor	Good	Mod.	V. poor
Soil physical charact. (s)																		
Texture	SiL	Sil	LS	Sil	SiL	SiL	SiL	LS	SL	SiL	L	Sil	SiL	SiL	SiL	SiL	SiL	SiL
Coarse frags. (%) 0-10cm	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
Fertility (f)																		
CEC (cmol/kg)	6.65	5.47	3.49	4.86	4.57	6.16	3.5	3.5	5.33	5.05	5.05	4.94	4.48	3.56	3.8	4.92	4.7	3.58
Base saturation (%)	62	69	66	55	52	74	49	49	66	64	50	43	67	52	55	53	38	36
pH-H20	5.46	5.44	5.52	5.76	5.64	5.67	5.64	6.16	5.74	6.3	5.7	5.67	5.79	5.55	5.67	5.58	5.64	5.42
OC (%)	2.25	1.03	0.84	1.07	1.32	2.33	1.6	1.28	1.2	0.95	1.58	5.25	1.84	1.3	1.29	1.51	2.06	2.81
Av. P (mg/kg)	18	16	15	12	16	19	12	17	15	13	19	21	20	22	18	5	1	3
Total N (%)	0.25	0.09	0.03	0.05	0.09	0.2	0.13	0.06	0.1	0.04	0.14	0.45	0.11	0.06	0.06	0.06	0.1	0.22
Exch. K (cmol/kg)	1.65	0.09	0.45	0.24	0.1	0.61	0.15	0.15	0.46	1.51	0.73	0.19	0.33	0.09	0.24	0.35	0.4	0.15
Exch. Ca (cmol/kg)	1.26	1.95	0.84	1.25	0.79	1.95	0.78	1.83	1.24	0.77	0.78	0.83	1.35	0.93	0.86	1.25	1.25	0.69
Exch. Mg (cmol/kg)	0.64	0.79	0.94	0.99	0.86	0.70	0.42	0.89	0.93	0.28	0.25	0.52	0.15	0.82	0.56	0.63	0.55	0.39
Salinity (ds/m)	0.06	0.06	0.04	0.12	0.12	0.67	0.09	0.01	0	0.08	0.02	0.33	0.09	0.09	0.32	0.08	0.07	0.09
Mg:K ratio	39	21	100	413	860	115	80	80	202	19	30	274	45	78	221	283	110	67

C=climate; t=topography; w=wetness; s=soil physical properties; f=fertility;

Table 4.27: Land Characteristics of the Surface 40 cm Depth of the Soil Mapping Units

	SMU																	
Land quality/characteristic	ELM 1	ELM 2	ELM 3	ODN 1	ODN 2	ODN 3	TEN 1	TEN 2	TEN 3	ODI 1	ODI 2	ODI 3	KRM 1	KRM 2	KRM 3	NDU 1	NDU 2	NDU 3
Climate (c)																		
Annual rainfall (mm)	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500
Length of dry season (days)	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130
Mean annual Temp. (c)	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
Relative humidity (%)	78	78	78	78	78	78	78	78	78	78	78	78	78	78	8	78	78	78
Topography (t)																		
slope (%)	1	2	4	1	2	3	1	2	4	1	2	3	1	2	3	1	2	4
Wetness (w)																		
Flooding	F0	F0	F1	F0	F0	F1	F0	F0	F1	F0	F0	F1	F0	F0	F1	F0	F0	F2
Drainage	Good	Mod.	Good	Good	Mod.	Poor	Good	Mod.	Good	Good	Mod.	Poor	Good	Mod.	Poor	Good	Mod.	V. poor
Soil physical charact. (s)																		
Texture	SiL	SiL	LS	SiL	SiL	SiL	SiL	LS	SL	SiL	L	SiL	SiL	SiL	SiL	SiL	SiL	SiL
Coarse frags. (%) 0-10cm	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
Fertility (f)																		
CEC (cmol/kg)	4.6	4.02	3.4	4.3	3.88	4.15	3.26	4.62	3.99	4.43	3.92	3.76	3.16	4.89	3.11	5.79	4.35	3.08
Base saturation (%)	55	55	58	54	44	53	46	43	57	59	47	36	56	34	43	46	39	41
pH-H20	5.62	5.46	6.22	5.76	5.91	6.04	5.70	6.10	5.76	6.30	5.89	5.95	5.64	6.01	5.68	5.64	5.88	5.68
OC (%)	2.0	0.42	0.81	0.83	1.22	1.36	1.03	0.74	0.82	0.95	1.02	2.27	1.80	0.76	0.80	1.50	1.41	2.22
Av. P (mg/kg)	14	14	14	14	13	17	10	14	9	13	18	12	21	19	19	8	2	2
Total N (%)	0.15	0.04	0.04	0.05	0.11	0.12	0.13	0.06	0.07	0.04	0.04	0.18	0.11	0.04	0.04	0.06	0.07	0.14
Exch. K (cmol/kg)	0.91	0.57	0.40	0.39	0.33	0.53	0.35	0.37	0.64	1.51	0.75	0.20	0.53	0.24	0.18	0.26	0.36	0.29
Salinity (ds/m)	0.06	0.06	0.04	0.12	0.12	0.67	0.09	0.01	0	0.08	0.02	0.33	0.09	0.09	0.32	0.08	0.07	0.21
Mg:K ratio	0.01	0.75	1.83	2.03	1.61	0.92	0.77	1.19	1.02	0.19	0.32	1.55	0.17	1.70	1.72	5.04	1.02	1.00

C=climate; t=topography; w=wetness; s=soil physical properties; f=fertility;

4.1.8.1 Suitability of the Soils for Maize Cultivation

The conversion Table (Table 3.3) of Sys (1985) was used to match the land characteristics of all the sites while the result of land evaluation for maize production are as presented in Table 4.28.

4.1.8.2 Suitability Evaluation of the Soils for Upland Rice Cultivation

The results of suitability evaluation of the SMUs for rainfed upland rice cultivation are as presented in Table 4.29.

4.1.8.3 Suitability of the Soils for Cassava Cultivation

Presented in Table 4.27 is the characteristics of the SMUs from the different locations at 40 cm soil depth while Table 3.5 presents the conversion table of Sys (1985) as modified, with which the characteristics were matched. Table 4.30 presents the suitability classes of the pedons after matching the characteristics.

4.1.8.4 Suitability of the Soils for Oil palm Cultivation

As in cassava, data in Table 4.27 which is characteristics of the pedons from the different locations at 40 cm depth from the soil surface was used and the conversion table of Sys (1985) modified (Table 3.6) was used to match the characteristics in Table 4.27. The results of the matching which gives the suitability of the specific LUR for the individual pedons is presented in Table 4.31.

4.1.8.5 Suitability of the Soils for Plantain Cultivation

The reference environmental data for banana is in Table 4.27 while the conversion table as modified by Djaenudin et al. (2003) is in Table 3.7. The suitability classification of banana for each characteristic for each pedon and the aggregate suitability is presented in Table 4.32.

4.1.8.6 Suitability of the Soils for Rubber Cultivation

In Table 3.8 is the conversion table modified by Djaenudin et al. (2003) for rubber cultivation while Table 4.33 presents the land suitability evaluation of the pedons from the different locations for rubber cultivation. The reference environmental data for the pedons used to match with the conversion table is in Table 4.27.

4.1.8.7 Suitability of the Soils for Coconut Cultivation

As with rubber, the environmental data in Table 4.27 was used to match with the conversion table (Table 3.9) of Djaenudin et al. (2003) to produce the suitability classes for coconut in Table 4.34.

Table 4.28: Land Suitability Evaluation of the Soil MappingUnits for Maize Cultivation

	SMU																	
Land quality characteristic	ELM1	ELM2	ELM3	ODN1	ODN2	ODN3	IFN1	IFN2	IFN3	ODI1	ODI2	ODI3	KRM1	KRM2	KRM3	NDU1	NDU2	NDU3
Climate (c)																		
Annual rainfall (mm)	N1	N1	N1	N1	N1	N1	N1	N1	N1	N1	N1	N1	N1	N1	N1	N1	N1	N1
Length of dry season (days)	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2
Mean annual Temp. (°C)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Relative humidity (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Topography (t)																		
slope (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Wetness (w)																		
Flooding	S1	S1	S3	S1	S1	S3	S1	S1	S3	S1	S1	S3	S1	S1	S3	S1	S1	N1
Drainage	S1	S1	S1	S1	S1	S3	S1	S1	S1	S1	S1	S3	S1	S1	S3	S1	S1	N1
Soil physical charact. (s)																		
Texture	S1	S1	S2	S1	S1	S1	S1	S2	S2	S1	S1	S1	S1	S1	S1	S1	S1	S1
Coarse frags. (%) 0-10cm	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Depth (cm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Fertility (f)																		
CEC (cmol/kg)	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3
Base saturation (%)	S1	S1	S1	S1	S1	S1	S2	S2	S1	S1	S2	S2	S1	S1	S1	S1	S2	S2
pH-H20	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
OC (%)	S1	S3	S3	S3	S2	S1	S2	S2	S2	S3	S2	S1	S2	S2	S2	S2	S1	S1
Av. P (mg/kg)	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	N1	N1	N1
Total N (%)	S1	S3	N1	N1	S2	S1	S2	N1	S3	N1	S2	S1	S2	N1	N1	N1	S2	S1
Exch. K (cmol/kg)	S1	N1	S2	S3	N1	S1	N1	N1	S2	S1	S1	N1	S2	N1	S3	S2	S2	N1
Limiting characteristics	**Cf**	**cf**	**cwf**	**cf**	**cf**	**cwf**	**cf**	**cf**	**cwf**	**cf**	**cf**	**cwf**	**cf**	**cf**	**cwf**	**cf**	**cf**	**cwf**
Aggregate suitability	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**

C climate; t topography; w wetness; s soil physical properties; f fertility; N1 presently unsuitable bur potentially suitble

Table 4.29: Land Suitability Evaluation of the Soil Mapping Units for Upland Rice Cultivation

	SMU																	
Land quality/characteristics	ELM1	ELM2	ELM3	ODN1	ODN2	ODN3	TFN1	TFN2	TFN3	ODI1	ODI2	ODI3	KRM1	KRM2	KRM3	NDU1	NDU2	NDU3
Climate (c)																		
Annual rainfall (mm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Mean annual Temp. (°C)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Relative humidity (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Topography (t)																		
slope (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Wetness (w)																		
Flooding	S1	S1	S3	S1	S1	S1	S1	S1	S3	S1	S1	S1	S1	S1	S1	S1	S1	S3
Drainage	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S3
Soil physical charact. (s)																		
Texture	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Coarse frags. (%) 0-10cm	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Fertility (f)																		
CEC (cmol/kg)	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2
Base saturation (%)	S1	S1	S1	S1	S1	S1	S2	S2	S1	S1	S2	S2	S1	S1	S1	S1	S2	S2
pH-H20	S2	S2	S2	S2	S2	S2	S2	S1	S2	S1	S2	S2	S2	S2	S2	S2	S2	S2
Av. P (mg/kg)	S1	S1	S2	S2	S1	S1	S2	S1	S2	S2	S1	S1	S1	S1	S1	S3	S3	S3
Exch Ca (cmol/kg)	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3
Exch. K (cmol/kg)	S1	S3	S1	S2	S3	S1	S2	S2	S1	S1	S1	S2	S1	S3	S2	S3	S1	S2
Exch. Mg (cmol/kg)	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3
Limiting characteristics	**F**	**f**	**wf**	**f**	**f**	**f**	**f**	**wf**	**f**	**f**	**f**	**f**	**f**	**f**	**f**	**f**	**f**	**wf**
Aggregate suitability	**S3**	**S3**	**S3**	**S3**	**S3**	**S3**	**S3**	**S3**	**S3**	**S3**	**S3**	**S3**	**S3**	**S3**	**S3**	**S3**	**S3**	**S3**

C climate: t topography; w wetness; s=soil physical properties; f=fertility; S3 marginally suitable

Table 4.30: Land Suitability Evaluation of the Soil Mapping Units for cassava Cultivation

	SMU																	
Land quality characteristics	ELM1	ELM2	ELM3	ODN1	ODN2	ODN3	IFN1	IFN2	IFN3	ODI1	ODI2	ODI3	KRM1	KRM2	KRM3	NDU1	NDU2	NDU3
Climate (c)																		
Annual rainfall (mm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Length of dry season (days)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Mean annual Temp. (°C)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Topography (t)																		
slope (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Wetness (w)																		
Drainage	S1	S2	S1	S1	S2	S3	S1	S2	S1	S1	S2	S3	S1	S2	S3	S1	S2	N1
Soil physical characteristics (s)																		
Texture	S1	S1	S2	S1	S1	S1	S1	S2	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Coarse frags. (%) 0-10cm	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Depth (cm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Fertility (f)																		
CEC (cmol/kg)	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2
Base saturation (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S2	S1	S1	S1	S1
OC (%)	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2
Limiting Characteristics	**F**	**wf**	**f**	**f**	**wf**	**wf**	**f**	**wf**	**f**	**f**	**wf**	**wf**	**f**	**wf**	**wf**	**f**	**wf**	**Wf**
Aggregate Suitability	**S2**	**S2**	**S2**	**S2**	**S2**	**S3**	**S2**	**S2**	**S2**	**S2**	**S2**	**S3**	**S2**	**S2**	**S3**	**S2**	**S2**	**N1**

C=climate; t=topography; w=wetness; s=soil physical properties; f=fertility; S2 = moderately suitable; S3 – marginally suitable; N1 – presently not suitable but potentially suitable

Table 4.31: Land Suitability Evaluation of the Soil Mapping Units for Oil palm Cultivation

	SMU																	
Land quality/characteristics	ELM1	ELM2	ELM3	ODN1	ODN2	ODN3	TFN1	TFN2	TFN3	ODI1	ODI2	ODI3	KRM1	KRM2	KRM3	NDU1	NDU2	NDU3
Climate (c)																		
Annual rainfall (mm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Length of dry season (days)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Mean annual Temp. (°C)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Relative humidity (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Topography (t)																		
slope (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Wetness (w)																		
Flooding	S1	S1	S2	S1	S1	S1	S1	S1	S2	S1	S1	S1	S1	S1	S1	S1	S1	S3
Drainage	S1	S2	S1	S1	S2	S3	S1	S2	S1	S1	S2	S3	S1	S2	S3	S1	S2	S3
Soil physical characteristics (s)																		
Texture	S1	S1	S3	S1	S1	S1	S1	S3	S3	S1	S1	S1	S1	S1	S1	S1	S1	S1
Structure	S1	S1	N2	S1	S1	S1	S1	S1	N2	S1	S1	S1	S1	S1	S1	S1	S1	S1
Coarse fragment	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Depth (cm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Fertility (f)																		
CEC (cmol/kg)	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3
Base saturation (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
pH-H20	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
OC (%)	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2
Exch. K (cmol/kg)	S2	S2	S3	S3	S3	S2	S3	S3	S2	S1	S2	S3	S2	S3	S3	S3	S3	S3
Mg:K ratio	S3	S3	S3	S2	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S1	S3	S3
limiting characteristics	**F**	**wf**	**wsf**	**f**	**wf**	**wf**	**f**	**wsf**	**wsf**	**f**	**wf**	**wf**	**f**	**wf**	**wf**	**f**	**wf**	**wf**
Aggregate suitability	**S3**	**S3**	**N2**	**S3**	**S3**	**S3**	**S3**	**S3**	**N2**	**S3**	**S3**	**S3**	**S3**	**S3**	**S3**	**S3**	**S3**	**S3**

C climate; t topography; w wetness; s soil physical properties; f fertility; S3 marginally suitable; N2 - usuitable

Table 4.32: Land Suitability Evaluation of the Soil Mapping Units for Plantain cultivation

	SMU																	
Land quality/characteristic	ELM1	ELM2	ELM3	ODN1	ODN2	ODN3	IFN1	IFN2	IFN3	ODI1	ODI2	ODI3	KRM1	KRM2	KRM3	NDU1	NDU2	NDU3
Climate (c)																		
Annual rainfall (mm)	N1	N1	N1	N1	N1	N1	N1	N1	N1	N1	N1	N1	N1	N1	N1	N1	N1	N1
Mean annual Temp. (°C)	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2
Topography (t)																		
slope (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Wetness (w)																		
Flooding	S1	S1	S3	S1	S1	S2	S1	S1	S3	S1	S1	S2	S1	S1	S2	S1	S1	S3
Drainage	S1	S1	S1	S1	S1	S2	S1	S1	S1	S1	S1	S2	S1	S1	S2	S1	S1	S3
Soil physical characteristics (s)																		
Texture	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Coarse frags. (%) 0-10cm	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Depth (cm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Fertility (f)																		
CEC (cmol/kg)	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2
Base saturation (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
pH-H20	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
OC (%)	S1	S3	S2	S2	S1	S1	S2	S3	S2	S2	S2	S1	S1	S3	S2	S1	S1	S1
Salinity (ds/m)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Limiting Characteristics	Cf	Cf	cwf	cf	cf	cwf	cf	cf	cwf	cf	cf	cwf	cf	cf	cwf	cf	cf	cwf
Aggregate suitability	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**	**N1**

C climate: t=topography: w=wetness: s soil physical properties: f=fertility: N1- presently not suitable but potentially suitable

Table 4.33: Land Suitability Evaluation of the Soil Mapping Units for Rubber Cultivation

	SMU																	
Land quality/characteristics	ELM1	ELM2	ELM3	ODN1	ODN2	ODN3	TFN1	TFN2	TFN3	ODI1	ODI2	ODI3	KRM1	KRM2	KRM3	NDU1	NDU2	NDU3
Climate (c)																		
Annual rainfall (mm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Length of dry season (days)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Mean annual Temp. (° C)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Topography (t)																		
slope (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Wetness (w)																		
Flooding	S1	S1	N1	S1	S1	S2	S1	S1	N1	S1	S1	S2	S1	S1	S2	S1	S1	N1
Drainage	S1	S2	S1	S1	S2	S3	S1	S2	S1	S1	S2	S3	S1	S2	S3	S1	S2	S3
Soil physical characteristics (s)																		
Texture	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Coarse frags. (%) 0-10cm	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Depth (cm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Fertility (f)																		
CEC-clay (cmol/kg)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Base saturation (%)	S3	S3	S3	S3	S2	S3	S2	S2	S3	S3	S2	S2	S3	S2	S2	S2	S2	S2
pH-H20	S1	S1	S2	S1	S1	S2	S1	S2	S1	S2	S1	S1	S1	S2	S1	S1	S1	S1
OC (%)	S1	S2	S1	S1	S1	S1	S1	S2	S1	S1	S1	S1	S1	S2	S2	S1	S1	S1
Salinity (ds/m)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Limiting Characteristics	F	Wf	wf	f	wf	wf	f	wf	wf	f	wf	wf	f	wf	wf	f	wf	wf
Aggregate suitability	**S3**	**S3**	**N1**	**S3**	**S2**	**S3**	**S2**	**S2**	**N1**	**S3**	**S2**	**S3**	**S3**	**S2**	**S3**	**S2**	**S2**	**N1**

C climate; t topography; w wetness; s soil physical properties; f fertility; S2 moderately suitable; S3 – marginally suitable; N1 – presently not suitably but potentially suitable

Table 4.34: Land Suitability Evaluation of the Soil Mapping Units for Coconut Cultivation

	SMU																	
Land quality/characteristics	ELM1	ELM2	ELM3	ODN1	ODN2	ODN3	TFN1	TFN2	TFN3	ODI1	ODI2	ODI3	KRM1	KRM2	KRM3	NDU1	NDU2	NDU3
Climate (c)																		
Annual rainfall (mm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Length of dry season (days)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Mean annual Temp. (°C)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Topography (t)																		
slope (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Wetness (w)																		
Flooding	S1	S1	N1	S1	S1	S2	S1	S1	N1	S1	S1	S2	S1	S1	S2	S1	S1	S3
Drainage	S1	S2	S1	S1	S2	S3	S1	S2	S1	S1	S2	S3	S1	S2	S3	S1	S2	S3
Soil physical characteristics (s)																		
Texture	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Coarse frags. (%) 0-10cm	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Depth (cm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Fertility (f)																		
CEC-clay (cmol/kg)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Base saturation (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
pH-H$_2$0	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
OC (%)	S1	S2	S1	S1	S1	S1	S1	S2	S1	S1	S1	S1	S1	S2	S2	S1	S1	S1
Salinity (ds/m)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Limiting Characteristics	-	wf	w	-	wf	Wf	-	wf	w	-	wf	wf	-	wf	Wf	-	wf	wf
Aggregate suitability	**S1**	**S2**	**N1**	**S1**	**S2**	**S2**	**S1**	**S2**	**N1**	**S1**	**S2**	**S2**	**S1**	**S2**	**S2**	**S1**	**S2**	**S3**

C=climate: t=topography: w wetness: s=soil physical properties: f=fertility: S1 – very suitable; S2 – moderately suitable; S3 – marginally suitable; N1 – presently not suitable but potentially suitable.

4.1.9 Identifying Properties in Important to Soil Fertility

Table 4.35 shows the important soil properties in the pedons in relation to soil fertility. identified through Principal component analysis (PCA).

4.1.10 Relationship between Soil Properties in the Soil Mapping Units

Pearson correlation analysis of some selected soil properties is as shown in Table 4.36.

4.1.11 Assessing Soil Fertility Status of Soil Mapping Units using SFI and SEF

In this study. both SFI and SEF were used to assess soil fertility and the quality of the SMUs. Table 4.37 presents the Turkey's t-test for differences between mean SFI and SEF for the study sites while Figures 4.25 to 4.30 show the graphical comparison of soil fertility index and soil evaluation factor for each of the pedons.

Table 4.35: PCA results of Soil Mapping Units

Factors loadings	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Soil mapping units +	EA, Al, %Al sat.	Org. C, Org. M, T-N.	ECEC, Ca^{2+}, Mg^{2+},	Sand		Zn, Fe	pH-H_2O, Ec	Mn
-	BS-ECEC		TEB	clay	pH-$CaCl_2$	Cu	K^+	C/N ratio
Contribution	Soil acidity, nutrient retention	Organic matter	Nutrient retention	Texture	pH	micronutrients	pH, Electrical conductivity, K	Mn, C/N ratio
Total	4.386	3.425	3.198	1.820	1.254	1.208	1.145	1.016
Variance (%)	18.275	15.422	13.326	7.585	5.225	5.033	4.770	4.233
Cumulative (%)	18.275	33.697	47.022	54.608	59.833	64.866	69.635	73.868

Note: + Factor loading with a positive value. - Factor loading with a negative value. EA=Exchangeable acidity

Table 4.36: Pearson's Correlation matrix of soil properties

	pH-H20	Ec	T-N	Org. C	Org. M	P	Ca	Mg	K	Na	TEB	Acidity	Al	ECEC	Al sat	BS	Sand	Silt	Clay
pH-H20	1.00																		
Ec	-0.08	1.00																	
T-N	-0.22*	0.33**	1.00																
Org. C	-0.31**	0.37***	0.92***	1.00															
Org. M	-0.31**	0.37***	0.92***	1.00	1.00														
P	-0.15	0.11	0.33**	0.31**	0.31**	1.00													
Ca	-0.09	0.09	0.05	0.01	0.01	0.06	1.00												
Mg	0.12	0.01	-0.07	-0.78	-0.07	-0.06	0.22*	1.00											
K	-0.06	-0.1	0.01	-0.06	-0.06	-0.01	-0.002	0.06	1.00										
Na	-0.14	0.10	0.17*	0.10	0.10	0.22*	0.51***	0.22*	0.25**	1.00									
TEB	-0.02	-0.02	-0.002	-0.06	-0.06	-0.003	0.58***	0.65***	0.64***	0.52***	1.00								
Acidity	0.01	-0.06	0.11	0.10	0.10	-0.07	-0.10	0.05	-0.06	-0.16	-0.07	1.00							
Al	0.004	-0.04	0.12	0.12	0.12	-0.05	-0.06	0.06	-0.08	-0.13	-0.06	0.93***	1.00						
ECEC	-0.01	-0.06	0.08	0.05	0.05	-0.05	0.25**	0.42***	0.32**	0.17	0.52***	0.81***	0.76***	1.00					
Al salt	-0.03	0.01	0.16	0.17	0.17	0.001	-0.28**	-0.26**	-0.34**	-0.31**	-0.48***	0.65***	0.81***	0.27**	1.00				
BS	0.002	0.01	-0.14	-0.21	-0.20*	0.03	0.40***	0.32**	0.34**	0.40***	0.57***	-0.78***	-0.69***	-0.34**	-0.73***	1.00			
Sand	0.02	-0.18*	0.001	-0.05	-0.05	0.07	-0.09	-0.08	0.03	0.09	-0.06	-0.18*	-0.09	-0.17	0.002	0.19*	1.00		
Silt	-0.02	0.21	0.04	0.09	0.10	0.01	0.05	0.09	-0.08	-0.06	0.02	0.07	-0.003	0.04	-0.05	-0.11	-0.94***	1.000	
Clay	0.01	0.01	-0.26**	-0.07	-0.07	-0.22*	0.14	0.04	0.10	-0.10	0.13	0.33**	0.25**	0.35***	0.07	-0.26**	-0.68***	0.40***	1.00

*. Correlation significant at 5% level

**. Correlation significant at 1% level

*** Correlation significant at 0.1% level

Table 4.37: T-test statistic for paired sample for SFI and SEF

Soil Mapping Unit	Mean SFI	Mean SEF	t-statistic
ELM1	18.48	9.87	6.57*
ELM2	18.02	5.85	8.14*
ELM3	17.85	6.80	6.62*
ODN1	16.35	6.17	6.63*
ODN2	15.08	6.97	3.56*
ODN3	18.94	8.59	3.76*
TFN1	16.46	6.19	5.38*
TFN2	19.05	6.19	5.35*
TFN3	15.72	6.78	5.65*
ODI1	19.03	6.17	8.43*
ODI2	19.64	6.16	7.55*
ODI3	16.60	6.86	5.10*
KRM1	21.89	7.76	5.57*
KRM2	21.89	7.76	5.57*
KRM3	20.71	6.17	7.25*
NDU1	11.53	7.58	3.67*
NDU2	9.17	7.01	5.35^{ns}
NDU3	11.65	7.48	8.10^{ns}

* Indicates t-test significant at 5% level, ns = not significant

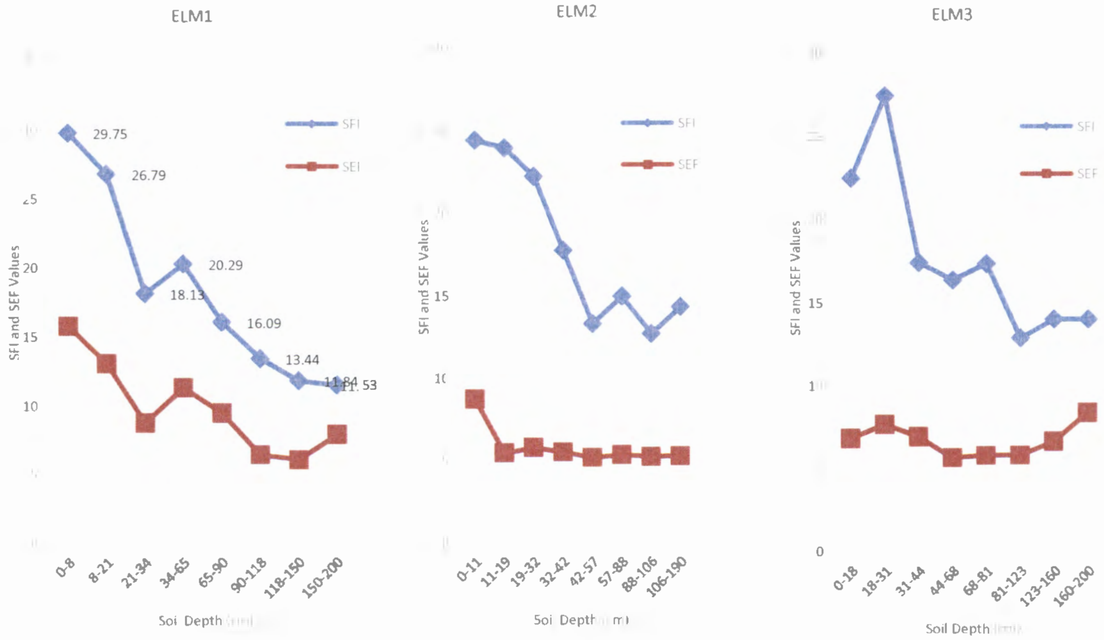


Figure 4.25: Comparison of SFI and SEF Values in Elemebiri Soils

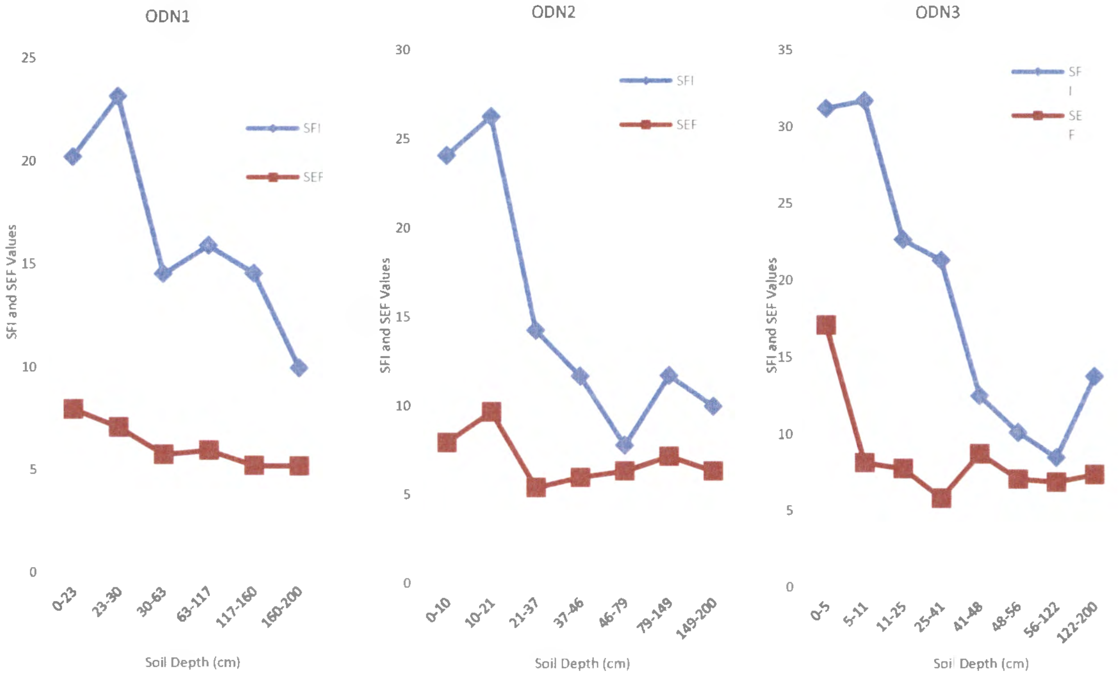


Figure 4.26: Comparison of SFI and SEF Values in Odoni Soils

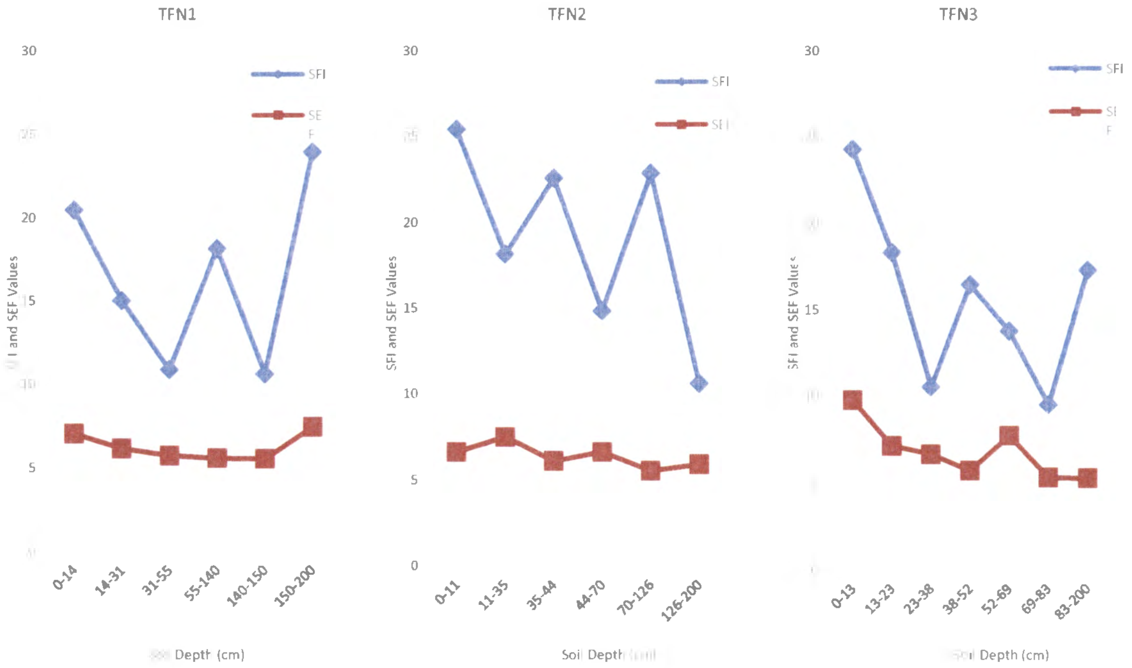


Figure 4.27: Comparison of SFI and SEF Values in Trofani Soils

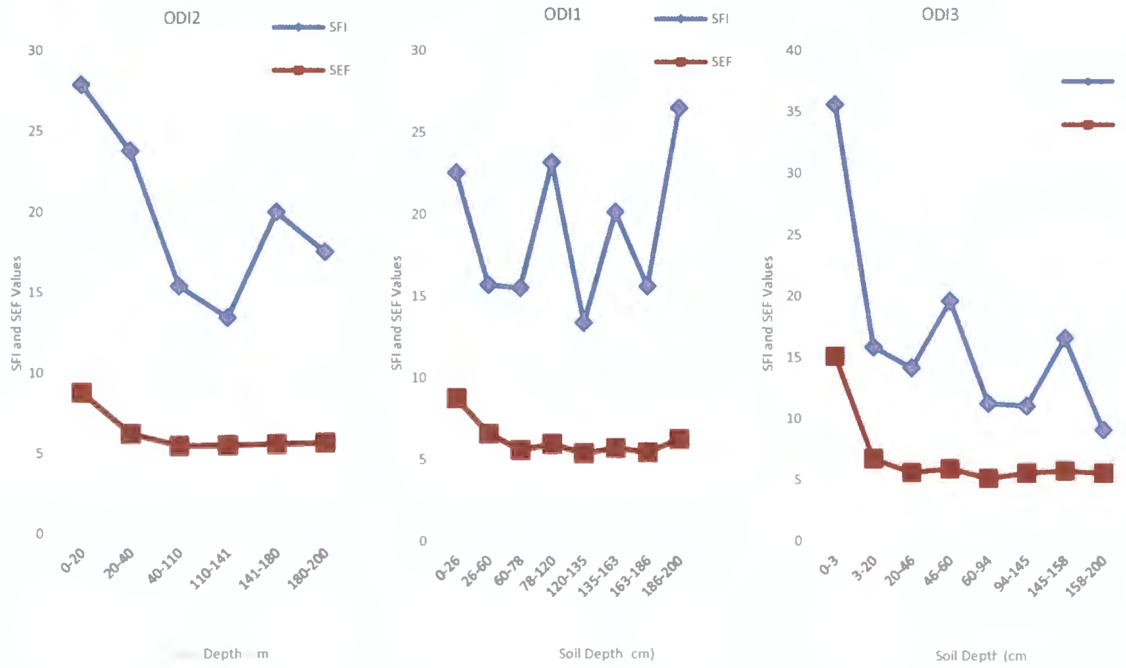


Figure 4.28: Comparison of SFI and SEF Values in Odi Soils

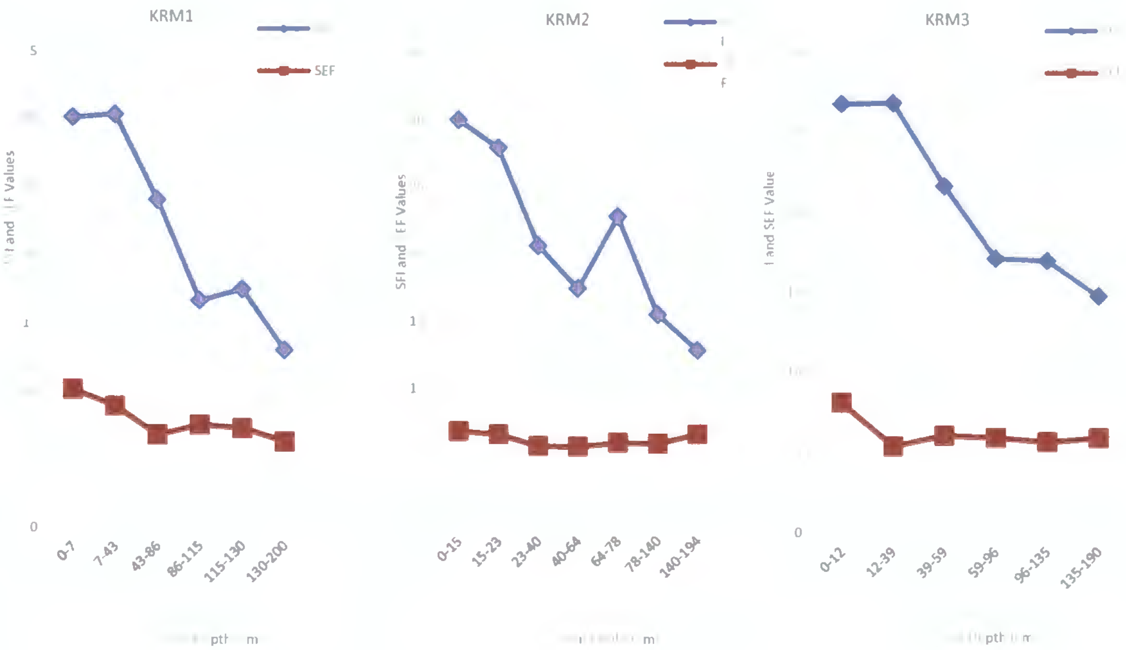


Figure 4.29: Comparison of SFI and SEF Values in Koroama Soils

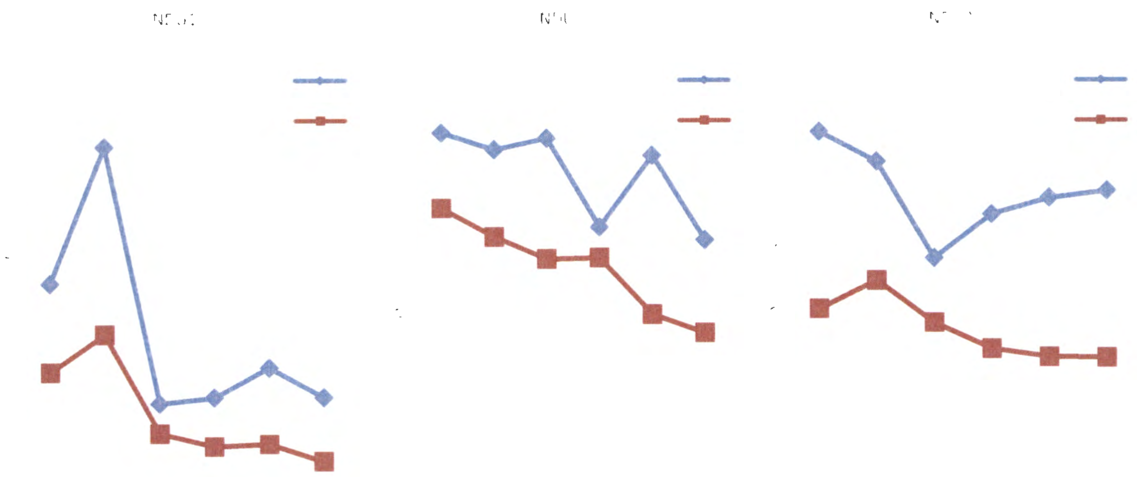


Figure 4.30: Comparison of SFI and SEF Values in Niger Delta University Soils

4.2 Discussions

4.2.1 Morphological Characteristics

One spectacular observation in the river plain soils was redoximorphic characteristics at various depths of the pedons depending on the location of the soil on the landscape. The ELM1 soils located on the levee crest of the landscape were moderately well drained while ELM3 was well drain but seasonally flooded. The ELM3 soils were from recent alluvial materials deposited on the channel of the present actively flowing Niger River. The ELM2 soils located on the middle slope were imperfectly drained. However, there was occurrence of few, medium, distinct, reddish brown mottles (5 YR 4/4) at the 21-34 cm depth of the subsurface soil layer of ELM1 (Table 4.1), which was attributed to the alluvial source from which the soil layer was formed. Redoximorphic characteristics were also observed at the two lowest layers of the ELM1 profile, as few, medium, distinct, brown (7.5 YR 5/6) and common, medium distinct, yellowish red (5 YR 4/6) mottles were present which indicated that the two layers came under ground water influence during the rainy season each year. These two soil layers are subject to ground water influence during the annual floods, starting May/June, peaking in September/October and recedes later in October to early November. In the case of ELM2, redoximorphic characteristics indicated by mottles occurred from the fifth layer down the profile revealing longer period of water saturation of the affected layers, especially in the rainy season.

The alternate wetting and drying conditions resulted in the reduction and subsequent release of iron oxides which accumulated in the form of reddish brown, brown and yellowish red mottles on the subsurface of the pedon (Akpan-Idiok and Ogbaji, 2013). Redoximorphic features are associated with flooding/wetness following alternating periods of reduction and oxidation of iron and manganese compounds in soils ((Hossain et al., 2011). Dark colour in the upper layers of the ELM1 soil was attributed to organic matter coloration. The colour matrix of the lowest three layers of ELM2 had chroma of 2 or less. It has been reported that grayish colouration at lower depths indicated ground water influence or poor drainage (Esu, 2010) and/or such soil layer was subjected to groundwater influence in most part of the year (Hossain et al., 2011). The soils were free of water during the period of soil sample collection. Senjobi et al. (2016) observed major differences in structure, texture, colour, and drainage and soil consistence of soils under organic-based oil palm plantations in Southwestern Nigeria. They observed that the pedons at the upper and middle slopes were well-drained while the pedons at the valley bottom were poorly drained. The observed differences were attributed to differences in clay contents and regional water table, with valley bottom section having higher clay content at the surface than other land types which invariably reduced water infiltration rate. In this study, there was no marked difference in clay content among the pedons that can be said to reduce water infiltration rate. The difference in drainage was attributed to differences in land type and how they are affected by the rise in seasonal water table. The presence of medium to coarse continuous pores along with few fine pores throughout ELM2 profile suggested good drainage during the dry periods and groundwater influence was caused by rain water and rise in water table with the annual floods which occurred between May/June and October/November each year. Owing to deposition of suspended materials during the rise and fall in water table, most of the fine pores were blocked. In spite of the fact that the ELM3 soils were formed from recent alluvial materials deposited in the middle of the actively flowing Niger River, drainage was near perfect. However, few, medium, distinct, dark reddish brown iron oxide concretions (2.5 YR 3/3) were spotted on the second layer (18-31 cm) of the profile.

The fact there were no mottles in any of the layers below except the few, medium distinct, dark reddish brown (2.5 YR 3/3) mottles in the 18-31cm depth from the soil mineral surface implied that the soil colour variations reflected differences in chemical and mineralogical composition, soil organic matter contents, parent materials and moisture regime of the alluvial materials that formed the pedon. The few mottles in the 18-31 cm depth were traced to the chemical and mineralogical composition of that layer. The presence of medium to coarse pores in the various soil layers was an indication of the soils having good drainage. Weak soil structural development and consistence strongly reflected differences in the source of the alluvial materials that formed the different soil layers and the embryonic nature of the pedon which is true particularly in ELM3. The horizon differentiation in ELM3 was A-Ap1-Ap2-C1-C2-C3-C4-C5 which means ELM3 was an A-C profile. The ELM3 SMU therefore, had no diagnostic subsurface horizon and was low in pedogenetic activities which could be defined as young. The presence of mica flakes in ELM1, ELM2 and ELM3 indicated the recentness of the soils.

In the Odoni soils, mottling was observed from 117 cm depth of ODN1, 46 cm depth of ODN2 and 5 cm depth of ODN3, from the mineral soil surface (Table 4.2). The presence of mottles from the afore-mentioned depths indicated that these soils come under the influence of groundwater at certain periods of the year. This influence occurred during the rainy season which coincided with the annual flood that lasts for about six months. Many medium to coarse pores occurred all through the profiles which eased movement of water. In the layers that were mottled, most of the fine pores were blocked due to the seasonal ground water influence. As noted for the Elemebiri pedons, the reduction and subsequent release of iron oxides in ODN1 probably accumulated in the form of reddish brown, and yellowish red mottles on the surfaces of the two lower horizons (Akpan-Idiok and Ogbaji, 2013). Similarly, hydromorphic influence on the layers below 46 cm depth of ODN2 led to the accumulation of yellowish red, dark reddish brown and reddish brown mottles on the subsurface of the profile.

Yellowish colour of mottles in these pedons was attributed to the presence of sesquioxides in hydrated forms, especially goethite (Lawal et al., 2013). Akpan-Idiok and Ogbaji (2013), reported that alternate wetting and drying in soils under hydromorphic influence leads to reduction and release of iron oxides accumulating in the form of mottles. Variation in the colour matrix of ODN3 was traced to differences in chemical and mineralogical composition, soil organic matter contents, textures, parent materials, topographic positions and most importantly, moisture regime or waterlogging, and redox reaction in the soil (Dengiz et al., 2012; Abate et al., 2014). The ODN3 soil was subject to longer period of flooding each year by the seasonal floods than ODN1 and ODN2. Hydromorphism was therefore, very obvious with mottles observed from 5 cm depth from the mineral soil surface. Common, medium, distinct, reddish brown (5 YR 5/3), light reddish brown (5 YR 6/4), gray (5 YR 6/1), and reddish gray (5 YR 5/2) mottles occurred on the second, third, fourth and fifth layers, respectively. On the sixth, seventh and eighth layers, many coarse, prominent, reddish brown (5 YR 4/4), reddish brown (5 YR 4/4) and yellowish red (5 YR 4/6) mottles were present. Mottle colours of chroma of 2 or less and hues of 5YR in some of the layers and even in the colour matrix of one of the ODN3 horizons suggested that the soils have aquic moisture regime during part of the year and gleitization is part of the soil forming process. These observations agreed with the results recorded for Onwu River floodplain soils in Cross River State, Nigeria (Akpan-Idiok and Ogbaji, 2013) and inland bottom Basement complex soils in sub-humid southwestern Nigeria (Babalola et al., 2011).

Akpan-Idiok and Ogbaji (2013), recorded grey colour matrix of chroma less than 2 and hues of 10 YR to 2.5YR in most of the horizons of Onwu river floodplain soils and suggested that the soils have aquic moisture regime for some months in the year. Similarly, Babalola et al. (2011), evaluated two wetland soils in Nigeria and reported that all the soils were mottled or gleyed and had hue of 10YR and low chroma which reflected poor drainage (aquic soil moisture) or seasonal mottling. As earlier stated, these soils are flooded annually during the annual floods that peak between September and October most years.

Since medium to coarse pores occurred all through the profiles and there was no groundwater at the time of sampling, it is obvious that the profile pits drainage condition during the dry period was good. As observed in other pedons in this study, hydromorphic influence was attributed to rise in groundwater table during the rainy season which accompanies the annual floods which affected ODN3 more, followed by ODN2 and lastly ODN1. Weak structure in the topmost layers of the Odoni soils, especially ODN3 indicated structural deterioration owing to intensive and continuous cultivation leading to disaggregation of peds. The soils of ODN3 are regularly farmed by the people.

As observed for Elemebiri soils, redoximorphic features were observed from 140 cm depth of TFN1, and 44 cm depth of TFN2 from the mineral soil surface. In TFN3 however, redoximorphic characteristics were observed only between 38 cm 66 cm depth from the mineral soil surface (Table 4.3). At 140-150 cm and 150-200 cm depths from the mineral soil surface of TFN1, dark reddish brown (2.5 YR ¾) and yellowish red (5 YR 4/6) mottles occurred, implying that these layers come under groundwater influence at certain periods of the year. Also, the occurrence of mottles from the 44 cm depth of from the mineral soil surface of TFN2 profile implied that alternate wetting and drying caused reduction and release of iron oxides resulting in the accumulation of yellowish red and dark reddish brown mottles on the surfaces of the affected layers (Akpan-Idiok and Ogbaji, 2013). It has been reported (Hossain et al., 2011) that redoximorphic features associated with flooding/wetness resulting from alternating periods of reduction and oxidation of iron and manganese compounds in soils produces mottles. The presence of many, coarse to medium pores and total dryness in the profile at the time of sampling showed that drainage was good the dry periods of the year. The presence of medium to coarse continuous pores and the dryness of the TFN2 modal profile during sampling in the month of January corroborated the fact that alternate wetting and drying of this soil occurred due to seasonal changes and rise in the water table in the rainy season, each year.

Unlike TFN1 and TFN2, variation in the colour matrix of TFN3 was attributed to differences in chemical and mineralogical composition, soil organic matter contents, texture and parent materials as the alluvium were recently deposited by the side of Forcados River. Abate et al. (2014) observed variation in soil colour within and among pedons in Ethiopia and attributed it to differences in chemical and mineralogical composition, topographic positions, soil organic matter contents, texture, parent materials, $CaCO_3$ accumulations and moisture regime or waterlogging, and redox reaction in the soil. Since the two last horizons of TFN3 were free of mottles and there was no concretional layer below the mottled layers, the mottles (redoximorphic characteristics) must have come from the alluvial materials (parent materials), that formed the layers. The change in wet consistence along the profiles with depth was attributed to change in particle size distribution of the soil, which agreed with the findings of Alemayehu et al. (2014) for southwestern lowland soils of Ethiopia. The dark surface soil colour of Trofani soils was traced to the effect of organic matter as noted previously by Dengiz et al. (2012) and Abate et al. (2014), while the occurrence of black concretions at the fifth layer of TFN1 and the second layer of TFN2 indicated previous anthropogenic activities in the area. Structural development of TFN3 was very weak due to the annual enrichment of the profile with new deposits which could be considered recent. The horizon succession of TFN3 was in the order Ap1-Ap2-C1-C2-C3-C4 and therefore defined as A-C. This means the profile has no textural B horizon and is therefore low in pedogenetic development, which qualified it as young. Also, the presence of mica flakes all through the profiles of the Trofani soils indicated the presence of weatherable minerals, implying the embryonic nature of the soils.

In the Odi soils, redoximorphic features occurred at the 135 cm depth from the mineral soil surface of ODI1, 40 cm depth of ODI2 and 3 cm depth of ODI3. The three lowest layers of ODI1 soil were subject to hydromorphic influence with mottles indicating that these layers were subject to alternate wetting and drying (Table 4.4). The colour of the first three layers of ODI2 had darker hue (10YR) but became redder (7.5YR) with depth (Table 4.4). In the case of ODI3, redoximorphism was evident from the second to the eighth layer as common, medium distinct, reddish brown (5 YR5/3), common, medium distinct, reddish brown (5 YR 5/4), common, medium, distinct, yellowish brown (5 YR 4/6), many, medium, distinct, reddish brown (5YR 4/4), many coarse, distinct, yellowish red (5 YR 4/6), many, coarse, prominent, weak red (2.5 YR 5/2) and many, coarse, prominent, reddish brown (5 YR 5/3) mottles were present in the second, third, fourth, fifth, sixth, seventh and eighth soil layers, respectively. As reported by Akpan-Idiok and Ogbaji (2013), for Cross Rivers State floodplain soils in Nigeria, the alternate wetting and drying of the soils led to reduction and subsequent release of iron oxides, accumulating in the form of strong brown, brown and red mottles on the subsurface layers of the profiles. Oxidation of iron oxides could be responsible for the reddish colour in subsoil horizons (Buol et al., 2003). Grayish coloration implied that the affected horizon was under hydromorphic influence for a longer time each year (Lawal et al., 2013). By implication, the alternate wetting and drying processes led to reduction and release of iron oxides resulting in the accumulation of light reddish brown, reddish brown and dark reddish brown mottles on the surfaces of the affected layers. Gleying (chroma of 2 or less) was observed in the two bottom layers of the ODI2 profile which indicated longer period of submergence by water. At the time of sampling which was in February, 2015 (dry season), the ODI2 soil profile was completely dry indicating that ground water influence occurred in the rainy season which accompanied the annual floods leading to rise in ground water table. The soils are flooded by the annual seasonal floods in most years which accompanied the rainy season. Even in years when the annual flood did not cover the entire land, a greater proportion of the soil was under groundwater influence due to rise in water table, creating room for alternate wetting and drying. The alternate wetting and drying process leads to reduction and release of iron oxides resulting in the accumulation of reddish brown, yellowish brown, and yellowish red mottles in the respective layers for ODI3. The dark coloration of the top soil layers of ODI1 and ODI2 soils was attributed to organic matter accumulation. Darkened surface layer of ODI3 indicated humification by organic materials (Dengiz et al., 2012; Abate et al., 2014), as the soils have been fallowed for some years. The presence of medium to coarse continuous pores in the ODI2 profile implied that the natural drainage of the profile was good enough to drain water during the dry season and the cause of hydromorphic influence is groundwater from the rains and natural flood. However, owing to rise and drop in water table in the profile, a lot of the fine pores at two the bottom layers were blocked, hence the two layers had chroma of 2 or less indicating longer period of submergence and gleitization as a soil forming process had set in. Medium to coarse continuous pores occurred also in the ODI3 profile and the profile was dry at the time of sampling with water table below the profile. Weak structure in the surface 40 to 60 cm of Odi soils was attributed to cultivation which weakened peds and such peds easily disaggregate. Again, variation in stickiness and plasticity down the ODI3 profile might not be unconnected with change in particle size distribution. Though the soil textural class is silt loam, clay content in the last two horizons was higher than the rest of the horizons. The occurrence of black concretions in the bottom layer of ODI2 and many dark concretions in the seventh and eighth layers of ODI3 suggested previous anthropogenic influence. Moreover, the occurrence of common to many mica flakes indicated the presence of weatherable minerals and that the pedons were embryonic in nature.

In the Koroama soils, redoximorphic characteristics were observed at the 115 cm depth from the mineral soil surface of KRM1, 40 cm depth of KRM2 and 12 cm depth of KRM3 (Table 4.5). For the KRM1 soils, mottles occurred on the two bottom layers of the profile which suggested that the two layers were subject to groundwater influence during the rainy season. In the KRM2 soils, value generally decreased with increase in depth indicating that moisture influence increased with depth. This can be explained by the fact that light reflection and purity of the spectral colour decreases when the soil was moist resulting in lower value. Therefore, variation in soil colour within the profile was very obvious. Whereas dark colour in the surface was attributed to organic matter content, brown, grayish brown and gray colours were due to iron compounds at various stages of oxidation/reduction reactions as the soil was subjected to alternate wetting and drying periods. Similar findings were reported by Dengiz et al. (2012) and Abate et al. (2014) who stated that variation in soil colour is related to chemical and mineralogical composition, organic matter, topographical position, texture, parent materials, $CaCO_3$ accumulations, moisture regime or waterlogging and redox reaction in the soil.

Nuga et al. (2006) asserted that drainage condition and physiographic position have influence on soil colour. Lawal et al. (2013) attributed grayish coloration in a soil profile from Southern Guinea Savanna of Nigeria to imperfectly or poorly drained condition. In this study, the colour matrix of the two bottom horizons graded from grayish brown to gray indicating imperfect or poor drainage conditions. At the 78-140 cm depth (before the bottom layer), chroma was 2 while the bottom layer had 1 as the chroma. The presence of mottles from the fourth to the bottom horizons of KRM2 and gleying of the two bottom layers corroborated the fact that the soils were under prolonged hydromorphic influence. In the KRM3 soils, dark coloration of the surface horizon was observed along with gray colour matrix and chroma of 2 throughout the profile. Dark colouration of the surface soil horizon suggested the influence of organic matter while gray colour matrix and chroma of 2 implied that KRM3 soils have aquic conditions for some months in the year. Gleitization therefore, might be part of the pedogenic processes in KRM3 as reported by Akpan-Idiok and Ogbaji (2013). The presence of black concretions in KRM1 indicated previous anthropogenic influence. Weak grade of peds and variation in the size of peds observed especially in the surface layers of Koroama soils indicates structural deterioration owing to prolonged cultivation that fragment or disaggregate peds. Variation in stickiness and plasticity within the profiles was attributed to variation in particle size distribution, as observed in other pedons. The presence of many mica flakes in the Koroama soils indicated that the soils were young with weatherable minerals.

For the Niger Delta University Teaching and Research farm soils, redoximorphic characteristics were observed at 81 cm depth from the mineral soil surface of NDU1, 36 cm depth for NDU2 and 5 cm depth for NDU3 (Table 4.6). Hydromorphic influence might not be unconnected with rise in the groundwater table during the rains (between May/June and September/October) each year, as the flood level rises. The colour shades of NDU1 included dark yellowish brown and light brownish gray. Yellowish and grayish colours were indicative of hydromorphic activities. Also, in the NDU2 soils, colour variation was very obvious. Colours varied from dark yellowish brown through brown, dark yellowish brown, yellowish brown to light brownish gray. Among the SMUs, there was no well-defined epipedon in the surface soils, except ochric epipedon. Ochric epipedon has a Munshell colour value of 4 or more when moist, and 6 or more when dry; or chroma of 4 or more; or includes an A or Ap horizon that has both a low colour value and low chroma. In addition, it also includes a horizon of organic materials that is too thin to meet the requirements of a mollic epipedon (Soil Survey Staff, 1999). Whereas ELM3 and NDU2 had value and chroma of 4 in the surface layers, the value and chroma of others were low. From the Munshell colour chart readings, the NDU3 soil colours were dark brown (10 YR 3/3), dark gray (10 YR 4/1), dark yellowish brown (10 YR 4/4), yellowish brown (10 YR 5/4), yellowish brown (10 YR 5 4) and pale brown (10 YR 6/3).

As noted for the other soils, brown colour indicated the presence of iron at various shades of oxidation and low organic matter content. Yellow colour indicates the presence of sesquioxides in hydrated forms, especially goethite while gray colour indicated soil under longer periods of submergence. It is necessary to note that the NDU3 soils are flooded by the early rains during the rainy season, hence, redoximorphism was very obvious and almost all the soil layers were mottled. The presence of mottles almost throughout the profile suggested that the soils were under aquic moisture regime. It has been reported that variation in soil colours observed within and among pedons reflect differences in chemical and mineralogical composition, topographic positions, soil organic matter contents, texture, parent materials, $CaCO_3$ accumulations and moisture regime or waterlogging, and redox reaction in the soil (Dengiz et al., 2012; Abate et al., 2014). The dark colour, in the surface horizon of these pedons was attributed to the effect of high organic matter contents, while brownish colour in the subsurface horizons reflected the presence of iron compounds in various states of oxidation and low organic matter contents (Dengiz et al., 2012; Abate et al., 2014). Gray colour on the other hand indicated long period of submergence by ground water (Dengiz et al., 2012; Abate et al., 2014), and yellowish colour matrix, the presence of sesquioxides in hydrated form, especially goethite (Lawal et al., 2013). Akpan-Idiok and Ogbaji (2013) similarly noted that the alternate wetting and drying process led to reduction and release of iron oxides resulting in the accumulation of dark reddish brown and reddish brown mottles on the subsoil surface of the profiles. Brownish gray colour in the bottom horizons indicated that the layer come under ground water influence for a longer period than the horizons above. Many, coarse to medium continuous pores were observed in NDU soils. The presence of many coarse to medium continuous pores in the profiles was indicative of the fact that the drainage condition of the profile was good during the dry periods. The presence of mica flakes in the NDU soils indicated the presence of weatherable minerals and the recentness of the soils.

4.2.2 Physical Properties of the Soils

Soil physical and chemical properties usually vary as a result of dynamic interactions among environmental factors such as climate, parent materials, topography and land cover/land use (Dengiz et al., 2006). The major physical properties of soils in this study are presented in Tables 4.7 to 4.12, and summarized in annexures 2 to 19. According to Ogbaji and Akpan-Idiok (2013), soil texture is the single most important characteristic which control water infiltration, influence soil chemical reactions, potential erosion factor and soil nutrient availability. Soil-plants relationships, to a large extent are influenced by soil texture. Several other soil properties are also affected by texture, especially properties relating to surface area and packing ratio as well as pore size. Fine textured soils for instance, are known for their good water retention properties, facilitate soil chemical reactions, store and release more nutrient elements and increase organic matter content. Soils with high clay content increase potential for formation of aggregates and macro-aggregates protect organic matter molecules from total mineralization by microbes. Coarse textured soils on the other hand, have good drainage characteristics and are resistant to erosion hazard. Therefore, the importance of soil texture in the characterization of river plain soils cannot be overemphasized.

Hazelton and Murphy (2007), rated sand, silt and clay contents of soils into high (>40%), moderate (25-40%) and low (10-25%). Based on Hazelton and Murphy ratings, silt was rated high in pedons ELM1 and ELM2 but low to moderate in ELM3, sand was rated high in

ELM3 but low to moderate in the surface 40 cm and subsurface of ELM2. Clay was rated low to moderate in the surface and subsurface layers of ELM1, while the remaining layers were rated low (Table 4.7). The high silt concentration in ELM1 and ELM2 agreed with the Mutter (1973) report on the Lower Niger soils which indicated that the levee soils were flooded to shallow depths (less than 2 m annually from August to November when the Niger River flood is in its high peak. The back swamp soils and the clay plain soils are flooded annually to greater depth (up to 5m). They are poorly and very poorly drained, mottled silty clays and clays, which receive a load of silt annually, due to flooding. In another development, Abua (2012) not only associated high soil silt fraction to good aggregation and high absorptive capacity but reported that soils with high sand fraction exceeding 70% implies that the mean silt content is below 15% and such soil would have weak surface aggregation.

The soil may lack adsorptive capacity for basic plant nutrients and may be susceptible to erosion menace while silt fraction greater than 15% for both top and sub soils indicated that the soils have strong surface aggregation and may not be vulnerable to erosion hazard. In the ELM1 and ELM2 SMUs, silt content of the surface 40 cm and subsurface layers were greater than 50% which means the soils have high adsorptive capacity, strong surface aggregation and may not be vulnerable to erosion hazard. Silt and clay content was low in ELM3 SMU located at the centre of the present actively flowing lower Niger River implying that coarse materials carried by the Niger River current were deposited there. Across the profiles, ELM1 recorded the highest clay content (31%) and ELM3 the lowest clay content (2%). Although an increase in clay content in the B-horizon of ELM1 occurred, clay skins (cutans) were not found on sides of the ped surfaces which implied that clay illuviation did not bring about the increase in clay content. The high clay content was attributed to in-situ weathering of the parent material. This agreed with earlier findings (Alemayehu et al., 2014) in Ethiopia which recorded increase in clay content in the B-horizons of Pedon 1 and 3, but found no cutans in the ped surfaces of Abobo soils in the south-western lowlands of Ethiopia. The study thus attributed clay increase to in-situ weathering of the parent materials.

Essoka and Esu (2000) reported increase in clay content with soil depth indicating that some clay had migrated by lessivage. Generally, the distribution of sand, silt and clays in the profiles was irregular which could be attributed to differences in sediments types with differing textures deposited yearly according to their sources (Azagaku and Idoga, 2012). Egbuchua and Enujeke (2013), in Nigeria reported that the irregular profile depth distribution of clay fractions for vertisols of Lake Chad Basin was an indication of stratification of the fluvial parent materials, while high silt contents were attributed to low intensity of weathering in the semi-arid environment. Textural class distribution in the profiles showed silt loam as the dominant textural class in the ELM1 and ELM2 and loamy sand and sandy loam in ELM3. Variation in textural class distribution down the profile occurred in ELM1 and ELM3. In ELM1, the first two surface layers were silt loam, followed by silty clay loam in the next two layers and then silt loam in the remaining soil layers. Texture of ELM3 varied from loamy sand through sandy loam, loamy sand to sandy loam. This further confirmed the fact that different types of sediments with different textures were deposited yearly according to their sources. The dominance of loam in the textural class of most of the soils indicated good infiltration rate and medium water holding capacity to sustain the commonly cultivated crops. In the ELM3 and TFN3 soils however, sand dominated the texture which is a good indication of observable high infiltration rate and low water holding capacity of the soils, whereby resulting into moisture stress as reported by Senjobi (2007) and Senjobi et al. (2016). During the time of soil sampling between January and March, farmers were seen pumping water from the Lower Niger River and Forcados River to water their crops at Elemebiri and Trofani, respectively.

Alemayehu et al. (2014), reported increased silt/clay ratio with depth of profiles that followed opposite pattern of variation with clay particles. In the Elemebiri SMUs, the distribution of silt/clay ratio was irregular with depth but silt/clay ratio increased with increase in silt content and vice versa. Higher silt/clay ratio in the surface layers indicated recent annual enrichment of the surface through deposition by the annual floods. In the case of Ethiopian soils, Alemayehu et al. (2014), reported high silt/clay ratios (2:1) in the subsoil layers along resistant skeletal composition of parent materials reflecting that the soils at the upper-slope position were at an embryonic stage of development. In this case, the levee crest, levee slope and soils on the present active Niger River of Elemebiri were at the early stage of development.

A close look at the particle size composition of Odoni soils showed a regular distribution of textural classes of soil in all the SMUs. For instance, surface and subsurface soil textures of ODN1 were silt loam as well as the surface textures of ODN2 and ODN3 (Table 4.8). Of the seven horizons delineated in ODN 2, the top five layers were silt loam while the remaining two bottom layers were loam. Of the eight horizons delineated in ODN3, the first four horizons from top were silt loam, the two horizons following them, silty clay loam and the remaining two, loam. The soils did not show so much variation, possibly because the alluvial deposits came from similar sources and soil development was still in the early stage. In southern Cross River State of Nigeria. Abua (2012) recorded dissimilar trend of variation in the texture of soils and attributed it to differences in parent material and topography. However. irregular distribution of the clay fraction with depth indicating stratification associated with fluvial parent materials and the recentness of the deposits which were yet to undergo serious soil development. Obviously. there was no sign of clay illuviation from surface horizon to subsurface horizon supporting the fact that the soils are young and soil development is not in advanced stage.

It has been reported (Egbuchua and Ojobor. 2011) that "old" parent materials usually have silt/clay ratio below 0.15 while silt/clay ratio of above 0.15 are indicative of young" parent materials. Silt/clay ratios of surface and subsurface soil horizons in all the Odoni soils are far higher than 0.15 indicating that the soils were relatively young with high potential for weathering.

The textural classes of TFN1and TFN3 were fairly uniform. This can be attributed to the fact that the deposits were either of the same source or similar. and soil development was still in the early stage. On the other hand. variation in textural classification down the profile was noticeable in TFN2 (Table 4.9) which may be attributed to differences in parent material sources and texture. No clay illuviation from surface to subsurface horizons was noticed. corroborating the fact that the soils were young and soil development is still at the early stages. However. there was irregular distribution of the clay fraction down the profiles indicating stratification which is associated with fluvial parent materials as the soils were of recent origin and profile development is not yet advanced. In these soils. movement of clay from A to B was not noticed. confirming that the soils were young. Movement of clay from A to B horizons in soils generally suggests the occurrence of argillic horizon. which is an indication of advanced stage of soil development (Sutton and Loganathan. 1986). According to Egbuchua and Ojobor (2011). silt/clay ratios of any given soil below 0.15 was an indication that such soil was of old parent material. while those above 0.15 were of young parent materials with low degree of weathering. It is indisputable the fact that all the soil layers from Trofani recorded silt/clay ratio of far more than 0.15 confirming that the soils were of young parent materials with great potential for weathering to release nutrients in future. The dominance of silt sized particles in the profiles indicated that the soils were young and had potential for weathering and other soil forming processes to release nutrients for plant use in the future. The soils showed no movement of clay from surface horizons to the B horizon confirming that the soils were young and soil profile development was in the early stages. Strong illuviation of clay from A to B horizons in soils, generally results in the development of argillic horizons, which indicate advanced stage of soil development (Sutton and Loganathan, 1986).

Silt loam textural class dominated the ODI soil textural class. From the surface layer of ODI3 to the bottom, all the horizons were silt loam while ODI2 had loam as textural class of the first two layers and silt loam in the remaining layers. The textural class of ODI1 soil varied between silt loam and loam down the profile (Table 4.10). Dissimilarity in the trend of texture of soils has been attributed to differences in parent material and topography (Abua, 2012). The textural class distribution of the soils from Odi showed no marked variation which means the chemical and physical characteristics of the parent materials were not very different. Whereas ODI3 was silt loam from surface to bottom of the profile, ODI1 and ODI2 soils varied between silt loam and loam (Table 4.10). Silt/clay ratios in the Odi soils ranged from 2.1 to 5.4 for ODI1, 3.2 to 4.8 for ODI2 and 3.3 to 7.1 for ODI3, suggesting that the soils were still very young and were yet to undergone ferralitic pedogenesis.

Using the ratings of Hazelton and Murphy (2007), silt was rated high in the surface and subsurface layers of all pedons, sand low to moderate in the surface layers of KRM2 and KRM3, and clay rated low to moderate in the surface and subsurface layers of KRM2 and KRM3 (Table 4.11). The high silt content recorded for these soils agreed with the report of land Resources Development for Lower Niger River floodplains. Moreover, Abua (2012) reported that soils having silt fraction greater than 15% for both top and sub soils indicated that such soils have strong surface aggregation and may not be vulnerable to erosion hazard. The silt concentrations of Koroama soils (KRM1, KRM2 and KRM3) at the top and sub soil layers were far higher than 50% which may well mean that these soils have strong surface aggregation and might not be not vulnerable to erosion. Among the profiles, the lowest clay content was recorded in KRM2 (9%) and the highest in KRM3 (30%). Though increased clay concentrations was noticeable in the lower layers of KRM2 and KRM3, no cutans were found which indicated that the increased clay was not connected to clay illuviation from upper horizons to lower layers but in-situ weathering of parent materials. As in other cases, sand, silt and clay distribution in the profiles showed irregularity which might not be unconnected with sediments types having different textures deposited yearly according to their sources (Azagaku and Idoga, 2012). Textural class distribution in the Koroama soil profiles showed silt loam as the dominant textural class as in the other soils. However, slight variation in textural class distribution down the profile occurred in KRM2 and KRM3 (Table 4.11). In KRM2, texture varied from silt loam in the first two top layers to silty clay loam in the two layers that followed and to silt loam in the succeeding layers. In KRM3, texture similarly varied from silt loam in the surface two layers to silty clay loam in the following layers back to silt loam in the succeeding layer. This again confirmed that different sediment types having different textures were deposited yearly according to their sources form the parent materials of Koroama soils.

Essoka and Esu (2000), reported that silt/clay ratio of less than unity indicates low values and could mean that the soils are pedogenetically ferralitic in nature. In the Koroama soils, silt/clay ratio of the surface 40 cm varied from 4.1 to 4.6 (4.4, mean), 1.9 to 7.4 (5.4, mean) and 4.0 to 6.8 (5.4, mean) for KRM1, KRM2, and KRM3 while in the respective subsurface layers, silt/clay ratio varied from 3.2 to 4.6 (3.7, mean) 1.8 to 5.8 (4.4, mean) and 1.8 to 2.3 (2.1, mean). The values suggest that Koroama soils are yet to undergo ferralitic pedogenesis. Alemayehu et al. (2014), in Ethiopia reported high silt/clay ratios (2:1) in the subsoil layers along resistant skeletal composition of parent material reflecting that the soils at the upper-slope position were at the young stage of development. On the other hand, Esayas (2005), reported low silt ratio in the subsoil layers indicating that the soils were at advanced stage of development. The high silt/clay ratio in the surface layers of KRM3 indicated recent annual enrichment of the surface through deposition by the annual floods. High silt/clay ratio in the subsurface layers indicated that the soils were still young. Nwaka and Kwari (2000), observed that in sandy soils, high silt/clay ratio may be related to the coarse texture or resistant skeletal composition of the parent material and youthfulness of the profile.

Using Hazelton and Murphy (2007), ratings, silt is rated high for all the layers in all the pedons, clay is rated low to moderate in the top and sub soil layers of NDU1 and NDU2 but low in NDU3 while sand is rated low in all the pedons (Table 4.12). Since the silt concentration in both top and subsoil layers in all the pedons is far above 50%, the NDU soils may have strong surface aggregation and have qualities that resist erosion hazard. Abua (2012), reported that soils with silt fractions greater than 15% for both top and sub soils is an indication of soil having strong surface aggregation and such soil may not be vulnerable to erosion hazard. Across the soil profiles, NDU1 recorded the lowest (7%) and highest (30%) clay concentration. Though increase in clay concentration was noticed in the B-horizons of NDU2 and NDU3, no cutans presence was observed. The clay increase recorded in those horizons might not be connected to agillation but in-situ weathering of the parent materials.

Sand, silt and clay distribution in the profiles were irregular which might be traced to different sediments types having different textures deposited yearly according to their sources (Azagaku and Idoga, 2012). Silt loam class dominated the soil textural class distribution followed by silty clay loam in the NDU soils. For instance, NDU3 was silt loam all through the profile while in NDU1 and NDU2, texture varied from silt loam to silty clay loam and to silt loam.

Silt/clay ratios of NDU soils ranged from 2.0 to 10.4 for NDU1, 1.9 to 5.0 for NDU2 and 3.5 to 4.9 for NDU3 which are far above unity. The silt/clay ratios of NDU soils suggested that the soils were young.

4.2.3 Chemical Properties of the Soils

The pH values of the soils fall within the moderately acid to neutral classes (Tables 4.13 to 18 and Annexures 2 to 19) according to categorization by Fertilizer Procurement and Distribution Department (FPDD) (2012) and Jones (2003). FPDD categorization of Bayelsa State soils into pH classes indicated that soils with pH values between 5.0 – 5.5 are strongly acid, 5.6 -6.0 as moderately acid and 6.0 – 6.5 as slightly acid, 6.6-7.2 as neutral and 7.3-7.8 as slightly alkaline. Using this categorization, topsoil layers of ELM1 (5.46), ELM2 (5.44) and NDU3 (5.42) as well as subsurface layers of ELM3 (5.31), ODN1 (5.33), ODN2 (5.18) and KRM3 (5.48) fall into strongly acid soil category while the remaining soils (surface layers of ELM3, ODN1, ODN2, ODN3, TFN1, TFN2, TFN3, ODI1, ODI2, ODI3, KRM1, KRM2, KRM3, NDU1 and NDU2 as well as the subsurface layers of ELM1, ELM2, ODN3, TFN1, TFN2, TFN3, ODI1, ODI2, ODI3, KRM1, KRM2, NDU1, NDU2 and NDU3) were slightly acid to neutral. Wong et al. (2001) opined that the optimum pH for most agricultural crops fall between 6.0 and 7.0 because nutrients are more available at about pH 6.5. According to FAO (2006), and Brady and Weil (2005), a pH range of 5.5 to 7.0 is the preferred range for most crops because it is optimal for the overall satisfactory availability of plant nutrients. Using this pH range, only the soil samples from the above listed layers fall below the 5.5 to 7.0 range indicating that the soils pH generally was suitable for most crops.

Using the classification by Jones (2003), the top 40 cm layers and the subsurface soil layers were slightly acid to neutral. On their suitability for the cultivation of most crops (Landon, 1991), both the surface 40 cm and subsurface layers were suitable. Generally, the soils were less acidic especially in the subsoil layers as compared to soils from Coastal plain sands and Sombreiro-Warri deposits in the Niger Delta reported by Sutton and Loganathan (1986).

Sutton and Loganathan characterized upland soils of Rivers State and reported that soils from the Meander belt deposits were less acidic than soils from the Coastal plain sands and the Sombreiro-Warri Deposits because of the nature of deposits and the shorter period of leaching influence of the relatively younger meander belt levee soils. Increase soil pH values with increase in depth have been attributed to downward translocation of basic cations and leaching Abate et al. (2014). The results of this study showed noticeable increase in soil pH with increasing soil depth especially within the top 40 cm depth suggesting that there was leaching loss of nutrients with the heavy rainfall experienced in the area. Khan et al. (2012) attributed this to ferrolysis which is acidification of topsoil caused by continual displacement of bases by ferrous ion during the reduction phase associated with annual flooding. Flooding occurs annually in this environment which comes with the long rainy season.

ΔpH values have been used to estimate the level of negatively charged clay colloids present in soil (Alemayehu et al., 2014). Usually, the value of ΔpH can be positive, zero or negative, depending on the net surface charge of the soil. A positive ΔpH indicates the presence of negatively charged soil colloids (Soil Survey Staff, 2006). The positive values indicated that the soils were all negatively charged. According to Papienik et al. (2007) and Alemayehu et al. (2014), higher ΔpH values for A-horizon that is positive, indicated the presence of appreciable amount of negatively charged clay colloids. In this study, ΔpH values (pH-H_2O – pH-$CaCl_2$) were positive for all the horizons from the various SMUs, ranging between 0.04 and 2.09 units. ΔpH values of soil layers within the top 40 cm varied between 0.09 to 1.83 units (Tables 4.13 to 18 and Annexures 2 to 19). The layers with higher ΔpH values are likely to have higher amounts of negatively charged clay colloids. This is to be expected because of the short period the soils have been exposed to weathering and leaching influence. The positive ΔpH values implied that the soils were relatively young, corroborating the silt clay ratio results.

The electrical conductivity (EC) values of the soils across all the pedons were found to be well below unity (Tables 4.13 to 18 and Annexures 2 to 19). The EC values show that the soils were non-saline and salinization was not a pedogenetic process within the areas studied. Going by Esu (2010) classification of saline soils, soils in the studied area could be categorized under non- saline soils. The low EC values recorded for these soils could be traced to parent materials (Abate et al., 2014) and the fresh water environment the soils were located.

Most soils are of mineral origin, but their top soils contain high organic matter. In spite of mineral soils low organic matter content: organic matter is of great importance to many aspects of soil fertility and plant growth. Soil organic matter can range from less than 1 percent in many tropical arid and semi-arid soils of the plain to 5 percent or more in temperate regions or under forest vegetation (FAO, 2006). Organic matter actually, is known to account for high soil nitrogen and phosphorus. (Akbar et al., 2010; Aiza et al., 2013).

The results of organic carbon and organic matter in the soils from the mapping units were presented in Tables 4.13 to 18 while in annexures 2 to 19 were the summaries of the physical and chemical characteristics of soils. The Fertilizer Procurement and Distribution Department (FPDD) (2012) rated organic matter concentration for surface 40 cm soils of Bayelsa State as less than 0.51% (very low), 0.51-1.27 (low), 1.27-1.78% (medium), 1.78-2.55% (high) and greater than 2.55% (very high). Based on the ratings given by FPDD for Bayelsa State soils, Nigeria, surface layer organic C and organic matter levels of the SMUs were medium to very high except ELM2 (0.71%) which was below the medium mark given by FPDD for Bayelsa soils. Organic carbon (5.25%) and organic matter (9.05%) levels of the 0-3 cm layer of ODI3 (Table 4.3) was rated very high which was attributed to accumulation of organic materials over time in the area. Using the mean values obtained in the surface 40 cm, the concentration of organic C in ELM2 was low according to the values given by FPDD but moderate to very high in the rest sampling locations. Using the ratings by Landon (1991) on the other hand, organic C and indeed organic matter concentration in the soils generally were very low to medium. In the Landon ratings, less than 2% is very low, 2-4% (low), 4-10% (medium), 10-20% (high) and greater than 20% (very high).

Generally, organic carbon and organic matter concentration in the soils of the study area decrease irregularly with increase in soil depth which agreed with the findings of Idoga and Azagaku (2005) and Atofarati et al. (2012), in Nigeria and Abate et al. (2014) and Alemayehu et al. (2014) in Ethiopia. Khan et al. (2012) reported organic C decrease with depth for soils of Bangladesh and generally low organic C content. The low organic C content in Bangledesh soils was attributed to rapid decomposition of organic matter under hyperthermic temperature regime. The low to moderate soil organic matter concentration, which decreased with increasing depth in most of the SMUs, was ascribed to low biomass return to the soil, owing to the short fallow periods coupled with the bush burning cultural practice which destroy most of the organic materials. Moreover, organic matter mineralization rate is high due to high temperature and heavy rainfall in this environment.

All the SMUs fall under the iso-hyperthermic temperature regime. In Ethiopian, Alemayehu et al. (2014), obtained low to medium organic matter concentration in soils and attributed it to long-term cultivation coupled with frequent burning of crop residues (common land clearing practice for cultivation) which accelerated turnover rates of organic materials of soils under cultivation. Adamu et al. (2015), also recorded low levels of organic matter related properties in a Tanzanian soil and attributed it partly to rapid organic matter mineralization and frequent bush burning in the area, commonly carried out in the dry season which destroys valuable organic materials that add to organic matter.

It is interesting to note that bush burning is the main method of bush clearing in the study area which most likely contributed to the lowering of the organic carbon content. Moreover, continuous cultivation with short fallow periods is now a normal agricultural practice in the study area which hitherto practiced land rotation as a means of restoring soil fertility. Increase in population led to fallow periods being shortened. The soils in mapping units ELM3 and TFN3 are almost always cultivated every other year due to continuous yearly supply of alluvium by the annual floods. Sanchez (1976), earlier noted that organic matter content can get reduced significantly when the soils are subjected to continuous intensive cultivation. The surface layers of ODN2 contained lower organic C than the underlying layer which was attributed to the prevalence of warm climate which enhances decomposition of organic matter in the surface layer (FAO, 2006). The higher organic C content in the layer underlying the surface layer of ODN2 was further attributed to long-term cultivation coupled with frequent burning of crop residues (common land clearing practice for cultivation) which accelerated the rapid turnover rates of organic materials under cultivation.

Generally, total N distribution in the profiles decreased with increase in depth (Tables 4.13 to 18 and Annexures 2 to 19) revealing that organic matter is the main source of total N in the soils. Relationship between organic C and total N has been established (Adeyanju, 2005). The total N contents of the studied soils were directly associated with organic C contents along soil profile depths, as the highest (0.45%) value was recorded in the surface layer of ODI3 soil from Odi designated 'Ah' where the highest organic C content (5.25%) was recorded. The total N content in all locations, except ELM3 and ODN2 were higher in the surface soil layers than the underlying horizon, which is attributed to higher organic C contents in the surface. The higher total N content in the layer underlying the surface layer of ODN2 soil may be attributed to long-term cultivation coupled with frequent burning of crop residues (a common land clearing practice for cultivation) which accelerated the rapid turnover rates of organic materials under cultivation since total N in the soils is closely associated with organic C. Studies in Ethiopia (Habtamu et al., 2009; Alemayehu et al., 2014), confirmed that bush burning and removal of crop residue significantly reduce soil organic carbon and total N contents as cultivated and uncultivated land were compared. This indicated high N release from the organic matter sources since soil N is positively associated with soil organic matter content. On the other hand, when compared to the ratings by Fertilizer Procurement and Distribution Department (FPDD) (2012) for Bayelsa State (0.3-0.5, very low, 0.6-1.0, low, 1.1-1.5, moderately low, 1.6-2.0, medium and 2.1-2.4, moderately high, and the critical value of 0.2% recommended by Enwezor et al. (1989), for Nigerian soils, the total N level in the samples was very low. Comparing with the Enwezor et al. (1989) recommended critical level, only 0-8cm layer of ELM1, 10-21cm layer of ODN2, 0-5cm layer of ODN3 and 0-3cm layer of ODI3 meet the critical N level out of the 122 soil layers encountered. This is in line with the report of Olaleye (1998), that N is normally deficient in most wet soils for growing rice. The low N values recorded may be associated with high rate of organic matter mineralization and leaching coupled with intermittent flooding and drying which is known to favour N loss through nitrification-denitrification processes (Brady and Weil, 2005).

In another development, Hartz (2007), reported that soils with less than 0.07% total N have limited N mineralization potential, whereas those having total N values greater than 0.15% would be expected to mineralize sufficient amount of N during the succeeding crop cycle. Using the Hartz (2007) ratings of <0.07% total N, the surface 40cm depth of ELM1, ODN2, ODN3, TFN1, TFN3, ODI3, KRM1, NDU2 and NDU3 have high mineralization potential while ELM2, ELM3, ODN1, TFN2, ODI1, ODI2, KRM2, KRM3 and NDU1 have low mineralization potentials (Tables 4.13 to 18 and Annexures 2 to 19). Furthermore, using the >0.15% rating, only the surface 40cm depth of ELM1 and ODI3 are expected to mineralize sufficient amount of N during the succeeding crop cycle which is not good for the succeeding crops. Most of the soils may therefore require N applications for successful crop production during each crop cycle.

The results of carbon to nitrogen ratio (C/N) showed irregular distribution with soil depth and topographical position in most of the soils (Tables 4.13 to 4.18). In most layers of the soils from ELM1, ELM2, ELM3, ODI1, KRM1, KRM2, KRM3, NDU1, NDU2 and NDU3, C/N ratio especially in the plow zone was relatively higher than the common range (8:1 – 15:1) proposed by Brady and Weil (2005) for arable soils. Using the 'optimum' range (10:1 - 12:1) for arable soils (Havlin et al., 2006) only ODN2, ODN3, TFN1, TFN3, ODI2, and ODI3 soils were within the range which means oxidation and loss of organic matter in the plow layers of most of the SMUs was not very rapid which is safe for the soils considering the important role organic matter plays in the retention of soil nutrients.

Also, available P concentration decreased with increase in soil profile depth in all the SMUs which showed a close relationship between organic matter and soil P except in NDU1, NDU2 and NDU3 (Tables 4.13 to 18 and Annexures 2 to 19). McCauley et al. (2017), identified organic matter as the principal source of soil P for many soils. The available P levels recorded for NDU1, NDU2 and NDU3 however, agreed with the figures recorded by Sutton and Loganathan (1986) for Mbiama-Kaiama soils which also fall into the Meander Belt Deposits. Abate et al. (2014), in a study of soils along a toposequence in Ethiopia reported that available P showed an increasing trend down the topographic position and a decreasing trend with depth which they attributed to an increase in clay content and a decrease in soil organic matter content. In this study, soil organic matter content in the various horizons showed positive relationship with available P as both of them decreased with depth indicating that P decrease was due to decreasing concentration of organic matter with depth. The low available P levels in NDU1 NDU2 and NDU3 (Tables 4.13 to 4.18 and Annexures 2 to 19) however, might be attributed to high exchangeable acidity in these soils in comparison to total exchangeable bases.

The Fertilizer Procurement and Distribution Department (FPDD) (2012) rating of available P (Bray-1-P) for Bayelsa Soils was <3-very low, 3-7 low, 7-20 moderate and >20 high. Using the FPDD ratings, available P level in all the soils generally were moderate except the soils from the Niger Delta University Teaching and Research farm. The results also revealed that mean available P levels in the surface 40 cm soil depth of the profiles were relatively higher than the levels in the subsurface layers. (Havlin et al., 2006) gave soil pH range of 6.0 to 7.5 as ideal pH range for P availability. Similarly, Alemayehu et al. (2014) considered high soil available P concentration as a reflection of slightly acidic to neutral soil reaction and low contents of exchangeable Al. From the FPDD Fertilizer Procurement and Distribution Department (FPDD) (2012) categorization of soil pH in Bayelsa State, only the topsoil layers of ELM1 (5.46), ELM2 (5.44) and NDU3 (5.42) as well as subsurface layers of ELM3 (5.31), ODN1 (5.33), ODN2 (5.18) and KRM3 (5.48) fell within the strongly acid soil category while the remaining soils were moderately acid to neutral. It is obvious that Havlin's 6.0 to 7.5 ideal pH ranges for increased P availability were not applicable to these soils. In line with the strongly acid to neutral pH values obtained, high exchangeable acidity values in comparison to total exchangeable bases were recorded in these soils. Moreover, the distribution of P in the profiles showed no regular pattern of decrease which agreed with the findings of Nuga et al. (2006). This could be due to P fixing capacity and the slow release by the soils as a result of the relatively high level of iron and aluminium oxides in the soils. Low P availability in tropical soils attributed to the nature of the chemical forms of soil P and the high content of oxides of Fe and Al which are associated with high P fixation. Ching et al. (2014), also noted that soils high in sesquioxides could experience high P fixation and such situation could be a hindrance to crop production. Consequently, P is likely to be one of the most limiting nutrients for crop production in these soils. However, Dickson et al. (2002), obtained P values ranging from 10 – 30 mgkg^{-1} in the top 40 cm of Oruma soils in Bayelsa State which was attributed to marine intrusion in the past (Kogbe et al., 1975) since Oruma is fairly close to brackish water area. Other researchers (Abate et al., 2014); (Sutton and Loganathan, 1986); and (Akpan-Idiok and Ogbaji, 2013) recorded similar results.

The physico-chemical results summarized in annexures 2 to 19 showed that Ca^{++} was the dominant cation in the exchange complex. When the mean values obtained in this study were compared with FAO (2006) ratings for Ca^{++} and Mg^{++}, the results indicated that surface 40 cm and subsurface exchangeable Ca^{++} in soils were very low while exchangeable Mg^{++} contents were low to medium based on the same rating. Low exchangeable bases in soils (Ca, Mg, K and Na) have been attributed to acidifying properties of organic matter, high aluminium concentration and leaching loss of exchangeable bases (Tisdale et al., 2004). The low exchangeable Ca and Mg in these soils was attributed to lack of ferromagnesian minerals, low nutrient retentive capacity, high exchangeable Al and Fe and leaching loss of the nutrients due to high rainfall. The X-ray diffraction results (Table 4.20) showed that these soils were low in ferromagnesian minerals. Biotite and vermiculite were the only ferromagnesian minerals found in the soils and their concentrations were low. Biotite was found in low concentrations in TFN1, TFN2, TFN3 and KRM1 only while vermiculite was detected in all the samples except ELM1, ELM2 and ODN3 though all was in small concentrations. The absence or low concentration of the ferromagnesian group of minerals known to supply Ca and Mg to soils probably was the main reason for the low levels of the nutrients.

The accumulation of Mg^{2+} over Ca^{2+} on the exchange complex of some of the soils is unfavourable because soils with high Mg tend to have poor structure (Lawal et al., 2013; Sharu et al., 2013). According to Garcia-Ocampo (2003), accumulation of Mg in soil causes deterioration of soil structure, lower water intake rates and affects chemical and biological properties of soils. Appropriate Ca/Mg ratios in soils will improve soil structure, reduce leaching loss of other nutrients, reduce weed population and generally improve the balance of most nutrients (Sharu et al., 2013). It has been reported also that, under gleization process of soil formation, exchangeable Mg^{2+} becomes the dominant cation in the exchange complex (Khan et al., 2012). From the results, the Ca^{2+}/Mg^{2+} ratio of ELM1 (surface and subsurface), ELM3 (surface), ODN1 (surface and subsurface), ODN2 (surface and subsurface), ODN3 (subsurface), TFN1 (subsurface), TFN3 (surface and subsurface), ODI1 (subsurface) ODI2 (subsurface), KRM1 (subsurface), KRM2 (subsurface), KRM3 (subsurface) NDU1 (surface and subsurface) and NDU2 (subsurface) fell below the "optimum" (2 – 4:1) value as proposed by Landon (1991), for most crops. Landon reported that Ca^{2+}/Mg^{2+} ratio below 3:1 results in unavailability of Ca and limitation of Ca uptake by crops due to excess amount of Mg. In this case, only ODI1 (surface), KRM1 (surface) and NDU3 (subsurface) would meet Landon's ratio of 3:1. It is possible the alluvial deposits from which these soils were formed were low in exchangeable Ca as the soils were considered to be in their early stages of development. The Ca^{2+}/Mg^{2+} ratio of less than unity indicated loss of Ca^{2+} due to gleization (Khan et al., 2012). Buol et al. (2001), reported that the Ca^{2+}/Mg^{2+} ratio in soils decreases with increasing maturity.

Exchangeable K in the soils (Tables 4.13 to 4.18) unlike exchangeable Ca and Mg varied from low to very high (FAO, 2006). Most of the average values fell within medium to very high rating of FAO (2006), and Fertilizer Procurement and Distribution Department (FPDD) (2012) indicating that most of the soils have sufficient K for crop growth. This is understandable because common to many and/or abundant mica flakes were seen during the field sampling. According to FAO (2006), rating for exchangeable K, soils with exchangeable K greater than 1.2 is very high, 1.2 - 0.6 high, 0.6 – 0.3 medium, 0.3 - 0.2 low and less than 0.2 very low. Comparing the mean K values obtained in this study with FAO (2006) rating, K concentration in ELM1 (surface), ODN3 (subsurface), ODI1 (surface), ODI2 (surface and subsurface) and TFN2 (subsurface) was high, medium in ELM1 (subsurface), ELM2 (surface and subsurface), ELM3 (surface and subsurface), ODN1 and ODN2 (surface and subsurface), ODN3 (surface), TFN1 and TFN3 (surface and subsurface), TFN2 (surface), ODI3 (subsurface), KRM1 (surface and subsurface) KRM3 (subsurface), NDU2 (surface) and NDU3 (subsurface) and low in ODI3 (surface), KRM2 (surface and subsurface), KRM3 (surface), NDU1 (surface and subsurface), NDU2 (subsurface) and NDU3 (subsurface). Of the six sites studied, the Elemebiri study location situate by Niger River, Odoni and Odi by the Nun River and Trofani by Forcados River. Koroama study site was located by Taylor Creek and the NDU study location situates by Igbedi River, which are tributaries to the Nun River.

The K concentrations in most of the soils from Koroama and Niger Delta University which were further away from the Niger River were low to medium while most of the samples from Elemebiri (ELM), Odoni (ODN), Odi (ODI) and Trofani (TFN) which were either on the Niger River or close to the Nun River Forcados bifurcation were medium to high. This development is difficult to explain since mica flakes presence was recorded in all the profile pits. This development might be attributed to lack of ferromagnesian minerals in the soils. It is important to note that the presence of muscovite was dominant over biotite in the soils. On the other hand, Fertilizer Procurement and Distribution Department (FPDD) (2012), rating of K concentration for the soils of Bayelsa State are 0.12-0.2 very low, 0.21-0.3 low, 0.3-0.6 moderate and 0.61-0.73 high. Comparing the average K values of the surface 40 cm and subsurface layers in this study (annexures 2 to 19) and the FPDD ratings for soils of Bayelsa State. K concentration in the Surface 40 cm of ODI3, KRM2, KRM3, NDU1 and NDU3 and the subsurface layers of KRM2, NDU1 and NDU2 were low while K concentration in the remaining twenty eight (28) samples were moderately high to high. In spite of the presence of visible mica flakes and high total K values, Sutton and Loganathan (1986) reported low K values in the Meander Belt soils which they attributed to low exchange capacity and high exchange acidity.

It is possible that more K-rich alluvial materials were deposited in the lower Niger River (ELM1) and the surrounding areas (ODN, ODI and TFN). KRM and NDU sampling sites were further down and are tributaries of the Nun River (Figure 3.1). Dickson et al. (2002) however, recorded very high exchangeable K levels for Oruma soils and attributed it to high CEC and the presence of easily weatherable minerals rich in K such as biotite, feldspar, vermiculite and muscovite as reported by Loganathan et al. (1995). In spite of the low CEC values across the sampling locations, medium to high K values were recorded in most of the sites which could be attributed to the presence of easily weatherable minerals rich in K. The concentration of Na in soils from all the SMU's was rated low which agreed with the observations of previous researchers in the area (Sutton and Loganathan, 1986; Loganathan et al., 1995; Dickson et al., 2002). More so, all pedons irrespective of study location and topographic positions were very low in electrical conductivity. The results of electrical conductivity corroborated the results of concentration of the exchangeable cations, especially Na. However, some level of variation in the distribution of basic cations down the profiles was observed which is attributed to differences in the source of the alluvial materials that formed the horizons rather than movement of nutrients from the top to the lower horizons since these soils were young and no marked clay illuviation was noticed.

Sum of the exchangeable bases in the soils was low which reflected the low concentration of basic cations in the soils. Effective cation exchange capacity of the soils across the SMUs was generally low when compared to the figures given by Esu (1991). Esu recorded low exchangeable bases in Hadejia alluvial complex in Nigeria and attributed it to low CEC. Low values of Ca, Mg and K have however been reported for most Nigerian soils (Akinirinde and Obigbesan, 2000; Uzoho et al., 2007), which was attributed to leaching losses by the high tropical rainfall as well as low content in the parent rock. The ECEC values recorded in this study were lower than the 15 cmol/kg reported by Udo et al. (2009), as the critical ECEC value for tropical soils. However, most of the soils have ECEC (cmolkg^{-1}) values of 4 and above which was the value Sanchez considered as having the ability to withstand heavy leaching losses of nutrients in tropical soils (Sanchez, 1976). Sanchez in his book on "Properties and Management of Soils in the Humid Tropics asserted that tropical soils with ECEC values of 4 cmolkg^{-1} and above could withstand heavy leaching loss of nutrients. From the figures above, majority of soils in the surface 40 cm depth have enough ECEC to withstand heavy leaching loss of nutrients.

Out of the 122 samples, the exchangeable acidity values of 66 samples were below the critical value of 2.0 cmolkg^{-1} (Tables 4.13 to 4.18) which indicated slightly to strongly acid nature of the soils (Ernest and Onweremadu, 2016). The acidic nature could be attributed to the humid nature of the environment which is characterized by intense rainfall and its leaching effect. This may account for the low concentration of exchangeable bases in the soils. Since the alluvial soils were of sedimentary origin and may not have gone through very prolonged period of weathering and leaching loss of basic cations, it is possible that the parent materials from which the soils were formed have acid characteristics. Aluminum ions cause acidity by hydrolysis reaction while hydrogen is by direct dissociation (Brady and Weil, 2005). Generally, exchangeable Al distribution down the profiles studied was irregular, suggesting no movement of Al from the surface to the bottom layers, corroborating the fact that the soils were in their early stages of development. Moreover, exchangeable H contributed more to the total exchangeable acidity of the soils studied than exchangeable Al which may well mean that weathering was not advanced enough to release more quantity of Al to the soils. Since meander belt soils were reported to be in their early stages of soil development as earlier stated, corroborated by the high silt/clay ratios recorded for all the soils, the moderate Al saturation level recorded for the soils was more likely to be from the alluvial deposits that formed the soils other than in-situ weathering of the deposits.

In Tables 4.13 to 4.18 are presented the concentration of micronutrients in the soils while annextures 2 to 19 summarizes micronutrient concentration in the soil sampling units. The concentration of Fe in all the soils was far higher than 5.0 mg/kg considered high by Tisdale et al. (1995) for savannah soils. It was also higher than the 7.0 mg/kg recorded by Uzoho et al. (2007), for coastal plain sands of Imo State Nigeria and the critical available level of 4.5 mg/kg (Kparmwang et al., 2000). Ukeagbu et al. (2015), however, reported available Fe values of 0 – 233mg/kg for soils supporting oil palm plantations in the coastal plain sand, Imo State Nigeria and the results obtained were within the range. The results indicated that Fe deficiency is not a likely problem as earlier reported by Kparmwang et al. (2000), for most acid soils of warm humid zones of Nigeria. Rather, there could be possible Fe toxicity, for areas that were flooded for longer period. Similarly, Ukeagbu et al. (2015) reported likelihood of Fe toxicity, particularly in the alluvial soils and attributed high contents of Fe to periodic flooding, especially sites 1, 2 and 3 in their study.

Unlike Fe, Mn concentration in the profiles was generally higher in the surface layers than in the lower horizons. Comparing the concentration values of Mn in the surface 40 cm and the subsurface layers, all surface 40 cm layers were higher than the subsurface layers except the concentration values in ODN3, NDU1, NDU2 and NDU3. The higher concentration of Mn in the surface layers might be attributed to lower pH values in the surface layers which correspond to the larger amounts of organic matter, implying that organic matter was responsible for acidification of the profiles through litter decomposition. The results agreed with the findings of Zaidey et al. (2010), who reported higher acidity in the surface layer of soils and attributed the high acidity to contribution by organic matter supplied from the vegetation as all the study sites were covered with trees. Ishuzika et al. (2000), and Hattori et al. (2005), similarly reported that organic matter and exchangeable Al contributed to the acidity of degraded land under rehabilitation in Sarawak, Malaysia. Brady and Weil (2005), confirmed that in uncultivated profiles, there was somewhat greater concentration of micronutrients in the surface soil, much of which presumably in the organic fraction. Although the elements held in this way were not always readily available to plants, their release through decomposition undoubtedly was an important fertility factor. The higher concentration of Mn in the surface 40 cm of the profiles probably, was therefore, contributed by organic matter decomposition and release. In addition, the higher Mn value recorded for the subsurface layer of NDU3 was attributed to flooding as this mapping unit was flooded for a longer period each year. As reported for Fe, the Mn values recorded in this study were within the 0.2 – 5 ppm range given by Tisdale et al. (2004) and lower than the range (4.9 – 145.6 mg/kg) reported by Ukeagbu et al. (2015) for coastal plain sands in Imo State Nigeria.

Uzoho et al. (2007), recorded variation in available Zn in soils under different land use with similar lithology in Nigeria, ranging between 2.46 and 14.00 mg/kg. Ukeagbu et al. (2015) similarly recorded Zn variation in the coastal plain sands of Imo State, Nigeria ranging between 0.3 and 14.0 mg/kg. The values recorded in this study were within the range recorded by the authors mentioned earlier indicating that the soils were not deficient in Zn. However, Zn deficiency has been reported for soils of coastal plain sand and in basaltic soils of Northern Guinea savanna (Kparmwang et al., 1995). As reported for Mn, the concentrations of Zn in the surface 40 cm of most of the profiles were higher than the subsurface layers, which also recorded higher amounts of organic matter. It is obvious that soil acidity in the surface 40 cm layers were increased through litter decomposition which increased the release and availability of the micronutrients.

Organic matter is an important secondary source of some of the trace elements as several of them tend to be held as complex combination by organic colloids. Copper is especially tightly held by organic matter- so much so that its availability can be very low in organic soils (Brady and Weil, 2005). Asadu et al. (2013), opined that organic matter is largely responsible for both storage and release of nutrient ions in tropical soils especially in the ultisols that are dominated by low activity clay. Ukeagbu et al. (2015), in their study on the soils of the coastal plain of Imo state recorded 0 – 1.5 mg/kg Cu. Tisdale et al. (1995) ratings of Cu concentration in soils of the savanna were low (0-2.5), medium 2.6-4.5) and high (>4.5 mg/kg). Using the recorded values of Ukeagbu as a basis for comparison, the Cu concentration values recorded for the soils were high but within the medium to high ratings of Tisdale and colleagues.

4.2.4 Classification of the Soils

The summary of the classification of the soils is presented in Table 4.19.

4.2.4.1 Soils of Elemebiri

In ELM1, there was substantial evidence of subsoil horizon differentiation with change in colour and structure of the pedon but the absence of illuviated clay and organic carbon with increasing depth shows that the soil was still at the early stages of development. The structural development of the B (B1 and B2) horizon was moderate and clay content was higher than the underlying horizon though no evidence of cutans which makes it a cambic horizon. Moreover the thickness of the B horizon met the requirements of cambic diagnostic horizon which qualifies ELM1 to be classified into the Inceptisols soil order. As the pedon was under udic moisture regime with fairly free drainage, it was classified into Udepts suborder and Dystruderpts Great Group because it has a low base saturation between 25 and 75cm depth. At the subgroup level, it was classified as Aquic Dystrudepts because of ground water influence at 118cm and below, while at the family level it was classified fine, loamy, with isohyperthermic temperature regime.

The corresponding soil group in the WBR system was Fluvic Cambisols (Eutric, siltic) RSG because horizon differentiation was evident in the subsoil from changes in structure, colour and clay content as well as absence of illuviated clay and organic carbon in the subsoil horizons. The prefix 'Fluvic' was given because this pedon received fluvic materials in the recent past while the suffixes Eutric and Siltic were included because between 20 and 100 cm depth of the profile was base saturation of 50% and above in the major part and within the 100 cm depth of the profile and beyond the soil has silty clay loam and silt loam as the textural classes.

The ELM2 soil was also classified into Inceptisols soil order due to the occurrence of cambic horizon within 100 cm of the soil with some structural development, having a base saturation of 50% and above in most of the horizons. It was included in the Aquepts suborder due to observed saturation by ground water. Since water saturation occurred between the surface and 200 cm depth with gleyic properties down the profile, no plinthite within 100 cm depth, and the fact that the exchangeable sodium percentage (ESP) of this soil was far less than 15%, it was grouped into the Epiaquepts Great Group. As the percent organic carbon content from 32-42 cm layer was less than 0.2, which decreased irregularly down the profile from that layer, it was grouped into Typic Epiaquepts. The ELM2 soils also belong to the isohyperthermic temperature regime and the family was fine, loamy.

In the WRB system, pedon ELM2 was classified Fluvic Cambisol (Eutric, Siltic). The pedon was considered a Cambisol in the RSG because of the structural development and the presence of cambic horizon in the soil profile. Eutric suffix given has to do with the pedon having base saturation of 50% and above in the major part between 20 and 100 cm from the mineral soil surface and the suffix 'siltic' due to the silt loam texture of the profile.

The ELM3 soil of Elemebiri was well drained with a deep profile, no lithic contact, but very weak profile development owing to the yearly deposition of fresh alluvium and the concentration of weatherable minerals was high. The pedon has no diagnostic horizon except ochric epipedon which qualified it to be placed into the Entisols soil order in the USDA system. As the pedon was located at the centre of the channel of the Lower Niger River which was subject to the annual floods, it was classed into the Fluvents Suborder and into the Great Group Udifluvent because it was located in the humid tropics and has Udic moisture regime. Due to the high base saturation of the upper layers of the profile, it was classified as Eutric Udifluvents at the Suborder level. The temperature regime was isohyperthermic and the family was loamy sand over sandy loam, mixed.

In the WRB system, the corresponding class of pedon ELM3 was Haplic-Fluvic Fluvisol (Eutric, Siltic). The pedon was classified into the Fluvisol RSG because the soil is made up of fluvic materials of the Lower Niger River. The haplic prefix was considered because of the limited structural development of the profile and fluvic attached because of stratification and the pedon was located at the centre of the Lower Niger River. The suffixes eutric and siltic were given because major part of the profile was having more than 50% base saturation and the textural class of the profile was silt loam.

4.2.4.2 The Soils of Odoni

The pedon, ODN1 which belongs to isohyperthermic temperature regime was embryonic in nature due to few diagnostic horizons, i.e. ochric epipedon and cambic B horizon with many weatherable minerals. This qualified the pedon to be placed under the Inceptisols soil order. Ground water influence was below 100 cm and soils were under udic moisture regime thus placed into the Udepts Suborder and as the exchangeable sodium percentage was far below 15%. Since the soil has base saturation of less than 60% in a horizon between 25 and 75 cm, it was classified into the Dystrudepts Great Group and into the Subgroup, Humic Dystrudepts because it has base saturation (by sum of cations) of more than 35% at a depth of 125cm from the top of the cambic horizon. At the family level, it was classified under fine, silt loam.

The corresponding RSG was Fluvic Cambisols (Eutric-siltic) in the WRB system. The RSG cambisol was given because structural development was evident in the subsoil with colour differentiation. Fluvic was attached as a prefix due to stratification and the pedon was situated on the floodplains of the Nun River at Odoni. The eutric and siltic suffixes referred to the soils having base saturation of 50% and above within 100 cm soil depth and the silt loam texture of the profile.

The ODN2 soils also belong to the isohyperthermic temperature regime, with ochric epipedon and cambic horizon as diagnostic horizons. Structural development was weak but has started in the subsoil indicating that the profile was embryonic with many weatherable minerals. The soil was therefore placed into Inceptisols order and Aquepts Suborder because the surface first three horizons have chroma of 2. Due to water saturation of the profile between the surface and below 200 cm depth, it was placed in the Epiaquepts Great Group and into the Sub Group, Typic Epiaquepts because the profile has Hue of 7.5YR. ODN2 was placed in the silt loam over loam, mixed family owing to the textural distribution down the profile.

The RSG for ODN2 was Fluvic Cambisol (Dystric-siltic) in the WRB system. The ODN2 soil was placed in the Cambisol RSG because of the presence of cambic horizon in the profile and structural development in the subsoil was evident. Since there was strafication in the profile and the soil was of alluvial origin on the floodplain of the Nun River, the prefix 'fluvic' was added while dystric and siltic suffixes were added because it has base saturation of less than 50% in major part of the depth between 20 and 100 cm from the surface and silt loam and loam were the textural classes of the pedon.

The solum of ODN3 was deep but no lithic contact but had moderate profile development indicated by the moderately firm structure and higher clay content in the B horizon than the underlying C horizon which met the requirements of cambic horizon. Hence the pedon was placed in the Inceptisols order and into the Suborder, Aquepts due to the occurrence of redoximorphic features from the surface horizon. The Great Group, Epiaquents was given because the ground water fluctuates between surface and below 200 cm at certain periods of the year while the Subgroup, Fluvaquentic Epiaquepts was given due to the fact that the pedon was most times flooded by the seasonal floods and organic carbon decreases irregularly down the profile. The family was silt loam over silty clay loam. mixed. The ODN3 soils also belong to the isohyperthermic temperature regime.

In the WRB system of classification. the RSG was Fluvic Cambisol (Dystric-siltic) just like ODN1 and ODN2. The presence of cambic horizon qualified the pedon to be placed in the cambisol RSG while its' location on the floodplains of the Nun River and the observed stratification were the reasons for the prefix. fluvic. The suffix. dystric was given because between 20 and 100 cm depth of the profile. base saturation was less than 50% and as the textural distribution of the pedon was silt loam. silty clay loam and loam. the suffix. siltic was applied.

4.2.4.3 The Soils of Trofani

The TFN1 soils were characterized by young profile development with changes in colour and absence of illuviated clay and organic carbon. The cambic B horizon was higher in clay than the underlying C horizon with moderately developed structure which qualified it to be placed in the Inceptisols order. The pedon was under Udic moisture regime with ground water influence below 140 cm depth and therefore placed in the Udepts Suborder. The Great Group Dystrudepts was given because base saturation was below 60% all through the horizons while the Subgroup Aquic Dystrudepts was given due to redoximorphic features in the bottom layers of the profile. The family was silt loam over silty clay loam mixed belonging to the isohyperthermic temperature regime.

Fluvic Cambisol (Dystric-siltic) was the corresponding RSG for TFN1 in the WRB system. The TFN1 was located on the floodplain of the Forcados River with stratification and structural development evident while the cambic horizon was higher in clay content than the underlying horizon. Consequently. the Cambisol RSG and the prefix 'fluvic' were given to this pedon. The suffixes dystric and siltic were given because between 20 and 100 cm depth of the profile. base saturation was less than 50% and as the textural distribution of the pedon was silt loam and silty clay loam.

TFN2 as observed in TFN1 has a deep solum with no lithic contact but has ochric epipedon over cambic B horizon. with some soil structural development. The cambic B horizon has more clay than the underlying C horizon but no evidence of clay and organic carbon illuviation which met the requirements of Inceptisols soil order. The Suborder Aquepts was given because the ground water was near the surface at sometimes during the year and the Great group Epiaquepts given because the ground water fluctuates between near the surface to below 200 cm depth. The Subgroup Typic Epiaquepts was applied because of the 10YR Hue and the low chroma (2) which indicated long periods of water saturation of the affected horizons. The family was silt loam over silty clay loam, mixed, and the temperature regime was isohyperthermic.

The corresponding RSG in the WRB classification system was Fluvic Cambisol (Eutric-siltic). The presence of cambic horizon coupled with some structural development in the profile qualified TFN2 soils to be considered in the cambisol RSG. The suffix 'eutric' was given because a major part of the 20 to 100 cm depth of the profile has base saturation of more than 50% and the suffix siltic was applied because the textural classes were silt loam and silty clay loam.

The soils of TFN3 has very weak profile development with no cambic B but only ochric epipedon with large quantities of weatherable minerals which met the requirements for Entisols soil order in the USDA classification system. The Suborder Fluvents was applied due to the fact that the profile was located on the channel of the present active Forcados River subject to seasonal flooding while the Great Group, Udifluvents was given because the moisture regime was udic. The pedon was placed in the Subgroup, Aquic Udifluvents because the pedon was flooded by the flowing seasonal flood waters of Forcados River yearly for more than 30 consecutive days and the Family fine, silt loam over loam, sand, mixed was applied because of the textural classification. Temperature regime of TFN3 was isohyperthermic. In the WRB system, the corresponding RSG of TFN3 was Haplic Fluvisol (Arenic-greyic). The RSG fluvisol was applied because TFN3 was part of a point bar by the side of the present active Forcados River, still receiving annual fresh alluvial deposits. The prefix, 'haplic' was considered because the profile though deep was an A-C profile with buried soil underneath. The use of the suffix, 'Arenic' was because the textural distribution of the pedon was sandy loam and sand. At the 0-5 cm depth from the soil surface was Munshell colours of value 3 and chroma of 3, hence the suffix 'greyic'.

4.2.4.4 The Soils of Odi

The soils of Odi were represented by ODI1, ODI2 and ODI3. The ODI1 pedon has deep profile, no lithic contact and due to the alluvial origin of the deposits, there was minimal soil development. Clay content increased from A to B horizon but no cutans present which satisfied the conditions of Cambic B-horizon while no other subsurface horizon was present except ochric epipedon. This pedon was therefore classified into the Inceptisols order of the USDA Taxonomy. It was placed in the Udepts suborder since the area belonged to udic moisture regime and Dystrudepts was given as the Great group level because it has base saturation of less than 60% in all the sub horizons between the depths of 25 and 75 cm. The Subgroup Humic Dystrudepts was applied because it has a cambic horizon and a base saturation (by sum of cations) of 35% or more at a depth of 125 cm from the top of the cambic horizon. The family was fine, silt loam over loam, mixed.

The equivalent RSG in the WRB system of classification of ODI1 was Fluvic Cambisol (Dystric-greyic). The RSG 'cambisol' was given because there was evidence of soil structural development in this pedon with cambic horizon having higher clay content than the underlying C horizon. The prefix fluvic was given because the soils lie on the alluvial plain of the Nun River with obvious stratification. The suffix 'dystric' was given due to the fact that the soil having base saturation of less than 50% in the major part of the depth between 20 and 100 cm from the soil surface while 'greyic' indicated Munshell colours with a value of 3 and a chroma of 3 at the surface 0-5 cm depth.

As in the other pedons, ODI2 had deep profile with no lithic contact and embryonic in profile development. It has weatherable minerals as indicated by the abundant mica flakes in the various horizons with no diagnostic horizons other than ochric epipedon and cambic horizon. Base saturation was low and redoximorphic features were present from 40 cm depth of the profile. Since there were no diagnostic horizons other than ochric epipedon and cambic horizon coupled with the fact that the clay content in the cambic B was higher than the underlying horizon, ODN2 was placed in the Inceptisols order. Since the soil was under udic moisture regime, it was classified into the Udepts Suborder and Dystrudepts as the Great group because base saturation was less than 60% in most of the horizons between 25 and 75 cm depth. Furthermore, ODI2 was placed in the Subgroup, Aquic Dystrudepts because in all normal years, the pedon seems to be saturated with water from 40 cm depth and below. The temperature regime was isohyperthermic and the soils family is fine, loam over silt loam.

The RSG equivalent for ODI2 in the WRB system was Fluvic Cambisol (Dystric-siltic). As in the previous cases, some structural development was evident and cambic horizon was present which met the requirements of Cambisol RSG. The fact that ODI2 was part of the Nun River floodplain and the profile was stratified, necessitated the attachment of the prefix, fluvic. The suffix, dystric was indicative of ODI2 having base saturation (by 1M NH_4OAc) of less than 50% in the major part between 25 and 100 cm from the mineral soil surface. The siltic suffix indicated the presence of 30 cm or more thick silt loam layer within 100 cm from the mineral soil surface.

The ODI3 pedon was also a deep profile, no lithic contact and embryonic in nature but with some structural development within the profile. There were no diagnostic horizons other than ochric epipedon and Cambic horizon and the soil characteristically was wet. Ground water influence was from 5 cm down and base saturation was low with irregular decrease in organic carbon down the profile. Due to the embryonic nature of the profile and the absence of serious profile development, ODI3 was placed in the Inceptisols order and into the Aquepts Suborder due to the presence of redoximorphic features from 5 cm down the profile. The Great Group of ODI3 was Epiaquepts because of ground water saturation of the profile from 5 cm to below 200 cm while Aeric Epiaquepts Subgroup was given because the base saturation (by NH_4OAc) was less than 50% in some horizons within 100 cm depth of the pedon. At the Family level, ODI3 was fine, silt loam.

Pedon ODI3, classified as Aeric Epiaquepts in the USDA system correlated with Fluvic Cambisol (Dystric-siltic) in the WRB system of classification. There was no diagnostic horizon other than cambic horizon in this profile and the observed structural development within the profile met the requirements to be considered in the cambisol RSG. The ODI3 soils were located on the floodplains of the Nun River and the profile was stratified due to different depositional periods which qualified the RSG to be attached with the prefix, Fluvic. A larger part of the pedon between 20 and 100 cm depth from the mineral soil surface was having base saturation of less than 50% thus given the suffix, dystric while siltic represented the silt loam textural classification of the pedon.

4.2.4.5 The Soils of Koroama

The soils of koroama were represented by KRM1, KRM2 and KRM3. In KRM1, clay content was higher in the B horizons than the A horizon but illuvial movement of clay from the surface to the subsurface as indicated by clay cutans was absent which met the requirements of cambic horizon. Organic carbon content decreased irregularly with increase in soil depth. The absence of diagnostic horizons other than ochric epipedon and cambic horizon qualified the pedon to be classified into the Inceptisols order. The iso-hyperthermic temperature regime of the soil qualified the pedon to be placed in the Tropepts Suborder while the Great group

Dystropepts was given because at the depth between 25 and 75 cm, the base saturation (by NH_4OAc) was less than 60%. The soil was placed in the Subgroup Udic Dystropepts because it belonged to the udic moisture regime and redoximorphic features were observed below the 100 cm depth. At the family level, the pedon was placed under fine, loam.

The USDA taxonomic soil classification of KRM1 correlated with Humic-fluvic Cambisol (Dystric-siltic) RSG of the WRB classification system. The presence of cambic horizon as the only diagnostic soil horizon in this pedon qualified it to be placed in the Cambisol RSG. The prefix 'fluvic' expresses the location of the pedon on the Taylor Creek floodplain with stratification. The suffixes dystric and siltic, as previously noted was given because a larger part of the depth between 20 and 100 cm from the mineral soil surface was having a base saturation (by 1M NH_4OAc) of less than 50%, while siltic suffix was added to indicate the silt loam textural classification dominating the pedon.

In the case of KRM2, higher concentration of clay in the B horizon over both the overlying A and the underlying C horizons was observed and profile development was still at the early stages as indicated by the high silt/clay ratios. The fact that no other diagnostic horizon was present except ochric epipedon and Cambic B-horizon met the requirements for the inceptisols order and KRM2 was classified into Inceptisols order in the USDA Soil Taxonomy. Since the moisture regime was Udic, it was placed in the Udepts Suborder and into the Great group, Dystrudepts because of the acid pH and a base saturation of less than 60% (by NH_4OAc) in the sub horizons between 25 and 75 cm below the soil surface. The pedon seem to be water saturated in three horizons within 100 cm of the mineral soil surface which qualified it to be placed in the Aquic Dystrudepts Sub Group. The family was fine, silt loam over silty clay loam, mixed.

The corresponding RSG of KRM2 in the WRB classification system was Fluvic Cambisol gl (Dystric-greyic-siltic). The absence of all other diagnostic horizons except cambic in the pedon and the evidence of some level of soil structural development met the requirements to be considered into the Cambisol RSG. The location of KRM2 on the floodplains of the Taylor Creek, the soil profile being stratified qualified the inclusion of 'fluvic' as prefix. Dystric was included as suffix because the base saturation of a major part of the pedon depth between 20 and 100 cm from the mineral soil surface was less than 50% while greyic represents the Munshell colours with a value of 3 and a chroma of 2 in the 0-5 cm of the mineral soil surface. The siltic prefix was attached reflecting the silt loam and silty clay loam dominated textural distribution of the pedon.

Similar to KRM2, the accumulation of clay in the B horizon of KRM3 was higher than the overlying A and underlying C horizons of KRM3 with no lithic contact but redoximorphic features occurred from the Ap2 horizon down. The presence of no diagnostic horizon apart from ochric epipedon and cambic horizon satisfied inceptisols soil order requirements and KRM3 was placed in the Inceptisols soil order in the USDA Soil Taxonomy. Due to chroma of 2 all through the profile and the presence of redoximorphic features from 12 cm depth down, KRM3 was classified into the Suborder, Aquepts and the Great group Epiaquepts because of low exchangeable sodium percentage and fluctuation of ground water from a level near the surface to below 200 cm. The Subgroup was Typic Epiaquepts because organic carbon content was less than 0.2% at a depth of 125 cm and below the soil surface and the decrease in organic carbon down the profile. At the Family level, it was placed in the fine, silt loam over silty clay loam family and the temperature regime was iso-hyperthermic.

Similarly, the corresponding RSG of KRM3 in the WRB system of classification was Fluvic Cambisol (Dystric-greyic-siltic). Cambisol was considered as the RSG because of evidence of some level of profile structural development though young and the presence of cambic horizon as the only diagnostic horizon. Fluvic prefix reflects the location of the pedon on the floodplains of the Taylor Creek, stratification of the profile and the fact that the pedon received fluvic materials in the recent past. The suffix 'dystric 'expresses the base saturation of less than 50% from 12-96 cm depth from the mineral soil surface while 'greyic' reflects the Munshell colours with a value of 3 and a chroma of 2 in the 0-5 cm of the mineral soil surface. The textural distribution of the profile varied between silt loam and silty clay loam hence inclusion of the suffix, 'siltic'.

4.2.4.6 The Soils of Niger Delta University Farm (NDU)

The soils of the Niger Delta University were NDU1, NDU2 and NDU3. Profile development in NDU1 was also at the initial stage. No lithic contact was encountered in the profile and no diagnostic horizons were present except ochric epipedon and cambic B horizon below the ochric epipedon. Clay content was higher in the cambic horizon than the overlying A and the underlying C horizon but no cutans in the B horizon which qualified NDU1 to be placed in the Inceptisols soil order. The Suborder is Tropepts due to the isohyperthermic temperature regime of the soil while the Great group Dystropepts was given because the base saturation of the soil from the soil surface down to 75 cm depth was less than 60%. Furthermore, it was classified into Udic Dystropepts Subgroup because NDU1 was under udic moisture regime and the Family of NDU1 was fine, silt loam over silty clay loam.

The RSG of NDU1 in the WRB classification system was Fluvic Cambisol (Dystric-greyic-siltic). Cambic horizon was the only diagnostic horizon present. KRM1 was located on the floodplains of Igbedi River and stratified hence, given the Cambisol RSG and attached with the prefix 'fluvic'. The suffix 'dystric' reflected the base saturation of less than 50% in the 19-81cm depth of the mineral soil surface while 'grey' reflects the Munshell Colours with a value and chroma of 3 each. The texture of the NDU1 varied between silt loam and silty clay loam hence the suffix 'siltic' was given.

Also, no lithic contact was encountered in NDU2 and it was lacking in diagnostic horizons except ochric epipedon and cambic horizons. As in NDU1, there was increase in the concentration of clay in the B horizon over the overlying A and underlying C horizons but no sign of illuvial clay accumulation in the B horizon which is indicated by the presence of cutans. Also, organic carbon regularly decreased with increase in depth of the profile all of which met the requirements for the Inceptisols soil order in the USDA Soil Taxonomy. ND2 was thus placed in the soil order Inceptisol and in the Suborder Udepts due to the udic moisture regime. It was placed in the Great group Dystrudepts because base saturation from the surface layer to 116 cm depth was less than 60% and the Subgroup Aquic Dystrudepts because at certain periods of the year, the pedon seem to be saturated by ground water from 36 cm from the surface down to below 200 cm. Pedon NDU2 was placed in the Family fine, silt loam over silty clay loam.

The correlating RSG in the WRB system for NDU2 was Fluvic Cambisol (Dystric-siltic). The RSG was cambisol because there was evidence of some soil structural development in this pedon with the cambic horizon. The prefix fluvic was given because NDU2 was located on the alluvial plain of the Igbedi River with obvious stratification with indication of having received fluvial materials in the recent past. The 'dystric 'suffix reflected the base saturation of less than 50% in the 12- 116 cm depth of the mineral soil surface while 'siltic' was given because the texture of the soil varied between silt loam and silty clay loam.

The NDU3 profile was deep, no lithic contact and embryonic in the profile development, lacking in diagnostic horizons except ochric horizon and cambic horizon. The soil has characteristic wetness with ground water influence at 5 cm below the surface. Organic carbon decreases irregularly down the profile and the clay distribution was also irregular while structural development was weak. Due to the weak and embryonic profile development and the lack of diagnostic horizons, NDU3 was placed in the Inceptisols Order of the USDA Soil Taxonomy. The Suborder Aquepts was given because of ground water saturation of the profile. It is placed in the Great group, Endoaquepts because ground water fluctuates between the soil surface and below a depth of 50 cm. The Subgroup, Fluvaquentic Endoaquepts was given because of the irregular decrease in organic carbon down the profile and organic carbon concentration at 125 cm depth was more than 0.2 percent. The temperature regime was isohyperthermic and the Family was fine, silt loam.

The corresponding RSG of NDU3 in the WRB classification system was 'Fluvic Cambisol (Dystric-greyic-siltic). Cambisol was the RSG because there was evidence of some structural development and cambic horizon is the only diagnostic horizon present. The prefix 'fluvic' denotes location of NDU3 on the floodplains of Igbedi River with obvious stratification and evidence of regular receipt of fluvial materials during the flood season, especially in 2012 when the area was flooded. The suffix 'dystric denotes base saturation of less than 50% in the 20-140 cm depth of the mineral soil surface while 'greyic' was a reflection of Munshell colours with value and chroma of 3. The suffix 'siltic' indicated dominance of the silt loam textural class in the profile.

4.2.5 Distribution of Clay Minerals in the Soil Mapping Units

The dominance of silt-sized quartz fraction further confirmed the assertion that the soils were recent in origin. Kaolinite, muscovite, microline ($KAlSi_3O_8$) and albite of the plagioclase group were also prominent (Table 4.20). Anorthite [$Ca\ (Al_2Si_2)O_8$], another mineral of the plagioclase group was present in four (ELM3, ODN1, ODN2 and ODN3) out of the eighteen locations. Zeolite, of feldspar composition but with a good deal of water in the crystal framework was present only in KRM3 and NDU1 while chlorite was present only in KRM2. There was also vermiculite, an interstratified clay mineral, present in fifteen of the study sites (ELM3, ODN1, ODN2, TFN1, TFN2, TFN3, ODI1, ODI2, ODI3, KRM1, KRM2, KRM3, NDU1, NDU2 and NDU3) though not in large quantities and biotite [$K(Mg,Fe)_2(AlSi_2O_{10})(OH,F)_2$] in four locations only (TFN1, TFN2, TFN3 and KRM1). These findings agreed with what was earlier reported by Loganathan et al. (1995). Loganathan and colleagues reported kaolinite, quartz, mica, vermiculite and interstratified or mixed layer silicates presence in the clay fraction of Mbiama-Kaiama soils from the meander belts region of Bayelsa State. Ukubiala (2012), similarly, identified quartz, kaolinite, illite, smectite, vermiculite and interstratified types as common minerals in the silt-clay fraction of floodplain soils. Osabor et al. (2009), in the characterization of clays in Odukpani, Southeastern Nigeria reported that Kaolinite is the dominant clay mineral. Lekwa (1979) cited by Chude (2012), earlier reported that although kaolinite is dominant in the well-drained soils derived from coastal plain sands and sandstones, trace (5%) amounts of mica, vermiculite, and mica-vermiculite mixed layered minerals are also found in the south-south zone soils. One stunning general observation in this study was that as one move towards the coastal area from Odi sampling location down, the concentration of kaolinite decreases. The only exceptions were KRM3 and NDU1 (Table 4.20) which had 25.8 and 18.5%, respectively. Chude (2012), in the literature review on the soil fertility investigation in southern Nigeria reported how the type of clay mineral formed is related not only to the parent rock but also to the position of the soil on a toposequence and the drainage conditions. Udo (1977), corroborated this as he reported that Ikom soil formed on basalt has predominantly kaolinitic type as the main clay mineral but the Ofanatam hydromorphic soils derived from acid crystalline rocks has smectite along the entire toposequence as the main clay type. In the Obubra toposequence, kaolinite was found abundantly in the well-drained pedon on the crest of the toposequence but at the valley bottom with poor drainage, smectite becomes prominent. The KRM1 and NDU1 soils found on the levee crest of the toposequence of Taylor Creek and Igbedi River were well-drained as compared to the soils located on the levee slope and lower slope on the same toposequence, hence the high concentration of kaolinite.

Another major observation in the clay mineralogy of the soils was the near absence of ferromagnesian minerals in the soils. The only minerals of the ferromagnesian family were vermiculite and biotite (Table 4.20) whose quantities were low. This may account for the low levels of basic cations such as Mg and Ca in the soils. Consequently, Mg:K ratio in the soils was low which placed most of the pedons in the marginally suitable class for oil palm production. The presence of several K bearing minerals in the pedons such as the micas (biotite and muscovite) and the feldspars suggests that the K pool in the pedons could naturally be replenished. This agreed with the medium to high K concentration results recorded in most of the pedons.

Among the silicate clay minerals, kaolinite was dominant (Table 4.20) which agreed with findings of Juo (1981) and Osabor et al. (2009), for Southern Nigerian soils and Ojanuga

(1979), for tropical humid forest soils. Ojanuga (1973), reported that in contemporary times, kaolinization is the apparently the dominant clay forming process in the soils overlying the basement complex rocks, particularly those over granites and gneisses. Kaolinization seems to be the dominant clay forming process in these pedons hence the dominance of kaolinite among silicate clays in all the pedons. Ojanuga (1979), reported that two dominant factors appeared to condition kaolinization process under tropical conditions which included composition of the soil solution in the weathering environment and mineralogical composition of the weathering soil or parent rock. The composition of the soil in any weathering environment is often modified by the prevailing climate (rainfall and temperature) and drainage (or topography). In tropical region and Nigeria in particular, the mean monthly soil temperatures are higher than the corresponding mean monthly air temperatures, which fluctuate around 27 C. The mean monthly soil temperatures measured to a depth of 120 cm in the rainy season when rainfall was adequate to promote weathering and leaching in the soil for some stations scattered over Nigeria by Kowal and Knabe (1972), fluctuated between 27.2 and 32 C. Warm soil temperatures were believed to cause marked dissociation of soil water leading to a build-up of hydrogen ions or lowering of the pH of the soil solution. Under such condition, hydrolytic or H-weathering of silicates to kaolinite progresses rapidly Ojanuga (1979). It is worthy to note that the environment under consideration has all year round rainfall and temperature is high, making it conducive for H-weathering of silicates to kaolinite. The loss of silica and basic cations might have been caused by the high rainfall rate in the area leading to leaching. However, enough silica seems to accumulate in the weathering environment not only to form and stabilize kaolinite but also to foster the formation of some quantities of 2:1 layer structures such as vermiculite and mica and even 2:1:1 structure such as chlorite.

The silica supplying power of the soils derived from the alluvial materials was high enough to maintain sufficient silica potential in the weathering environment, thus stabilizing kaolinite and promoting the formation of mica, vermiculite and chlorite. This phenomenon possibly explained why free alumina in the form of gibbsite was not identified in the soils, as the soils were reported to be recent in origin (Dickson et al., 2002). Ojanuga (1979) reported similar trend for soils derived from granites and gneisses in the Nigerian tropical savanna regions. The formation of montmorillonite in poorly drained environment according to Ojanuga was promoted by the import into the soil solution of silica, alumina and bases leached from higher topographical sites.

The near absence of ferromagnesian minerals in the clay mineralogical composition of the soils and the dominance of kaolinite implied that the soils are dominated by low activity clays (LAC) and can be easily eroded. Consequently, split application of recommended fertilizers rates is suggested to avert leaching loss of nutrients when applying fertilizer. In addition, cultural practices such as bush burning that destroy soil organic matter should be avoided to maintain organic matter levels in the soils.

4.2.6 Capability Classification of the Soil Mapping Units

Natural classification systems indeed, are very helpful in the understanding and remembering of the properties and behaviour of soils and play vital role for communication, among soil scientists and between them and other agriculturists or professionals that deal with soil both within a given region and/or from one ecological region to another. It is unfortunate to note that taxanomic names often convey very little or no meaningful information to many users of land, especially the farmers. Moreover, the ultimate interest of most land users' is in the response of soils to management and manipulation including:

a. The use to which a piece of land is best suited or the relative suitability of a parcel of land for alternative uses;
b. The crops that are most suited and most profitable to be raised on that land;
c. The limitation(s) of the land to a particular use or several alternative uses and how such limitation(s) can be overcome.

Consequent upon these facts, for the present soil survey information to be made useful to the people of Bayelsa State and other land users in the area, the information generated must be translated into units with practical implications for use of the soils characterized and classified. Only land evaluation can inform farmers how suitable their land is in terms of soil limitations, crop yield or profit (Olaleye et al., 2002). Land evaluation is an assessment of land performance when used for specific purposes. For land evaluation to be meaningful to the end user of land, the evaluation needs to be made in terms relevant to the conditions of the country or ecological region of interest. In as much as the principles are the same, the relevant land qualities and their critical values for determining suitability classes differ to a great extent, between countries or ecological regions. The aim of this section is to emphasize the relevance of land evaluation to the agricultural development of Bayelsa State and Nigeria in general and assess the suitability of the floodplain soils of Bayelsa State, southern Nigeria for the cultivation of various crops. Land capability classification (Tables 4.21 and 22) and fertility capability classification (Tables 4.23 and 4.24) were used to evaluate the soils studied. The study areas were also evaluated for their suitability for the cultivation of maize, cassava, upland rice, banana, oil palm, coconut and rubber.

4.2.6.1 Land Capability Classification of the Soil Mapping Units

The criteria for the LCC system as summarized in annexure 20 showed some slight modification from Ogunkunle and Babalola (1986), by the non-inclusion of total soluble salts (ss), and percent rock outcrop as the environment is freshwater environment without rocks. Also, permeability and available water capacity (cm) were excluded. Furthermore, due to the peculiar kind of limitations owing to the peculiar environment which may likely have different effects on crop performance, subclass designations were modified. Consequently, instead of using erosion (e), excess water (w), root- zone limitation (s) and climate limitation (c), as subclass designations, angle of slope (a), soil texture (t), wetness (w), and nutrient holding capacity (n) were used. Flooding (f) was introduced in this report because the study environment was subject to yearly seasonal floods which affect the farming season and the time of crops harvest.

Of the eight capability classes in the LCC system, class II was mainly encountered in the study area covering about 95% of the area. The class II SMUs, numbering 17 out of 18 were suited for wide range of arable crops with limitations ranging from wetness, flooding, low nutrient retentive capacity, low exchangeable Ca^{2+} and Mg^{2+} level and high exchangeable Al^{3+}. Conservation measures included drainage to improve wetness, liming to increase exchangeable Ca^{2+} and Mg^{2+} and reduce Al^{3+} as well as increase nutrient capacity. Good management strategies to improve organic matter levels can also improve nutrient retentive capacity. The NDU3 soils fall into the VW special class of Ogunkunle and Babalola (1986), covering 5% of the area studied and was suited for lowland rice production. The NDU3 SMU could be used for other crops if drainage is improved. Detailed information on the pedons and the corresponding LCC classification by the methods of Klingebiel and Montgomery (1961) and Land capability index (LCI) (Van Ranst and Verdoodt (2005) are presented in tables 4.21 and 22, respectively.

The land capability classification for the humid tropics (Sys and Frankart, 1971), characterises the capability of land units in the humid tropics for the production of three groups of crops namely: exacting crops, moderately exacting crops and less exacting crops, which was also adopted by Van Ranst and Verdoodt (2005), and included LCI. The crop groups were further distinguished into annuals and perennials crops. The land capability classification for the humid tropics is a parametric system which assigned numerical values (ratings) to different capability classes of the land characteristics. Profile development is a key factor determining the capability index or soil index obtained as the numerical values assigned ranged from 55 to 100 (Annexure 23). For the SMUs under consideration, ELM3 and TFN3 were assigned 100 as they fell into A-C profiles, having weak profile development without diagnostic subsurface horizons while all the other SMUs were assigned 95 for having cambic horizon with a CEC ‹24 cmol (+) kg^{-1} clay. This helped in boosting the capability index values obtained for the soils. Since all the profiles were deeper than 120 cm, the numerical value (100) was assigned to all. Regarding the rating for the development of the A horizon, the numerical value 120 was assigned because all the SMUs had well developed A horizon, deeper than 20 cm except ELM2 having A horizon depth of 19cm and was assigned 110.

The soil characteristics that varied in their ratings in the SMUs studied were rating for texture, rating for colour/drainage conditions and rating for pH-base saturation (Annexures 4.29 to 4.46). These were regarded as limiting factors for crop production for the SMUs. As showed in annexure 24, light textured soils were rated low and heavy textured soils having ‹ 60% clay like silty clay, silty clay loam and clay loam were rated high (100, 95 and 90, respectively). Therefore, the ratings for texture in the SMUs with silt loam such as ODN1 were assigned 85 and those with silty clay loam, 95 and loam, 75, dictating the ratings for texture. The SMUs dominated by sandy loam and loamy sand textures had low rating for texture while those with silty clay loam as part of the profile had high ratings. That is why the rating for texture for TFN3 was 60 (Annexure 37) since the profile was dominated by sandy loam and that of ELM3, 52 (Annexure 31) as loamy sand (50) and sandy loam (60) dominated the profile while that of KRM3 was 91 (Annexure 43) and NDU2, 93 (Annexure 44) due to the presence of silty clay loam texture which was used in calculating the ratings for texture in the two SMUs. As for the rating of colour/drainage class (Annexure 34), a soil is rated 100 if the moist soil colour is red (5YR and redder), no mottling, and well drain while 95 rating is given when the moist colour is yellow (yellower than 5YR), mottling at a depth deeper than 120cm and is well drain (Van Ranst and Verdoodt, 2005). All the SMUs except TFN1 had mottles at depths less than 120cm and were given the appropriate ratings, ranging from 60-90 for annuals and 40-80 for perennials. The TFN1 SMU was mottled at 140cm depth and was given 100. For ELM3 and TFN3, though flooded seasonally and mottling was observed at depths shallower than 120 cm, the succeeding horizons were not mottled indicating that the mottling could not be ascribed to rise in ground water table and were considered in the well drain group of soils, therefore, assigned 100 (Annexures 31 and 37). For the rating for pH and base saturation, none of the SMUs attained 100 because of low base saturation and variation in pH, the assigned values ranging from 90-98 and LCI calculated.

Based on the calculated capability index or soil index of the SMUs (Van Ranst and Verdoodt, 2005), ELM1 was grouped in capability class I, ODN1, TFN1, ODI1, KRM1 and NDU1, class II and ELM2, ELM3, ODN2, ODN3, TFN2, TFN3, ODI2, ODI3, KRM2, KRM3, NDU2 and NDU3, class III for annual crops while for perennial crops, ELM1, ODN1, TFN1, KRM1 and NDU1 were grouped in class II, ELM3, ODN2, TFN2, TFN3, ODI1, KRM2 and NDU2, class III and others (ELM2, ODN3, ODI2, ODI3, KRM3 and NDU3), class IV. From the definition of the capability classes (Annexure 22), capability class III is good for annual crops, class II, high and class I, excellent while for perennial crops, class IV is good, class III, high and classes II and I, excellent. It was therefore, concluded that the capabilities of the SMUs were good to excellent for the production of annual and tree crops. Understandably, oil palm, whose roots concentrate within the 0-60 cm depth was found growing in SMU's with imperfect drainage e.g. ELM2 and in the poorly drained soils like ODI3 during the field investigation, confirming the results of capability classification (LCI) of the soils. The ELM3 and TFN3 SMUs were placed in capability class III for both annual and perennial crops in this rating. But these SMU's are flooded annually by the Niger River flood between September and October and might not be suitable for raising perennial crops. This implied that land capability classification using LCI did not consider flooding as a limiting factor.

4.2.6.2 Fertility Capability Classification of the Soil Mapping Units

According to Olaleye et al. (2002), the FCC system focused attention on surface soil properties most directly related to the management of field crops and is best used as an interpretative classification in conjunction with the more inclusive natural soil classification. Using the FCC system in the classification of the soils in the study area revealed that the soils were predominantly loamy textured (Tables 4.23). The ELM3 and TFN3 soils located on the channel of present actively flowing Niger River and Forcados River, respectively, were sandy textured while TFN2 on the backslope of River Forcados was sandy in the surface layer and loamy in the succeeding layers.

Based on the fertility classification guide (Sanchez et al., 2003), soil fertility limiting factors characterizing the soils included low nutrient reserve, soil acidity and Al toxicity, wetness, K deficiency and the likelihood of Fe toxicity. From Tables 4.23 and 4.24, the acid nature of these soils was revealed by FCC as 89% (ELM1, ELM2, ELM3, ODN1, ODN2, ODN3, TFN1, TFN3, ODI2, ODI3, KRM1, KRM2, KRM3, NDU1, NDU2 and NDU3) of SMUs included the condition modifier 'h', indicating strong to medium acidity. This corroborated the Al saturation results as all the pedons included the condition modifier 'a-', implying that the pedons have Al saturation of between 10 and 60% within the plow layer. An Al saturation of between 10 and 60% within the plow layer is harmful to Al- sensitive crops, and may require liming. These results agreed with the findings of Ukeagbu et al. (2015), on soils supporting oil palm plantations in the coastal plain sands of Imo State, Nigeria. Sanchez et al. (2003), earlier reported that Al toxicity was most prevalent in the humid tropics and acid savanna soils and high concentration of Al correlated with low nutrient capital reserves. Aluminum toxicity is caused by excess amounts of Al^{3+} in soil solution. Its' negative effects are poorly developed root systems, to drought, lodging and nutrient deficiencies (Meriga et al., 2010). Moreover, principal component analysis of the physico-chemical properties of the soils revealed high positive factor loading in PC1 for exchangeable acidity and Al which amplified the prominent role played by Al in these soils. Low amounts of Ca and Mg were recorded in the soils, which commonly, is associated with high Al as Ca and Mg gave high positive factor loading in PC3. According to Izac and Sanchez (2001), soils with low (less than 10%) reserves of weatherable minerals in their sand and silt fraction constituted low nutrient capital reserves in the INRM context and 36% of soils of the tropics fall into this category. It is necessary to note that the only other source of nutrient capital reserves is organic matter, which contains all the nitrogen and much of the phosphorus and sulphur capital of tropical soils.

Another striking limitation in these soils was the low nutrient reserve and the likelihood of Al^{3+} and Fe^{3+} toxicity in all the SMUs was high due to the high concentration of these nutrients. Low nutrient reserve in the soils was captured by the FCC system by the inclusion of the condition modifier 'e' in 78% of the SMUs which means ECEC values of the surface layers of such soils were less than 4 cmol/kg.. The low nutrient reserve coupled with high concentration of Al^{3+} and Fe^{3+} revealed that the exchange complex was dominated by Al^{3+} and Fe^{3+}. The ECEC values signified that the soils were dominated by 1:1 type of clay with low ability to retain nutrient, hence fertilizer application to these soils should be split. The mineralogical analysis results corroborated this finding as quartz and kaolinite constituted about 48 to 69% of the clay mineral assemblage of these soils. Comparing to critical levels of 5.0 cmol/kg Ca^{2+} and 1.5 cmol/kg Mg^{2+} for Nigerian soils (Federal Ministry of Agriculture and Natural Resources, 1990), the soils were considered deficient in Ca and Mg. Furthermore, the condition modifier 'k' was included in 50% (ELM3, ODN2, ODN3, TFN1, TFN2, KRM2, KRM3, NDU1 and NDU3) of the soils indicating that the affected soils were deficient in K^+ and the K values were below the 0.2 cmol/kg critical value for Nigerian soils.

The Fertility Capability Classification (FCC) of the soils (Tables 4.23 and 4.24) included the condition modifier 'g' for 39% of the soils (ODN2, ODN3, ODI2, ODI3, KRM2, KRM3 and NDU3), indicating wetness, gleying or prolonged water saturation each year. The wetness quality makes the affected SMUs unsuitable for the cultivation of deep rooted crops like oil palm due to the defective oxygen supply. However, shallow crops and short season crops could be raised except on NDU3. Cultivation of shallow rooted and short-season crops on NDU3 can only be possible if artificial drainage is carried out to drain the excess water. It is obvious that organic matter played an important role in sustaining soil fertility and its' management should be given top priority.

4.2.7 Comparison of the various Capability Classification Systems

The effectiveness of Land Capability Classification, Land Capability Index and Fertility Capability Classification in evaluating the capabilities of the Soil Mapping Units was compared. The results of this study (Table 4.25) indicated that Land Capability Classification allocated all the levee crest soils (ELM1, ODN1, ODI, KRM1 and NDU1) except TFN1 classified into IInf0. And whereas the TFN1 SMUwas grouped in IIfo; the levee slope soils (ELM2, ODN2, ODI2, KRM2, and NDU2) were classified into IIwnf0, and of the flood plain soils, ODN3, ODI3 and KRM3 were grouped in IIwnf1, ELM3 and TFN3 in IIwnf2 and NDU3 into a special class, VWnf3. Land Capability Index (LCI) of Van Ranst and Verdoodt (2005), classified ELM1 into class I for both arable and permanent crops production. ODN1, TFN1, ODI1, KRM1, and NDU1 in class II and ELM2, ELM3, ODN2, ODN3, TFN2, TFN3, ODI2, ODI3, KRM2, KRM3, NDU2 and NDU3 in class III for arable crops production. For permanent crops, ODN1, TFN1, KRM1 and NDU1 were grouped in class II, ODI1, ODN2, TFN2, KRM2, NDU2, and ELM3 in class III and ELM2, ODN3, ODI2, ODI3, KRM3 and

NDU3 in class IV. Fertility Capability Classification (FCC) included ELM1, ELM2 and KRM1 in Lha-e class, ODN1, ODI2 and NDU2 in Lha-, ODN2, ODN3, KRM2, KRM3 and NDU3 in Lgha-ek class, ELM3, TFN1, TFN2, TFN3, ODI1, ODI3, AND NDU1 in Sha-ek, Lha-ek, SLa-ek, Sha-e, La-, Lga-eh and Lha-k, respectively (Table 4.5). It is obvious that the systems have close relationship but no absolute agreement to a point where all the systems consider one soil best and another worst. This observation agreed with the report of Ogunkunle and Babalola (1986), in Nigeria who compared Land Capability Classification (LCC), Fertility Capability Classification (FCC), Index of Classification (IC) and Irrigation Capability Classification (ICC) systems for 13 SMUs, and reported that as the approaches differ, one may not expect absolute agreement among the systems. However, it is expected that the assessments of the capability of the soils relative to one another was similar between any two systems. They concluded that LCC and FCC were very similar and more efficient than ICC and IC which are also less similar.

In this study, LCC classified the soils as well suited for a wide range of arable crops with limitations ranging from wetness, flooding, low nutrient retentive capacity, low exchangeable Ca^{2+} and Mg^{2+} level and high exchangeable Al^{3+}, ireespective of location on the landscape. The LCC considered flooding 'f' greatly, as a basis for the classification hence the symbol 'f' was very prominent, knowing fully well that the parent materials of the SMUs are alluvium. On the other hand, LCI did not consider flooding hence the appearance of ELM3 and TFN3 flooded seasonally by the Nun and Forcados rivers, respectively, being placed in the class III for arable and permanent crops while others, ELM2 and ODI2, not flooded were placed in class IV. Furthermore, the NDU3, flooded for 3 to 6 months or more each year, classified by LCC into the special class VW was grouped into class IV, along with ODI, ELM2, ODN3 and KRM3 by LCI. The LCI considered texture, colour,/drainage and pH-base saturation as the limiting characteristics to crop production for the SMUs. Neither was flooding considered an important characteristic in the FCC system nor location on the landscape. What was considered prominently by the FCC system as the soil fertility limiting characteristics were textural distribution in the profile, nutrient reserve status, soil acidity and Al toxicity, wetness, K deficiency and the likelihood of Fe toxicity. Apart from the fact that the FCC system classified the soils as predominantly loamy, 94% of the SMUs were considered having high soil acidity and Al toxicity. One major challenge of the use of FCC is the designations which at a glance did not convey the relative capability of soils. Generally speaking, though the systems have close relationship they have no absolute agreement and none can be considered best.

Concerning the criteria employed in the evaluation systems (Annextures 20 to 46) and the capability classifications (Table 4.25), it is evident that some criteria are more relevant than others in allocating capability groupings of the SMUs. Soil texture, drainage/wetness and nutrient status stand out as the main criteria common to all systems. Flooding, though very important in the study area, was applied prominently in allocating the soils to capability groups by the LCC system only. Although, topography (angle of slope) and soil effective depth are common to all the systems, their variation in the area of study is not so much as to have great impact in deciding capability groupings. These results confirmed the report of Ogunkunle and Babalola (1986) for Nigerian soils that the criteria of relevance to land capability evaluation are site specific.

4.2. 8 Suitability of Soil Mapping Units for the Cultivation of various Crops

4.2.8.1 Suitability of the Soils for Maize Cultivation

Among the climatic parameters, the most important limitation to maize production were length of dry season (days) which stands between 130 to 150 days and the annual rainfall in all the sites which was 2500 mm and above (Table 4.26). The length of dry days in all the study sites was insufficient when compared to the 150 to 220 days for the highly suitable class as stated by Sys (1985) (Table 3.3). This makes all the sites to be placed into the suitability class S2 with reference to length of dry season. The highly suitable rainfall range was 850-1250 mm while rainfall in all sites was 2500 mm and above which was in excess and all the sites were placed in the actually not suitable but potentially suitable (N1) class as annual rainfall greater than 1800 mm was considered actually not suitable but potentially suitable. The mean temperature and the relative humidity of all the study locations were all within the highly suitable categorization and all pedons were placed in S1 suitability class in terms of temperature and relative humidity. ELM3 on the channel of the presently active Niger River and TFN3 on the channel of the presently active Forcados River are subject to the Niger River annual floods for a short period. Similarly, ODN3, ODI3, KRM3 and NDU3 located on the flood plains of various rivers suffer flooding during the rainy season. Consequently, ELM3, TFN3, ODN3, ODI3, KRM3 and NDU3 have flooding problems were placed in the S3 suitability class. When drainage was considered, ODN3, ODI3, KRM3 and NDU3 are poorly drained and placed in the S3 suitability class. When textural class was used as an evaluation factor, all the sites are placed in the S1 suitability class except ELM3, TFN2 and TFN3 whose textural classes were loamy sand, loamy sand and sandy loam, respectively, and were placed into the S2 suitability class. Soils from the three locations were likely to have low moisture retentive capacity. All the locations have low coarse fragments content and deep soil profiles and were classified into S1 suitability class with reference to coarse fragments and soil depth.

The soils have low cation exchange capacity (ECEC 3.50 – 6.65 cmol/kg) and all locations were classified into the S3 suitability class. In spite of the low CEC, base saturation of the ELM1, ELM2, ELM3, ODN1, ODN2, ODN3, TFN3, ODI1, KRM1, KRM2, KRM3 and NDU1 were above the 50% stated in the conversion table (Table 3.3) for the highly suitable category and were placed into the S1 suitability class. Soils from TFN1, TFN2, ODI2, ODI3, NDU2 and NDU3 have between 35 and 50% base saturation which qualified them to be placed in the S2 suitability class. Using pH as basis for evaluation, all the locations qualified to be placed in the S1 suitability class. When organic matter was considered as a yardstick for evaluation, ELM1, ODN3, ODI3, NDU2 and NDU3 were placed in the S1 suitability class, ODN2, TFN1, TFN2, TFN3, ODI2, KRM1, KRM2, KRM3 and NDU1 in the S2 suitability class and ELM2, ELM3, ODN1 and ODI1 in the S3 suitability class. When available P is used as the basis for evaluating the locations, ELM1, ELM2, ELM3, ODN1, ODN2, ODN3, TFN1, TFN2, TFN3, ODI1, ODI2, ODI3, KRM1, KRM2, and KRM3 have available P levels within 13 – 22 mg/kg and were placed in the S1 suitability class while NDU1, NDU2 and NDU3 were placed in the N1 suitability class due to insufficient P concentration. In evaluating the locations using total N, locations ELM1, ODN3, ODI3 and NDU3 were placed in the S1 suitability class, locations ODN2, TFN1, ODI2, KRM1 and NDU2 in S2 suitability class, ELM2 and TFN3 in S3 suitability class and locations ELM3, ODN1, TFN1, ODI1, KRM2, KRM3 and NDU1 in N1 suitability class. When exchangeable K was used as the basis for evaluation, ELM1, ODN3, ODI1, and ODI2 were placed in the S1 suitability class, ELM2, TFN3, KRM1, NDU1 and NDU2 in S2 suitability class, ODN1 and KRM3 in the S3 suitability class and ELM2, ODN2, TFN1, TFN2, KRM2 and NDU3 in N1 suitability class. When all the parameters were considered, it is observed that the limitations were similar and common to most of the locations (excessive rainfall, length of dry season, flooding and drainage, low CEC, organic C, low available P, total N and exchangeable K). Due to the excessive rainfall, all the sites were rated N1, all the sites are therefore classified actually not suitable but potentially suitable. Measures that could be adopted to improve the limitations included early planting in the dry spell to avoid the excessive rains and drainage challenges in each planting year, incorporation of organic and inorganic fertilizers that contain NPK, avoiding bush burning and practices that lead to destruction of topsoil organic materials and accelerated mineralization of organic matter and mixed cropping with leguminous crops to incorporate N into the soils.

4.2.8.2 Suitability of the Soils for Upland Rice Cultivation

The important elements of climate (°C) in evaluating a land for the cultivation of upland rice were mean annual rainfall, mean annual temperature and relative humidity. When these characteristics (Table 4.26) were matched with the conversion table of LUR for upland rice (Table 3.4), the results showed that the pedons representing the different locations were highly suitable (S1) for the successive cultivation of upland rice (Table 4.29). When topography (t) was used as a yardstick for evaluating the suitability of the locations, all the locations proved to be suitable in terms of slope. However, when the elements of wetness (w) namely flooding and drainage were considered, ELM1, ELM2, ODN1, ODN2, ODN3, TFN1, TFN2, ODI1, ODI2, ODI3, KRM1, KRM2, KRM3, NDU1 and NDU2 fall into the S1 suitability class while ELM3, TFN3 and NDU3 were placed in the S3 suitability class (Table 4.28). But when drainage was considered, all the locations fall in the S1 suitability class except NDU3 which fall into S3 suitability class. Considering the elements of soil physical characteristics (s) namely texture and coarse fragments, all the locations qualified to be placed in the S1 suitability class.

The important elements of fertility (f) limiting the cultivation of upland rice included CEC, base saturation, pH, available P, exchangeable Ca, Mg and K. Using CEC as a yardstick for evaluating the suitability of the locations for cultivating upland rice, all the locations were placed in the S2 suitability class. Considering base saturation as the basis for evaluation, ELM1, ELM2, ELM3, ODN1, ODN2, ODN3, TFN3, ODI1, KRM1, KRM2, KRM3, and NDU1 were placed in the S1 suitability class while TFN1, TFN2, ODI2, ODI3, NDU2 and NDU3 fall into the S2 suitability class. Using the pH, only TFN1 and ODI1 were placed in the S1 suitability class while the remaining locations fall in the S2 suitability class. For available P, ELM1, ELM2, ODN2, ODN3, TFN2, ODI2, ODI3, KRM1, KRM2 and KRM3 fall into the S1 suitability class. ELM3, ODN1, TFN1, TFN3, and ODI1 into the S2 suitability class while NDU1, NDU2 and NDU3 qualified to be in the S3 suitability class. When exchangeable Ca and exchangeable Mg were used as the basis for evaluation, pedons from all the locations fall into the S3 suitability class and when exchangeable K was considered, ELM1, ELM3, ODN3, TFN3, ODI1, ODI2, KRM1 and NDU2 were placed in the S1 suitability class, ODN1, TFN1, TFN2, ODI3, KRM3 and NDU3 in the S2 suitability class and ELM2, ODN2, KRM2 and NDU1 in the S3 suitability class.

Climatically, it is obvious that all the locations are suitable for rice cultivation as previously reported by Olaleye *et al.* (2002), for the entire Nigeria. Major limitations to the cultivation of upland rice in the study areas were the annual Niger River flooding in some of the locations, low CEC, low exchangeable cations (Ca, Mg and K), low available P and sub-optimal pH. The limitations reported in these soils were in line with the limitations reported by Olaleye et al. (2002) when they evaluated the suitability of selected wetland soils in Nigeria for rain fed rice cultivation. The implication of the low CEC values recorded in the locations is that sustained rice cultivation is impossible without additional fertilizer input. Sahrawat et al. (1997) reported a critical P value of 12.50-15.0 mgkg^{-1} for some upland rice soils in West Africa. The results showed that apart from ODN1, TFN1 and soils from the Niger Delta University farm, soils from all other locations were within or above the critical P level for West African Soils reported by Sahrawat and colleagues. To achieve good results in the cultivation of rice, however, there is need to incorporate additional fertilizer during the cultivation season. The incorporation of organic materials that can decompose fast could be an advantage. For NDU3 site, flooding and drainage control measures might be required.

4.2.8.3 Suitability of the Soils for Cassava Cultivation

The most important climatic characteristics in the cultivation of cassava were mean annual rainfall, mean annual temperature, and length of dry season in months. Cassava required a minimum of 1600-1800 mm of annual rainfall and all the locations in this study experience a minimum of 2500 mm annually (Table 4.27). The length of dry season in months for the highly suitable class was 3-5 months which falls in line with the dry period experienced in the area. The mean annual temperature required by cassava for the highly suitable class was 26-30°C and the mean temperature experienced in the different locations was 28 °C. It is obvious climatically that all the pedons qualified for the highly suitable class and all were placed in the S1 suitability class. Similarly, for the topography (t) group, the slope of all the locations was with the 0-8% slope range for the highly suitable class and all pedons from the different locations were placed in the S1 suitability class. In the wetness group. drainage is the most important limiting characteristic for cassava cultivation. When drainage was considered as a yardstick for the evaluation. the well drain and moderately well drain locations (ELM1. ELM3. ODN1. TFN1. TFN3. ODI1. KRM1. and NDU1) were placed in the S1 suitability class. the imperfectly drain locations (ELM2. ODN2. TFN2. ODI2. KRM2. and NDU2) placed in the S2 suitability class while the poorly drain locations (ODN3. ODI3 and KRM3) were placed in S3 suitability class. NDU3 which is easily flooded with the onset of the rainy season was placed in the N1 suitability class. Among the soil physical characteristics. texture is the most important limitation to the cultivation of cassava. The soils of ELM3. and TFN3 with either loamy sand or sandy loam textures were placed in the S2 suitability class because such soils have low moisture reserve. For coarse fragments and soil depth characteristics. all pedons from the locations met the LUR requirements for cassava cultivation and were placed in the S1 suitability class (Table 4.30).

Among the characteristics in the fertility (f) group. CEC and organic carbon pose the greatest limitations to the cultivation of cassava. When the CEC and organic C values of the locations in Table 4.26 were compared to the values in the conversion table (Table 3.5). CEC and organic C values were low and insufficient to meet the highly suitable class. Therefore. all the pedons were placed in the S2 suitability class in terms of CEC and organic C. Using base saturation as yardstick. all pedons from the locations recorded have base saturation of 35% and above and were placed in the S1 suitability class.

Since the aggregate suitability score of the assessment is dictated by the most limiting characteristics. ELM1. ELM2. ELM3. ODN1. ODN2. TFN1. TFN2. TFN3. ODI1. ODI2. KRM1. KRM2. NDU1 and NDU2 were placed in the S2f suitability class. ODN3. ODI3 and KRM3 placed in the $S3_{-wf}$ suitability class and NDU3 was placed in the $N1_{-wf}$ suitability class. The most limiting land characteristics were wetness (w) and fertility (f) (Table 4.30). To improve the performance of cassava production in the study locations. drainage need to be improved and additional nutrients supplied in the form of inorganic or organic fertilizers to improve the nutrient retentive capacity of the soils. Liming may be required to reduce exchangeable H and Al and improve the nutrient retentive capacity. Bush burning which reduces the organic C levels in the soils should be avoided and measures be taken to reduce organic matter breakdown and mineralization. Intercropping cassava with leguminous crops is suggested to increase the supply of nitrogen and organic C to the soils.

4.2.8.4 Suitability of the Soils for Oil palm Cultivation

All the important characteristics of the climatic group (mean annual rainfall, length of dry season, mean annual temperature and relative humidity) for the pedons in all the locations matched the highly suitable class requirements of oil palm and all sites were placed in the S1 suitability class. Using slope as a yardstick for evaluation, the acceptable slope range for the highly suitable class was 0-8% and the slopes encountered in this study all fall within this range. Consequently, all the sites were placed in the S1 suitability class (Table 4.31). In the wetness category, flooding and drainage presented some important limitations in some locations. For instance, ELM3, located on the channel of Niger River and TFN3 on the channel of Forcados River are flooded by the annual Niger River floods. NDU3 is also flooded easily with the setting-in of the rainy season. Therefore, ELM3, TFN3 and NDU3 were placed in the S2 suitability class due to flooding. Using drainage as a basis of evaluation, ELM1, ELM3, ODN1, TFN1, TFN3, ODI1, KRM1 and NDU1 were well-drain to moderately well-drained and were placed in the S1 suitability class. ELM2, ODN2, TFN2, ODI2, KRM2 and NDU2 were imperfectly drain and placed in the S2 suitability class while ODN3, ODI3, KRM3 and NDU3 were poorly drain and were placed in the S3 suitability class. The poorly and/or imperfectly drain locations are likely to pose limitation to oil palm cultivation due to defective oxygen supply. According to Mutert (1999), although the majority of oil palm roots are found within the first 60 cm of the soil, firm anchorage of adult palms of more than 8 m height can only be assured in a deep soil (greater than 90 cm). "Thus a soil suitable for oil palm permits extensive root development, firm anchorage, and … due to its clay loam texture and friable consistency… stores sufficient water and plant nutrients." The LUR of the soil physical characteristics group posing important limitations to oil palm cultivation in some of the locations were texture and structure. Therefore, pedons from all locations were placed in the S1 suitability class except ELM3, TFN2 and TFN3 whose textural classes were loamy sand, loamy sand and sandy loam, respectively. These pedons were placed into the S3 suitability class and soils from the three locations are likely to have low moisture retentive capacity as oil palm loves soil with high moisture retentive capacity. Similarly, ELM3 and TFN3 with single grained structure were placed in the N2 suitability class. For coarse fragments and soil depth, all the pedons met the highly suitable LUR for oil palm production and were placed in the S1 suitability class (Table 4.31).

For the characteristics under fertility (f), base saturation and pH met the highly suitable LUR requirements for oil palm production and all pedons were placed in the S1 suitability class. The ECEC of the soils were low and none of the pedons met the highly suitable LUR for oil palm. Consequently, all pedons from the different locations were placed in the S3 suitability class with respect to ECEC. Similarly, the organic C levels of the pedons met only the moderately suitable LUR and all pedons were placed in the S2 suitability class. For exchangeable K, only ODI1 met the highly suitable LUR and was placed in the S1 suitability class. ELM1, ELM2, ODN3, TFN3, ODI2 and KRM1 met the moderately suitable LUR for exchangeable K and were placed in the S2 suitability class. The exchangeable K levels of ELM3, ODN1, ODN2, TFN1, TFN2, ODI3, KRM2, KRM3, NDU1, NDU2, and NDU3 met the marginally suitable class for oil palm and were placed in the S3 suitability class. Another important element of the fertility category is the Mg:K ratio which all pedons except NDU1 could not meet the highly suitable class. Therefore, only NDU1 was placed in the S1 suitability class in terms of Mg:K ratio. ODN1 in the S2 suitability class while ELM1, ELM2, ELM3, ODN2, ODN3, TFN1, TFN2, TFN3, ODI1, ODI2, ODI3, KRM1, KRM2, KRM3, NDU2 and NDU3 were placed in the S3 suitability class (Table 4.30). Aggregate suitability rating shows that all the pedons except ELM3 and TFN3 fall into S3 suitability rating. ELM3 and TFN3 were graded into the N2 suitability rating due to the fact that the pedons are directly covered by the Niger River annual floods. The most important limitations were flooding and drainage under the wetness (w) category, texture and structure under the soil physical properties (s) category and ECEC, organic C, exchangeable K and Mg:K ratio in the fertility (f) category (Table 4.31). For better performance of oil palm in the soils, drainage need to be improved, measures should be taken to increase organic matter in the soils to improve texture and structure in the affected pedons. Fertilizers need to be added to improve the nutrient retentive capacities of the pedons, especially Mg and K and such application should be cautiously made to balance the Mg:K ratio.

4.2.8.5 Suitability of the Soils for Plantain Cultivation

Among the climatic variables, mean annual rainfall and mean annual temperature were the most limiting characteristics to plantain/banana cultivation. The conversion table (Table 4.27) indicated that 1,250-1750 mm mean annual rainfall was the highly suitable range for plantain cultivation while a mean annual rainfall greater than 2500 mm was considered not actually suitable but potentially suitable. The mean annual rainfall of the study sites fell short of the highly suitable rainfall range for plantain cultivation but within the not actually suitable but potentially suitable. Therefore all the study locations were placed in the N1 suitability class for rainfall. Similarly, all the study locations fall short of the highly suitable temperature range of 20-23 C but within 23-30 °C. They were therefore placed in the S2 suitability class. For topography, the slope of all the sites was within the highly suitable range and was placed in the S1 suitability class.

Under wetness, flooding and drainage impacted the locations differently and posed limitation to plantain cultivation. When flooding was used to evaluate the suitability for plantain/banana cultivation, ELM1, ELM2, ODN1, ODN2, TFN1, TFN2, ODI1, ODI2, KRM1, KRM2, NDU1, and NDU2 were placed in the S1 suitability class, ODN3, ODI3 and KRM3 in the S2 suitability class while ELM3, TFN3, and NDU3 which suffer greater flooding placed in the S3 suitability class. Using drainage, ELM1, ELM2, ELM3, ODN1, ODN2, TFN1, TFN2, TFN3, ODI1, ODI2, KRM1, KRM2, NDU1, and NDU2 were placed in the S1 suitability class, ODN3, ODI3 and KRM3 in the S2 suitability class and NDU3 in the S3 suitability class. For soil physical characteristics (texture, coarse fragments and depth), all were within the highly suitable range and were placed in the S1 suitability class (Table 4.32).

Among the fertility characteristics, CEC and organic C were the most limiting characteristics affecting the pedons differently. The CEC values of all the pedons fall short of the highly suitable class (16 cmol/kg) and all the pedons were placed in the S2 suitability class. For organic C, the values recorded for ELM1, ODN2, ODN3, ODI3, KRM1, NDU1, NDU2 and NDU3 were within the highly suitable range and were placed in the S1 suitable class. ELM2, ODN1, TFN1, TFN3, ODI1, OD12 and KRM3 were placed in the S2 suitability class and ELM2, TFN2 and KRM2 were placed in the S3 suitability class. For base saturation, pH and salinity, pedons from all locations proved to be in the highly suitable range and were placed in the S1 suitability class. Since the most limiting characteristics determine the aggregate suitability class, pedons from all the locations were placed in the N1 suitability class (Table 4.32). The limiting characteristics were rainfall, temperature, flooding, drainage, CEC and organic carbon. In as much as climatic characteristics are difficult to manage unless in control environments, flooding and drainage may be improved through flood/drainage control measures. Additional nutrient sources may be supplied to increase the nutrient retentive capacities of the pedons. Bush burning and other measures that accelerate loss of organic matter should be avoided. There is also need to incorporate organic materials into the soil in the process of cultivating banana/plantain.

4.2.8.6 Suitability of the Soils for Rubber Cultivation

The important climatic elements necessary for the cultivation of rubber were mean annual rainfall, length of dry season in days and mean annual temperature. Matching the environmental data in Table 4.27 with the conversion table in Table 3.8, all the pedons from the 18 locations fall into the highly suitable class for the cultivation of rubber and were placed in the S1 suitability class (Table 4.33). Similarly, the slope of all the pedons were within the highly suitable class for the cultivation of rubber and were placed in the S1 suitability class. Under wetness, flooding and drainage pose limitation and affect the pedons differently. The ELM3 and TFN3 soils are affected annually by the Niger River floods and NDU3 is easily flooded with the onset of the rainy season. Other soils of the flood plains (ODN3, ODI3, and KRM3) are affected by flood only to limited extent and flooding is either absent short-lived. Therefore, ELM3, TFN3 and NDU3 were placed in the N1 suitability class while ODN3, ODI3 and KRM3 were placed in the S2 suitability class. ELM1, ELM2, ODN1, ODN2, TFN1, TFN2, ODI1, ODI2, KRM1, KRM2, NDU1, and NDU2 which are not affected by flood were placed in the S1 suitability class. When drainage was used as a yardstick for evaluating the pedons, ELM1, ELM3, ODN1, TFN1, TFN3, ODI1, KRM1 and NDU1 which are moderately well drain were placed in the S1 suitability class. ELM2, ODN2, TFN2, ODI2, KRM2 and NDU2 which are imperfectly drained were placed in the S2 suitability class. ODN3, ODI3, KRM3 and NDU3 which have poor drainage were placed in the S3 suitability class. Using the soil physical characteristics (texture, coarse fragments and depth), all the pedons were within the highly suitable range and were placed in the S1 suitability class for texture, coarse fragments and depth (Table 4.33).

For the elements of fertility (f), base saturation, pH and organic C showed some limitations and have varying impacts on the pedons. Using base saturation as a basis for the evaluation, ELM1, ELM2, ELM3, ODN1, ODN3, TFN3, ODI1 and KRM1 which have base saturation levels above 50% were placed in the S3 suitability class and ODN2, TFN1, TFN2, ODI2, ODI3, KRM2, KRM3, NDU1, NDU2, and NDU3 which recorded base saturation range of 35-50% were all placed in the S2 suitability class. Using pH as an evaluation factor, ELM1, ELM2, ODN1, ODN2, TFN1, TFN3, ODI2, ODI3, KRM1, KRM3, NDU1, NDU2 and NDU3 all fall within the highly suitable range and were placed in the S1 suitability class while ELM3,ODN3, TFN2, ODI1 and KRM2 all qualified to be in the moderately suitable range and were placed in the S2 suitability class. When organic C was used as the yardstick for evaluation, pedons ELM1, ELM3, ODN1, ODN2, ODN3, TFN1, TFN3, ODI1, ODI2, ODI3, KRM1, NDU1, NDU2 and NDU3 all qualified to be in the highly suitable range and were placed in the S1 suitability class while ELM2, TFN2, KRM2 and KRM3 all qualify for the moderately suitable range and are placed in the S2 suitability class. The salinity level of all the pedons were within the highly suitable salinity range and all pedons were placed in the S1 suitability class. Assessing the aggregate suitability of the pedons, ODN2, TFN1, TFN2, ODI2, KRM2, NDU1 and NDU2 were placed in the S2 suitability class, ELM1, ELM2, ODN1, ODN3, ODI1, ODI3, KRM1, and KRM3 were placed in the suitability class S3 and ELM3, TFN3 and NDU3 were placed in the N1 suitability class. The most limiting characteristic groups were wetness (w) and fertility (f) (Table 4.33).

For the flooded and poorly drain locations, measures should be taken to prevent flooding and improve drainage. There might be no need to add additional organic or inorganic fertilizers to the soils but organic matter conservation need to be improved and sustained.

4.2.8.7 Suitability of the Soils for Coconut Cultivation

Mean annual rainfall, length of dry season in months and mean annual temperature were the important climatic elements for coconut cultivation and when the data in table 4.26 was matched with the conversion table (Table 3.9), all the climatic elements for all the pedons were in the highly suitable range (Table 4.34). Consequently, all the pedons were placed in the S1 suitability class for rainfall, length of dry season and temperature. Similar to the climatic elements, slope of the topography element for all the pedons were in the highly suitable range and all pedons were placed in the S1suitability class. When flooding as an element of wetness was used as a yardstick for evaluating the suitability of the pedons for coconut cultivation, ELM1, ELM2, ODN1, ODN2, TFN1, TFN2, ODI1, ODI2, KRM1, KRM2, NDU1 and NDU2 all fall within the highly suitable range and were placed in the S1 suitability class, ODN3, ODI3, and KRM3 fall into the moderately suitable range and were placed in the S2 suitability class, NDU3 in the marginally suitable range and placed in the S3 suitability class and ELM3 and TFN3 in the not actually suitable but potentially suitable range and were placed in the N1 suitability class. Using drainage as a basis for evaluation, ELM1, ELM3, ODN1, TFN1, TFN3, ODI1, KRM1 and NDU1 were within the highly suitable range and were placed in the S1 suitability class, ELM2, ODN2, TFN2, ODI2, KRM2 and NDU were within the moderately suitable range and were placed in the S2 suitability class and ODN3, ODI3, KRM3 and NDU3 in the marginally suitable range and were placed in the S3 suitability class. The elements of soil physical characteristics necessary for coconut cultivation were texture, coarse fragments and depth. For all pedons, these elements fall within the highly suitable range and all pedons were placed in the S1 suitability class in terms of texture, coarse fragments and depth (Table 4.34).

Organic C was the most limiting element of fertility to the cultivation of coconut in the soils under consideration. As seen in Table 4.34, ELM1, ELM3, ODN1, ODN2, ODN3, TFN1, TFN3, ODI1, ODI2, ODI3, KRM1, NDU1, NDU2 and NDU3 were within the highly suitable range and are placed in the S1 suitability class, while ELM2, TFN2, KRM2 and KRM3 fall into the moderately suitable range and were placed in the S2 suitability class. For base saturation, pH, and salinity, all the pedons fall into the highly suitable range and were placed in the S1 suitability class. For the aggregate suitability, ELM1 ODN1, TFN1, ODI1, KRM1 and NDU1 fall into the S1 (highly suitable) class for the cultivation of coconut, ELM2, ODN2, ODN3, TFN2, ODI2, ODI3, KRM2, KRM3, and NDU2 into the S2 (moderately suitable) class, NDU3 in the S3 (marginally suitable) class and ELM3 and TFN3 in the N1 (actually not suitable but potentially suitable) class. For the pedons studied, the main limitations to the cultivation of coconut were wetness, flooding and fertility. To achieve the best in terms of coconut cultivation, organic matter need to be maintained and improved and drainage improved for the poorly drained areas. Flood control might be necessary also.

4.2.9 Identifying Soil Properties Important to Soil Fertility

PCA in this study revealed the eight most important components of the selected soil physical and chemical properties (Table 4.35). The components (PC1, PC2, PC3, PC4, PC5, PC6, PC7, and PC8) identified based on Varimax rotation Kaiser Normalization, explained 74% of the total variability and each component represented a series of variables which simplified the analysis and interpretation. The results showed positive and negative factor loading contributions in seven of the components. Positive factor contributions were recorded in PC1, PC2, PC3, PC4, PC6, PC7 and PC8 while negative factor loading contributions were recorded in PC1, PC3, PC4, PC5, PC6, PC7 and PC8. The positive factor loading contributions in PC1 was dominated by soil acidity (including exchangeable Al and H), Al saturation and nutrient retention capacity (effective CEC). The dominance of soil acidity in PC1 factor loading corroborated the chemical analyses results as pH of most of the soils fall into the acid pH range.

Exchangeable Al in PC1 suggested that this cation significantly affect soil quality in the pedons, which was line with what Aiza et al. (2013), recorded for degraded tropical rainforest soils of Malaysia. Exchangeable Al is known to inhibit Ca and Mg uptake (Arifin et al., 2008a; De Wit et al., 2010), reduce root growth and lead to nutrient imbalances in soils (Angelica et al., 2012). Also, Al toxicity was reported to be most prevalent in the humid tropics and acid savannas soils according to Sanchez et al. (2003) and high concentration of Al correlated with low nutrient capital reserves. Similarly, in the opinion of Lu et al. (2002), the chemical components of Ca and Al in soils have strong negative relationships. High amounts of Ca and Mg were associated with a low amount of Al and lead to a high pH value, making soils alkaline. Conversely, low amounts of Ca and Mg were associated with a high amount of Al resulting in a low pH value, making soils acidic.

It is worthy of note that neither a very high nor a very low pH value is suitable for good vegetation growth. PC2 was dominated by soil organic matter, total organic carbon, and total nitrogen all with high positive factor loading, reflecting a strong positive relationship between organic matter and total nitrogen. This explained the fact that total nitrogen in the soils under consideration was stored in organic matter. Suitable range of organic C and total N in soils as well as environmental conditions enhances organic matter breakdown and mineralization by soil microbes (Van Eekeren et al., 2008), ultimately releasing N and other nutrients in reserve. Hence, plant roots will be able to absorb nutrients released from organic matter for growth. Soil organic matter is related to nutrient availability, soil structure, air and water infiltration, and water retention (Knoepp et al., 2000). In PC3, ECEC, Ca, and Mg dominated the component scores, giving a high positive factor loading and TEB giving a negative factor loading, indicating that cation retention capacity contributed to this component. High amounts of Ca, Mg, and K are beneficial to vegetation growth while high Al restricts vegetation growth (Lu et al., 2002). As reflected in Table 4.35, organic matter, organic C, exchangeable bases and clay gave strong positive relationship which explained the fact that these nutrients were stored in organic matter and clay. Generally, Pc1, PC2 and PC3 are more closely related than the other component units. Sand and clay dominated the factor loading of PC4. Sand showed a positive factor loading while clay gave a negative factor loading for PC4 indicating the recentness of the soils and that sand contributes nothing to increases in the clay content of the soils.

The component scores of PC5 was dominated by pH-$CaCl_2$ while that of PC6 was dominated by micronutrients, Fe and Zn contributing positive factor loading and Cu contributing negative factor loading. For PC7, pH-H_2O and electrical conductivity contributed positive facto loading K contributed negative factor loading while in PC8, Mn contributed positively to the component scores and C/N ratio contributed negatively. The concentration of micronutrients in the three last PCs 6 and 8 could be a reflection of the quantities of these nutrients required by plants and not their level of importance. The fact that Fe, Zn, Mn, and pH (H_20) gave positive factor loading in their respective PCs might mean that the pH ranges recorded were favourable to the availability of these nutrients. In general, the information generated from principal component analysis allowed the development of specified indicators that can represent more complex variability of soil chemical and physical properties of the soils studied which confirmed the earlier report by Arifin et al. (2008b).

4.2.10 Relationship between Soil Properties in the Soil Mapping Units

The results (Table 4.36) indicated that clay has very highly significant, positive relationship with silt ($r = 0.40$, $p<0.001$), ECEC ($r = 0.35$, $p<0.001$), and highly significant positive relationship with exchangeable acidity ($r = 0.33$, $p<0.01$) and exchangeable Al ($r = 0.25$, $p<0.01$) while it had inverse relationship with sand ($r = -0.675$, $p<0.001$), BS-ECEC ($r = -0.26$, $p<0.01$) and P ($r = -0.22$, $p<0.05$). Similarly, the relationship between silt and sand was inverse and very highly significant ($r = -0.94$, $p<0.001$). The results indicated that the weathering of silt fraction added to the clay fraction of the soils as increasing clay concentration was associated with increasing silt while the sand fraction did not contribute to increase in clay content. Whenever the concentration of clay and silt was increased, the sand concentration decreased and vice versa. Moreover, the significantly positive correlation between clay and silt in the soils may mean that the two soil separates were influenced by similar climatic, pedogenic and biotic factors while sand which showed significantly negative correlation with clay and silt might not be favoured by the same factors. Furthermore, due to the negatively charged sites on clay, clay contributed to exchangeable acidity, Al and ECEC hence the significant positive correlation between clay and these properties. Angelica et al. (2012) reported that negatively charged sites from clay bond Al cations, helping to reduce exchangeable Al. The correlation analysis between clay and available P was inverse but significant ($r = -0.22$, $p<0.05$) which implied that clay contributed negatively to P availability in the soils. It is possible that Al and Fe which are part of the clay structure fix P in these soils hence the negative relationship. In the case of clay relationship with Ca, Mg and K, the correlation analysis was positive but not significant indicating that clay contributed to the availability of these nutrients.

The correlation between organic matter as well as organic carbon with total nitrogen was positive and very highly significant (r = 0.37, $p<0.001$). It is obvious that the content of total N in the soils is a function of the amount of organic matter present. Similar findings have been reported by Deekor et al. (2012), for Odukpani soils, Cross River State in southern Nigeria. This is understandable because organic matter and total N are primarily sourced from the accumulation of biomass in soils. The correlation analysis between organic matter and available P was also positive and highly significant (r = 0.31, $p<0.01$) which indicated that organic matter contributed positively to P accumulation and availability in the soils. Similarly, the correlation between organic matter and Ca was positive but negative for Mg and K, though not significant. It is possible that organic matter contributed more to the accumulation of Ca in these soils than Mg and K.

4.2.11 Assesing Soil Fertility Status of Soil Mapping Units using SFI and SEF

In this study, both SFI and SEF were used to assess soil fertility and the quality of the pedons. Figures 4.25 to 4.30 showed graphical comparison of soil fertility index and soil evaluation factor for each of the pedons. Using Turkeys's t-test, mean SFI values were significantly higher ($p<0.05$) than SEF values in all the pedons except in NUD2 and NDU3 (Table 4.37). Higher values of SFI recorded in this study resulted from the contributions of pH, organic matter and phosphorus. The highest SFI value (35.56) was recorded in the surface layer of ODI3 followed by 31.66 in ODN3 while the lowest value (7.66) was recorded in the bottom layer of NDU2. For soil evaluation factor, the highest value (17.06) was recorded in Odoni soil (i.e. the surface layer of ODN3) while the lowest value (5.07) was in the subsurface of ODI3. Generally, SFI values decrease with increase in depth for all the profiles except in TFN1 and ODI1 where the bottom layers recorded the highest SFI values. The higher SFI values in the bottom layers of TFN1 and ODI1 was due to higher concentration of organic matter and available P in those layers expressing the dominant role played by organic matter and available P in dictating SFI values in these soils. Just as recorded for SFI values, SEF values in the profiles decrease with increased depth in all the profiles except in ELM3 profile. In ELM3, the SEF value in the bottom layer (8.46) was higher than the values recorded in all other layers which can be traced to higher nutrient cation concentration in the bottom layer.

Akbar et al. (2010) and Aiza et al. (2013) reported higher SFI values than SEF values while Yetti et al. (2011) found no significant differences in SFI and SEF values among three soil series under khaya ivorensis plantation and regenerated degraded secondary forests all in

Malaysia. Akbar et al. (2010) traced high SFI values to soils containing high organic matter and nutrients contents derived from the 'resam' vegetation that covered the surface. Azai et al. (2013) in assessing soil fertility status of rehabilitated degraded tropical rainforest reported that soil with the highest SEF value was high in organic matter and low in exchangeable Al. They also recorded SEF values of less than 5 for both rehabilitated and secondary forests, and considered them as soils with extremely poor soil fertility (Lu et al., 2002). Azai and his colleagues therefore concluded that vegetation growth contributed to rapid increase in soil fertility on the soil surface, supporting the previous findings of Lu et al. (2002). In this study, all horizons in the various pedons recorded SEF values of more than 5 (Figures 4.25 to 4.30) and by the standard set by Lu et al. (2002), the soils were considered fertile. This is understandable because all the profile pits were located in areas under natural vegetation except ELM3 and TFN3 which are cultivated almost every year and space is not given for organic matter accumulation. In spite of the fact that organic matter was not allowed to accumulate in the ELM3 and TFN3, located on the channels of the present active Niger and Forcados Rivers, respectively, their SEF values were higher than 5. These soils, therefore, were considered fertile by the standard of Lu et al. (2002). It can be inferred that the annual addition of new alluvial materials to ELM3 and TFN3 during the annual floods added to the level of fertility in these soils.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

Bayelsa state soils have agricultural potentials but information and knowledge on the current characteristics, capabilities and suitability of the soils are inadequate and obsolete. The state is known to be inherently lacking in relatively well-drained land while urban expansion and oil exploration and exploitation activities seriously compete with agriculture for land. Furthermore, much land is damaged and lost to oil pollution and river bank erosion. These have prevented the efficient management of the soils for optimum and sustainable crops production. Therefore, this study was conducted to characterize, classify and evaluate the suitability of agricultural soils in selected communities located along different rivers in Bayelsa State, Nigeria.

Detailed soil survey was conducted in six different locations within Bayelsa State namely: Elemebiri (ELM) by the Lower Niger River, Odoni (ODN) by the Nun River, and Trofani (TFN) by Forcados River, all in Sagbama Local Government area, Odi (ODI) by Nun River in Kolokuma/Opokuma Local Government area, Koroama (KRM) by Taylor Creek in Yenagoa Local Government area and Niger Delta University (NDU) farm by Igbedi River in Southern Ijaw Local Government area, covering about 1.216 km^2. These locations were chosen because they are major agricultural communities in the state and agriculture is practiced in some sites that are very unique. The locations lie between latitude 05 22' 03.9" N and 04 59' 08.9" N and longitude 006 30' 21.1" E and 006 06' 54.1" E. The rigid grid system of soil survey was employed and soils augered to a depth of 200 cm. Morphological characteristics such as texture, colour, drainage, mottling pattern and intensity were examined and soil boundaries delineated between levee crest, levee slope and flood plain. Areas with similar morphological characteristics were considered as part of the same SMU unit and the major soil types identified represented levee crest, levee slope, flood plain and/or recent alluvial soils in channels of present active rivers. In each SMU, 1 modal profile pit was dug making 3 modal pits per study location and a total of 18 profile pits were dug. Using the geographic positioning system (GPS), coordinates of the SMU boundaries and profile pit locations were taken and digital camera used to capture the profile pits and surrounding environment. The designation of the SMU's and land area (ha) were ELM1 (29.1), ELM2

(21.2) and ELM3 (162.1) for Elemebiri, ODN1 (89.9), ODN2 (52.1) and ODN3 (90.6) for Odoni, TFN1 (87.6), TFN2 (51.5) and TFN3 (148.5) for Trofani, ODI1 (142.5) , ODI2 (65.1) and ODI3 (138.6) for Odi, KRM1 (13.2), KRM2 (10.6) and KRM3 (21.4) for Koroama and NDU1 (24.0), NDU2 (7.5) and NDU3 (60.5) for Niger Delta University Farm. Soils were morphologically described in-situ and samples collected at different horizons for physico-chemical and mineralogical analysis following standard procedures. Parameters determined include particle size distribution, pH in water and in 0.01M $CaCl_2$ solution, electrical conductivity (EC), total nitrogen, organic carbon, and available phosphorus, exchangeable bases (Ca, Mg, K and Na), exchangeable acidity and Al, cation exchange capacity (CEC) by summation and micronutrients (Cu), (Zn), (Mn), and (Fe). Mineralogical study on the clay fraction was based on random powder analysis. The soils were classified according to the USDA Soil Taxonomy and World Reference Base systems. Land and fertility capability classification were assessed and suitability of the SMUs for maize, upland rice, cassava, oil palm, plantain, rubber and coconut cultivation evaluated. Fertility and site quality was evaluated using Soil Fertility Index (SFI) and Soil Evaluation Factor (SEF) and the most important soil parameters influencing fertility detected using Principal Component Analysis (PCA). Soils physical and chemical characteristics were correlated using Pearson correlation at $p<0.001$.

All the soils were stratified and RMF encountered at different depths depending on location of the SMU on the landscape, reaching A-horizon sometimes. In the ELM3 and TFN3 SMUs located in the channel of the actively flowing Niger and Forcados Rivers, no RMF was observed but profile development was weak due to annual enrichment of alluvium by flood water. Various shades of colour were encountered including dark brown, dark yellowish brown, dark grayish brown, grayish brown, brown and light brownish gray, gray, depending on horizon depth and the influence of ground water. In the ELM2, ODN2 ODN3, TFN2, ODI2, ODI3, KRM2, KRM3, NDU2 and NDU3 SMUs located on the levee slope and flood plain, grayization was prominent in the subsurface horizons, sometimes reaching the surface. The colour matrixes and mottle colours of the levee slope and flood plain soils indicated that these soils were under aquic moisture regime in most part of the year. Silt loam dominated the texture of the soils followed by silty clay loam except ELM3 and TFN3 dominated by sandy loam and loamy sand. Structure of surface soil layers was crumbly to weak sub angular blocky while subsurface structure was sub angular blocky except ELM3 and TFN3. The structure of ELM3 profile was a mix of crumbly, single grain, very weak sub angular blocky and while that of TFN3 was massive, granular and single grain. Mica flakes were common to many.

The results of soil textural determination in the field and in the laboratory were similar. Silt-sized particles dominated the particle size distribution of the soils except ELM3 and TFN3 dominated by sandy loam and loamy sand. Silt/clay ratios in the soils varied from 1.3-14.0.

The pH of the soils generally, was strongly acid to neutral. The pH (H_2O) of surface 40 cm of ELemebiri, Odoni, Trofani, Odi, Koroama and Niger Delta University soils, was 5.44-7.00, 5.38-6.70, 5.55-6.16, 5.67-6.30, 5.48-6.39 and 5.42-6.07 and in the sub surface horizons 5.31-6.55, 5.33-6.48, 5.30-6.80, 5.60-6.405.72-6.35 and 5.92-6.32, respectively. The ΔpH values were all positive ranging from 0.01-1.70, 0.20-1.38, 0.50-1.09, 0.39-1.30, 0.16-1.83 and 0.13-1.16 in the surface 40 cm of the ELemebiri, Odoni, Trofani, Odi, Koroama and Niger Delta University soils and in the sub surface horizons, 0.04-1.18, 0.16-1.30, 0.21-1.55, 0.38-1.17, 0.32-1.45 and 0.431.99, respectively. Organic C (%) in the surface 40 cm of ELemebiri, Odoni, Trofani, Odi, Koroama and Niger Delta University soils was 0.16-2.250.20-2.33, 0.35-1.60, 0.38-5.25,0.31-1.84 and 0.93-2.81 and in the subsurface horizons, 0.11-1.50, 0.01-0.99, 0.19-1.04, 0.11-0.93, 0.14-1.03 and 0.23-0.92, respectively while total N (%) was 0.01-0.25, 0.03-0.2, 0.05-0.13, 0.03-0.45, 0.02-0.11 and 0.05-0.22 in the surface 40 cm and in the subsurface horizons, 0.01-0.09, 0.01-0.09, 0.01-0.06, 0.01-0.040.01-0.05 and 0.01-0.04, respectively.

Available P (mg/kg) was low to moderate ranging from 9-18, 8-22, 8-17, 7-21, 16-22 and 0.9-11 in the surface 40 cm of the ELemebiri, Odoni, Trofani, Odi, Koroama and Niger Delta University soils and in the subsurface horizons, 3-10, 1-9, 2-16, 2-19, 4-15 and 0.6-4, respectively. Calcium (cmol/kg) dominated the exchange complex followed by Mg^{2+}. Exchangeable K^+ (cmol/kg) was low to high ranging from 0.18-1.65, 0.10-0.68, 0.14-0.94, 0.19-1.51, 0.09-0.73 and 0.15-0.44 in the surface 40 cm of the ELemebiri, Odoni, Trofani, Odi, Koroama and Niger Delta University soils and in the subsurface horizons, 0.12-1.81, 0.15-2.13, 0.16-1.88, 0.10-1.44, 0.12-1.51 and 0.09-0.60, respectively.

Exchangeable acidity (cmol/kg) in the surface 40 cm was 0.90-2.70, 1.50-2.90, 1.60-3.30, 1.22-2.80, 1.30-5.40 and 1.50-4.00 in the ELemebiri, Odoni, Trofani, Odi, Koroama and Niger Delta University soils and in the subsurface horizons, 0.50-3.40, 1.10-6.20, 0.80-5.40, 0.90-5.00, 0.70-4.90 and 0.90-4.50, respectively, indicating slightly to strongly acidic nature of the soils. Exchangeable Al (cmol/kg) in the surface 40cm was 0.60-1.20, 0.80-1.90, 0.90-

1.90, 0.90-1.70, 0.70-3.80 and 0.70-2.30 and in the subsurface horizons, 0.30-1.90, 0.70-3.60, 0.50-2.40, 0.40-3.00, 0.30-2.40 and 0.40-2.40, respectively. The ECEC (cmol/kg) of the soils was low ranging from 2.44-5.62, 2.97-4.99, 2.89-6.29, 3.22-4.43, 2.83-6.80 and 2.90-7.14 in the surface 40 cm of the ELemebiri, Odoni, Trofani, Odi, Koroama and Niger Delta University soils and in the subsurface horizons, 1.49-6.11, 2.47-8.06, 2.79-6.37, 2.38-5.87, 2.71-6.43 and 2.03-6.20, respectively. Aluminium saturation (%) in the surface 40cm of the soils was 14-34, 16-41, 26-39, 23-38, 20-59 and 20-44 in the ELemebiri, Odoni, Trofani, Odi, Koroama and Niger Delta University farm soils and in the subsurface horizons, 15-46, 17-45, 14-39, 17-51, 10-30 and 16-39, respectively while base saturation (%) in the surface 40cm was 43-63 in Elemebiri, 37-68 in Odoni, 38-60 in Trofani, 34-59 in Odi, 21-57 in Koroama and 30-51 in Niger Delta University farm and in the subsurface horizons, 39-68, 23-73, 15-77, 14-65, 24-78 and 27-64, respectively. Iron concentration (mg/kg) in the soils was 50-68, 41-67, 46-85, 41-85, 40-76 and 59-95 in the ELemebiri, Odoni, Trofani, Odi, Koroama and Niger Delta University soils while Mn concentration was 1.51-3.16, 0.93-2.98, 0.53-2.91, 1.48-3.45, 1.12-2.60 and 1.37-2.67, respectively. Similarly, Zn concentration was 7.39-13.15, 7.32-16.60, 7.69-11.07, 3.73-18.00, 5.33-8.83 and 4.83-11.01 in the ELemebiri, Odoni, Trofani, Odi, Koroama and Niger Delta University soils while Cu concentration was 2.66-4.01, 2.85-3.78, 2.15-4.83, 3.11-4.40, 2.15-4.21 and 2.77-4.10, respectively.

Using the USDA Soil Taxonomy and the WRB systems, the Elemebiri soils were classified as Aquic Dystruderpts (ELM1), Typic Epiaquepts (ELM2) and Eutric Udifluvents (ELM3) in the USDA classification system corresponding to Fluvic Cambisols, Fluvic Cambisols and Haplic-Fluvic Fluvisol in the WRB. Odoni soils classified as Humic Dystrudepts (ODN1), Typic Epiaquepts (ODN2) and Fluvaquentic Epiaquept (ODN3) in the USDA Soil Taxonomy and Fluvic Cambisols, Fluvic Cambisols and Fluvic Cambisols respectively, in the WRB. Trofani soils classified as Aquic Dystrudepts for TFN1, Typic Epiaquepts for TFN2 and Humic Dystrudepts for TFN3 in the USDA classification system and Fluvic Cambisol, Fluvic Cambisol and Haplic Fluvisol, in the WRB, respectively. Odi soils classified as Humic Dystrudepts and Fluvic Cambisol for ODI1, Humic Dystrudepts and Fluvic Cambisol for ODI2 and Aeric Epiaquepts and Fluvic Cambisol for ODI3 in the USDA Soil Taxonomy and the WRB systems, respectively. The Koroama soils classified as Udic Dystropepts and Humic-fluvic Cambisol for KRM1, Aquic Dystrudepts and Fluvic Cambisol for KRM2 and Typic Epiaquepts and Fluvic Cambisol for KRM3 in the USDA Soil Taxonomy and the WRB, respectively while the Niger Delta University Teaching and Research Farm soils classified as Udic Dystropepts and Fluvic Cambisol for NDU1. Aquic Dystrudepts and Fluvic Cambisol for NDU2 and Fluvaquentic Endoaquepts and Fluvic Cambisol for NDU3 in the USDA Soil Taxonomy and the WRB. respectively.

Ten different mineral phases were identified among which kaolinite. quartz. muscovite and albite occurred in all the locations. Quartz was the dominant mineral in all the locations and quartz and kaolinite constituted 48 to 69% of the mineral assemblage. Vermiculite was present in fifteen of the study sites though in low quantities while biotite was found in four only. The soils were low in ferromagnesian minerals concentration.

About 95% of the area surveyed (including ELM1. ELM2. ELM3. ODN1. ODN2. ODN3. TFN1. TFN2. TFN3. ODI1. ODI2. ODI3. KRM1. KRM2. KRM3. NDU1. and NDU2 SMUs) belong class (II) of the LCC system while NDU3. covering 5% belonged to the VW special class. Using capability index. ELM1 was grouped into capability class I. ODN1. TFN1. ODI1. KRM1 and NDU1. class II and ELM2. ELM3. ODN2. ODN3. TFN2. TFN3. ODI2. ODI3. KRM2. KRM3. NDU2 and NDU3. class III for annual crops while for perennial crops. ELM1. ODN1. TFN1. KRM1 and NDU1 were grouped into class II. ELM3. ODN2. TFN2. TFN3. ODI1. KRM2 and NDU2. class III and others (ELM2. ODN3. ODI2. ODI3. KRM3 and NDU3). class IV. The FCC revealed the acid nature of the soils as 89% of the SMUs included the condition modifier 'h' while all the SMUs included the condition modifier 'a-'. Low nutrient reserve was also captured by FCC with the inclusion of the condition modifier 'e' in 78% of the SMUs. Furthermore. K deficiency was captured with the inclusion of the condition modifier 'k' in 50% of the SMUs and wetness by the inclusion of 'g' in 39% of the soils. Comparing the capability classification systems. all the systems have close relationship but no absolute agreement as to where all the systems considered one soil best and another worst. Soil texture. drainage/wetness and nutrient status stand out as the main criteria common to all systems. Flooding. though very important because of the alluvial nature of the soils. was applied prominently in allocating soils to capability groupings. only in the LCC system.

For maize cultivation. temperature and humidity were highly suitable in all the sites but low nutrient retentive capacity was a problem. Length of dry days was insufficient and rainfall. above the highly suitable class in the sites. Flooding was a challenge in ELM3. ODN3. TFN3. ODI3. KRM3 and NDU3 and drainage in ODN3. ODI3. KRM3 and NDU3. Therefore. the main limitations to maize cultivation were excessive rainfall. insufficient length of dry days, flooding and drainage, low CEC, organic C, low available P, total N and exchangeable K. For upland rice cultivation, annual rainfall, mean annual temperature, relative humidity, slope and soil physical characteristics were highly suitable in all the sites as well as drainage except NDU3 that is marginally suitable. On flooding and drainage, ELM1, ELM2, ODN1, ODN2, ODN3, TFN1, TFN2, ODI1, ODI2, ODI3, KRM1, KRM2, KRM3, NDU1 and NDU2 were highly suitable and ELM3, TFN3 and NDU3 marginally suitable. In as much as ELM3, TFN3 and NDU3 are limited due to wetness (flooding), all the sites were limited by low soil fertility. Climate, topography and coarse fragments were highly suitable for cassava cultivation in all the sites. For drainage, ELM1, ELM3, ODN1, TFN1, TFN3, ODI1, KRM1, and NDU1 of were highly suitable, ELM2, ODN2, TFN2, ODI2, KRM2, and NDU2 moderately suitable and ODN3, ODI3 and KRM3, marginally suitable. The NDU3 site, easily flooded with onset of rainy season was not suitable but potentially suitable (N1). The most limiting characteristics to cassava cultivation were wetness (w) and fertility (f). Climate and topography were highly suitable for oil palm cultivation in all SMUs, wetness (w) soil physical properties (s) and fertility (f) being the limiting characteristics. The ELM3, TFN3 and NDU3 SMUs were moderately suitable due to flooding. The ELM1, ELM3, ODN1, TFN1, TFN3, ODI1, KRM1 and NDU1 SMUs were highly suitable. ELM2, ODN2, TFN2, ODI2, KRM2 and NDU2, moderately suitable and ODN3, ODI3, KRM3 and NDU3, marginally suitable.

On soil physical characteristics, all the sites were highly suitable except TFN2 that is marginally suitable and ELM3 and TFN3, unsuitable. Under the fertility (f) category, CEC, organic C, exchangeable K and Mg:K ratio were limiting to oil palm cultivation. Slope under topography, coarse fragment and depth soil physical characteristics as well as base saturation, pH and salinity under fertility were highly suitable for banana/plantain cultivation in all SMUs. Annual rainfall was not actually suitable but potentially suitable and temperature, moderately suitable for all SMUs. Considering flooding, ELM1, ELM2, ODN1, ODN2, TFN1, TFN2, ODI1, ODI2, KRM1, KRM2, NDU1, and NDU2 were highly suitable (S1), ODN3, ODI3 and KRM3, moderately suitable and ELM3, TFN3, and NDU3, marginally suitable (S3) and for drainage, ODN3, ODI3 and KRM3 were moderately suitable, NDU3, marginally suitable, and all others, highly suitable (S1).

Both CEC and organic C were limiting to banana/plantain cultivation. Climate, topography and soil physical characteristics were highly suitable for rubber cultivation. Considering flooding, ELM3, TFN3 and NDU3 were not actually suitable but potentially suitable, ODN3, ODI3 and KRM3, moderately suitable and the remaining SMUs, highly suitable while for drainage, ELM1, ELM3, ODN1, TFN1, TFN3, ODI1, KRM1 and NDU1 were highly suitable (S1), ELM2, ODN2, TFN2, ODI2, KRM2 and NDU2), moderately suitable, ODN3, ODI3, KRM3 and NDU3, marginally suitable. Base saturation, pH and organic C were limiting to rubber cultivation. Similar to rubber, climate, topography and soil physical characteristics for all SMUs were highly suitable for coconut cultivation as well as base saturation, pH, and salinity. Considering flooding, ODN3, ODI3, and KRM3 were moderately suitable, NDU3, marginally suitable, ELM3 and TFN3 not actually suitable but potentially suitable (N1) while all others were highly suitable (S1) and for drainage, ELM2, ODN2, TFN2, ODI2, KRM2 and NDU were moderately suitable, ODN3, ODI3, KRM3 and NDU3, marginally suitable and ELM1, ELM3, ODN1, TFN1, TFN3, ODI1, KRM1 and NDU1 highly suitable. Considering organic matter, ELM1, ELM3, ODN1, ODN2, ODN3, TFN1, TFN3, ODI1, ODI2, ODI3, KRM1, NDU1, NDU2 and NDU3 were highly suitable (S1), and ELM2, TFN2, KRM2 and KRM3, moderately suitable.

The PCA revealed the eight most important components of the selected soil physical and chemical properties (PC1, PC2, PC3, PC4, PC5, PC6, PC7, and PC8) which explained 74% of the total variability, each component representing a series of variables which simplified analysis and interpretation. Positive factor loading contributions was recorded in all the components except PC5 and negative factor loading contribution in PC1, PC3, PC4, PC5, PC6, PC7, and PC8. The positive factor loading contributions in PC1 was dominated by soil acidity (including exchangeable Al and H), Al saturation and nutrient retention capacity (effective CEC). PC2 was dominated by soil organic matter, total organic carbon, and total nitrogen, all with high positive factor loading, reflecting strong positive relationship between organic matter and total nitrogen. In PC3, ECEC, Ca, Mg, and TEB dominated the component scores, giving a high positive factor loading, indicating this component was dominantly contributed by cation retention capacity. Sand contributed positive factor loading for PC4 while the contribution of clay was negative indicating that sand particles contributed little in increase in the clay content of the SMUs.

Correlation analysis results indicated very highly significant, positive relationship between clay and silt ($r = 0.40$, $P<0.001$), and with ECEC ($r = 0.35$, $p<0.001$), a highly significant positive relationship with exchangeable acidity ($r = 0.33$, $p<0.01$) and with exchangeable Al ($r = 0.25$, $p<0.01$). On the other hand, clay relationship with sand ($r = -0.68$, $p<0.001$), BS-ECEC ($r = -0.26$, $p<0.01$) and with P ($r = -0.216$, $p<0.05$) were inverse and significant. The correlation between organic matter and total nitrogen was positive and very highly significant ($r = 0.37$, $p<0.001$) and with available P positive and highly significant ($r = 0.31$, $p< 0.01$).

SFI values in this study were significantly higher ($p< 0.05$) than SEF values in all SMUs except NUD2 and NDU3, contributed mainly by pH, organic matter and phosphorus. The highest SFI value was 35.56, recorded in the surface layer of OD13 and that of SEF, 17.06 recorded in the surface layer of ODN3. Both SFI and SEF values generally decreased with increase in depth and the SEF values recorded were higher than 5, the measure of a fertile soil.

5.2 Conclusions

The soils were formed from alluvial materials carried and deposited by the Niger River. The levee crest soils were being depleted fast by river bank erosion. Mottle colours and the colour matrixes of the levee slope and flood plain soils revealed that the soils were under aquic moisture regime during the rainy season and gleitization was a major soil forming process. Silt-sized particles dominance in the SMUs, mica flakes presence and the absence of cutans showed recent soil development and the soils could weather to release nutrients.

Low soil organic matter and Total N concentration were occasioned by low biomass return, bush burning and high organic matter mineralization. Though available P concentration was moderate, high P fixation is likely due to the concentration of Al and Fe. The soil pH values were suitable for the cultivation of most crops. The positive ΔpH values implied the soils negatively charged. Effective cation exchange capacity was generally low but high enough to withstand heavy leaching loss of nutrients. There is no likelihood of micronutrient deficiency in the SMUs. Based on the morphological, physical and chemical characteristics, the soils are classified into the Entisol and Inceptisol soil orders of the USDA Soil Taxonomy and Fluvisol and Cambisol in the World Reference Base. Kaolinization seems to be the dominant clay mineral forming. The concentration of ferromagnesian minerals was low which dictated concentration of basic cations like Ca and Mg.

The SMUs according to LCC and LCI were good to excellent for the cultivation of annual and perennial crops with limitations ranging from wetness, flooding, low nutrient retentive capacity, and low exchangeable Ca^{2+} and Mg^{2+} levels to high exchangeable Al^{3+} while the VW special class was suited for lowland rice production. The FCC system characterized the fertility limiting factors of these soils as low nutrient reserve, soil acidity and Al toxicity, K deficiency and water logging. For the area of study, none of the three systems could be considered best and the criteria of relevance to land capability evaluation are site specific.

All the sites were actually not suitable but potentially suitable for maize cultivation. For upland rice cultivation, all the SMUs were marginally suitable (S3). For cassava cultivation, ELM1, ELM2, ELM3, ODN1, ODN2, TFN1, TFN2, TFN3, ODI1, ODI2, KRM1, KRM2, NDU1 and NDU2 were moderately suitable, ODN3, ODI3 and KRM3, marginally suitable and NDU3 not suitable but potentially suitable. All the SMUs except ELM3 and TFN3 were marginally suitable for oil palm cultivation while ELM3 and TFN3 were unsuitable. And for plantain/banana cultivation, all the SMUs were not suitable but potentially suitable while for rubber, ODN2, TFN1, TFN2, ODI2, KRM2, NDU1 and NDU2 moderately suitable , ELM1, ELM2, ODN1, ODN3, ODI1, ODI3, KRM1, and KRM3, marginally suitable and ELM3, TFN3 and NDU3 not suitable but potentially suitable (N1). For coconut cultivation, ELM1 ODN1, TFN1, ODI1, KRM1 and NDU1 were highly suitable, ELM2, ODN2, ODN3, TFN2, ODI2, ODI3, KRM2, KRM3, and NDU2, moderately suitable, NDU3, marginally suitable and ELM3 and TFN3, actually not suitable but potentially suitable. Suitability evaluation of the SMUs for the cultivation of the named crops was based on the present (current) state of the pedons. Most of the identified limitations could be reduced or eliminated through good management (e.g. wetness by drainage, fertility limitation by good agricultural practices, application fertilizers and liming). Therefore, potential suitability of the SMUs could be improved from their present state to moderately and highly suitable for the crops.

The PCA information allowed the development of specified indicators that can represent more complex variability of soil chemical and physical properties in the SMUs. The PC1 factor loading indicated the importance of soil acidity in dictating chemical reactions in the SMUs while PC2 factor loading amplified organic matter contribution to nitrogen. The correlation results indicated that weathering of the silt fraction added to the clay fraction. Also, total N and the accumulation and availability of P were a function of amount of organic matter. Based on the SEF values, all the soils were fertile.

The measured morphological, physical and chemical properties exhibited spatial variations of different degrees with depth and topography indicating different degrees of limitations, potentials and management requirements, the consideration of which is fundamental to the sustainable use of these soils.

5.3 Recommendations

Based on the findings of this study, the following recommendations were made:

1. For the state to achieve food security through increased production and productivity of the soils, good agricultural practices such as liming, avoidance of bush burning as well as incorporation of inorganic and organic fertilizers was recommended. Ameliorating soil acidity through liming to increase calcium contents and soil pH, and organic amendments to complex or arrest aluminium is of utmost significance in these soils. Care must be taken concerning agricultural pressure (including residue burning practices) that deteriorates soil quality.

2. Given the variability of measured soil characteristics, soil fertility research in the state should gear towards site specific fertilizer recommendations such as modeling lime and fertilizer rates. Another research focus should be on improving crop genetics for tolerance to soil acidity and Al toxicity.

3. Flooding drainage control and artificial drainage facilities should be provided for soils due to excessive rain, flooding and wetness, especially for improved cassava and oil palm cultivation. For better oil palm performance in the soils, nutrient retentive capacity should be improved through liming and the application of fertilizers.

4. For improved maize cultivation, early planting during the dry spell is recommended to avoid excessive rainfall and drainage challenges. Avoid bush burning and practices that destroy top soil organic materials and the incorporation of organic and inorganic fertilizers is recommended.

5. For the cultivation of upland rice, the incorporation of inorganic and organic fertilizers is recommended.

6. Given the state's inherent lack of relatively well-drained land, urbanization and oil activities competing with agriculture for land, and the continuous damage/ loss of land to oil pollution and river bank erosion, government should establish effective land use

planning/management strategy to protect agricultural land in Bayelsa State. This will keep in check oil companies arbitrary siting oil installations on the limited dry and well-drained land suitable for agriculture and urban development activities encroaching on them.

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ANNEXURES

Annexure 1: Field Description of the Soil Profiles

Soil Profile: Elemebiri 1 (ELM1) Sagbama Local Government Area (Levee Crest)

Parent material: Alluvium

Geology: Lower Niger Deposits

Geomorphology: Alluvial plain. levee crest of the Niger River

Location on site: Elemebiri. bank of Niger River (N 05° 21' 11.5" E 006° 30' 02.2")

Topography: Almost flat (0-1%)

Drainage: Moderately well-drained

Depth to water table: No ground water encountered in the profile

Depth to impermeable layer: None encountered within profile depth

Erosion: No evidence of erosion

Flooding: None

Vegetation: Elephant grass. pureria. mango trees. cassava farm close to site

Date sampled: 23/03/2015

Soil Depth	Description of the Soil profile
0 – 8 cm	very dark grayish brown (10 YR 3/2 moist): fine. silt loam. weak sub-angular blocky: friable. slightly sticky. slightly plastic: many medium to coarse continuous pores: many mica flakes: many medium to fine roots: clear smooth boundary to
8 – 21 cm	dark brown (10 YR 3/3 moist): fine. silty clay loam. sub-angular blocky: moderately firm. slightly sticky. slightly plastic: many medium to coarse continuous pores: many mica flakes: common medium roots: clear smooth boundary to
21 – 34 cm	dark yellowish brown (10 YR 3/4 moist): fine. silty clay loam. sub-angular blocky: moderately firm. slightly sticky. slightly plastic: few medium roots: common mica flakes: many medium to coarse continuous pores: clear smooth boundary to
34 – 65 cm	dark yellowish brown (10 YR 3/4 moist): fine. silt loam. sub-angular blocky: moderately firm. slightly sticky. slightly plastic: carbon found: many mica flakes: many medium to coarse continuous pores: clear smooth boundary to
65 – 90 cm	dark yellowish brown (10 YR 4/4 moist): fine. silt loam. sub-angular blocky: slightly firm. slightly sticky. slightly plastic: many fine mottles: many medium to coarse continuous pores: common mica flakes: clear smooth boundary to
90– 118 cm	dark yellowish brown (10 YR 4/4 moist): fine. silty clay loam. sub-angular blocky: slightly firm. slightly sticky. slightly plastic: common mica flakes:

	common medium to coarse continuous pores; clear smooth boundary to
118–150 cm	yellowish brown (10 YR 5/4 moist); fine, silt loam; sub-angular blocky; slightly firm, slightly sticky, slightly plastic; common medium, distinct, strong brown mottles (7.5 YR 5/6); common medium to coarse continuous pores; common mica flakes; clear smooth boundary to
150 – 200 cm	brown (10 YR 5/3 moist); fine, silt loam, sub-angular blocky; slightly firm, slightly sticky, slightly plastic; many medium, distinct yellowish red mottles (5 YR 4/6); common medium to coarse continuous pores; many mica flakes; depth to ground water below the profile

Soil Profile: Elemebiri 2 (ELM 2) Sagbama Local Government Area

Parent material: Recent Alluvial Deposits of Sedimentary origin

Geology: Lower Niger Deposits

Geomorphology: Alluvial plain, back slope or middle slope or levee slope of the Niger River

Location on site: Elemebiri, bank of Niger River (N 05° 21' 12.4", E 006° 30' 51.3")

Topography: Gently sloping (2-3%)

Drainage: Imperfectly drain

Depth to water table: No ground water encountered in the profile

Depth to impermeable layer: None encountered within profile depth

Erosion: No evidence of erosion

Flooding: None

Vegetation: Indian bamboo, plantain farm, sugar cane, elephant grass, camba grass

Date sampled: 25/03/2015

Soil Depth	Description of the Soil Profile
0 – 11 cm	very dark brown (10 YR 2/2 moist); silt loam; crumbly to weak sub-angular blocky; friable, slightly sticky, slightly plastic; many medium to fine roots; many mica flakes; many medium to coarse pores; clear smooth boundary to
11 – 19 cm	dark brown (10 YR 3/3 moist); fine, silty clay loam, weak sub-angular blocky; moderately firm, slightly sticky, slightly plastic; many medium to large roots; medium to coarse continuous pores; many mica flakes; clear smooth boundary to
19 – 32 cm	very dark grayish brown (10 YR 3/2 moist); fine, silty clay loam, weak sub-angular blocky; moderately firm, slightly sticky, slightly plastic; many mica

	flakes; common medium to large roots; many medium to coarse continuous pores; clear smooth boundary to
32 – 42 cm	brown (10 YR 4/3 moist): fine, silt loam, weak sub-angular blocky; slightly firm, slightly sticky, slightly plastic; many medium to coarse continuous pores; common large roots; common mica flakes; clear smooth boundary to
42 – 57 cm	brown (10 YR 5/3 moist): fine, silt loam, sub-angular blocky; slightly firm, slightly sticky, slightly plastic; few large roots; many mica flakes; many medium to coarse continuous pores; clear smooth boundary to
57 – 88 cm	grayish brown (10 YR 5/2 moist): fine, silt loam, sub-angular blocky; slightly firm, slightly sticky, slightly plastic; many medium distinct dark brown mottles (7.5 YR 3/4); many mica flakes; common medium to coarse continuous pores; no root activity; clear smooth boundary to
88 – 106 cm	grayish brown (10YR 5/2 moist): fine, silt loam, sub-angular blocky; slightlyfirm, slightly sticky, slightly plastic; many medium distinct strong brown mottles (7.5 YR 4/6); many mica flakes; common medium to coarse continuous pores; no root activity; clear smooth boundary to
106 – 190 cm	gray (10 YR 5/1 moist): fine, silt loam, sub-angular blocky; slightlyfirm,slightly sticky, slightly plastic; many medium, distinct, strong brown mottles (7.5 YR 4/6); many mica flakes; common medium to coarse continuous pores; no root activity, depth to ground water below the profile

Soil Profile: Elemebiri 3 (ELM 3) Sagbama Local Government Area

Parent material: Recent Alluvial Deposits of Sedimentary origin

Geology: Lower Niger Deposits

Geomorphology: Recent Alluvial fans or alluvial deposits on the centre of the Niger River

Location on site: Elemebiri (N 05° 21' 22.6" E 006 30' 51.3")

Topography: Almost Flat (0-5%)

Drainage: Well-drained but seasonally flooded

Depth to water table: No ground water encountered in the profile

Depth to impermeable layer: None encountered within profile depth

Erosion: No evidence of erosion

Flooding: Seasonally flooded each year

Vegetation: grassy vegetation with cultivated patches of pepper, okra, yam, cassava.

Date sampled: 27/03/2015

Soil Depth	Description of the Soil Profile
0 – 18 cm	dark yellowish brown (10 YR 3/6 moist): silt loam, crumbly to very weak sub angular blocky: very friable, non-sticky, non- plastic: many mica flakes: many medium to coarse continuous pores: many medium to fine roots: clear smooth boundary to
18 – 31 cm	dark brown (10 YR 3/3 moist): fine, silt loam, weak sub-angular blocky: friable, non-sticky, non-plastic: few medium, distinct, dark reddish brown mottles: (2.5 YR 3/3): many mica flakes: many medium to coarse continuous pores: common medium to fine roots: clear smooth boundary to
31 – 44 cm	dark yellowish brown1(0 YR 6/4 moist): fine, silt loam, single grain: loose, non-sticky, non-plastic: many mica flakes: few medium roots: many medium to coarse continuous pores: clear smooth boundary to
44 – 68 cm	dark yellowish brown (10 YR 4/6 moist): fine, silt loam, single grain, loose: non sticky: non plastic: many mica flakes: many medium to coarse continuous pores: no root activity: clear smooth boundary to
68 – 81 cm	yellowish brown (10 YR 5/4 moist): fine, silt loam, very weak sub-angular blocky: friable, non-sticky: non-plastic: many medium to coarse continuous pores: many mica flakes: clear smooth boundary to
81 – 123 cm	dark yellowish brown (10 YR 3/4 moist): fine, silty clay loam, sub-angular blocky: slightly firm, slightly sticky, slightly plastic: few fine mottles: many medium to coarse continuous pores: many mica flakes: clear smooth boundary to
123 – 160 cm	brown (7.5 YR 4/4 moist): fine, silty clay loam, sub-angular blocky: moderately firm, moderately sticky, moderately plastic: many medium to coarse continuous pores: many mica flakes: gradual boundary to
160– 200 cm	very dark brown (7.5 YR 2.5/3 moist): fine, silty clay loam, sub-angular blocky: moderately firm, moderately sticky, moderately plastic: few fine mottles: many medium to coarse continuous pores: many mica flakes: depth to ground water below the profile

Soil Profile: Odoni 1. (ODN 1) Sagbama Local Government Area

Parent material: Alluvium

Geology: Upper Delta Plain of the Meander Belts

Geomorphology: Alluvial plain, levee crest or upper slope

Location on site: Odoni, bank of Nun River (N 05 14' 12.4" E 006 22' 37.2")

Topography: Almost flat (1%)

Drainage: Moderately well-drained

Depth to water table: None encountered

Depth to impermeable layer: None encountered within profile depth

Erosion: No evidence of erosion

Flooding: None

Vegetation: Plantain farm, secondary bush

Date sampled: 23/02/2015

Soil depth	Soil Description of the Soil Profile
0-23cm	very dark brown (7.5 YR 3/2 moist): fine, silt loam, very weak sub angular blocky, slightly firm, slightly plastic, slightly sticky: many coarse continuous pores: many mica flakes: many medium to fine roots: clear smooth boundary to
23 – 30cm	brown (7.5 YR 4/4 moist): fine, silt loam, very weak sub-angular blocky, very friable, slightly plastic, slightly sticky: many coarse continuous pores: many medium to fine roots: many mica flakes: clear smooth boundary to
30 – 63cm	brown (7.5 YR 4/4 moist): fine, silt loam, sub-angular blocky: moderately firm, moderately plastic, moderately sticky: many coarse continuous pores: common large root activities: common mica flakes: diffuse wavy boundary to
63 – 117cm	strong brown 7.5 YR 4/6 moist): fine, silt loam to loam, sub-angular blocky: moderately firm, moderately plastic, moderately sticky: many coarse continuous pores: few large roots activity, common mica flakes: diffuse wavy boundary to
117–160cm	brown (7.5 YR 4/3 moist): fine, silt loam, sub-angular blocky: moderately firm, moderately plastic, moderately sticky: common coarse to medium continuous pores: many coarse, distinct, reddish brown mottles (5 YR 4/4): common mica flakes: diffuse wavy boundary to
160–200cm	strong brown (7.5 YR 4/6 moist): fine, silt loam, sub-angular blocky: firm, non-plastic, slightly sticky: common medium continuous pores, many coarse prominent yellowish red mottles (5 YR 4/6): common mica flakes: depth to ground water below the profile

Soil Profile: Odoni 2 (ODN2) Sagbama Local Government Area

Parent material: Recent Alluvial Deposit of Sedimentary origin

Geology: Upper Delta Plain of the Meander Belts

Geomorphology: Alluvial plain, levee slope or middle slope or back slope of the Nun River

Location on site: Odoni, bank of Nun River (N 05 14'33.3" E 006 22'25.5")

Topography: Almost flat (1-3%)

Drainage: Imperfectly drain

Depth to water table: None encountered

Depth to impermeable layer: None encountered within profile depth

Erosion: No evidence of erosion

Flooding: None

Vegetation/Land use: Grassy vegetation, pepper farm, plantain, cassava

Date sampled: 25/02/2015

Soil depth	Soil Description of the Soil Profile
0 – 10cm	brown (7.5 YR 4/2 moist): fine, silt loam, sub-angular blocky structure: slightly firm, slightly plastic, slightly sticky: many coarse continuous pores: many medium to fine roots: many mica flakes: clear smooth boundary to
10 – 21cm	dark brown (7.5 YR 3/2 moist): fine, silt loam: sub-angular blocky: moderately firm, slightly plastic, slightly sticky: many coarse continuous pores: common mica flakes: many medium to fine roots: clear smooth boundary to
21 – 37cm	brown (7.5 YR 4/2 moist): fine, silt loam, sub-angular blocky: moderately firm, moderately plastic, moderately sticky: few fine mottles: common medium roots: many mica flakes: many coarse continuous pores: clear smooth boundary
37 – 46cm	brown (7.5 YR 4/3 moist): fine, silty clay loam, sub-angular blocky: moderately firm, moderately plastic, moderately sticky: many scattered, fine, non-distinct mottles: few roots, common mica flakes: many coarse to medium continuous pores: diffuse wavy boundary to
46 – 79cm	strong brown (7.5 YR 4/6 moist) silt loam to loam, sub-angular blocky: moderately firm, moderately plastic, moderately sticky: many, coarse, prominent yellowish red mottles (5 YR 4/6), few fine roots: many coarse to medium continuous pores: clear smooth boundary to
79 – 149cm	brown (7.5 YR 4/4 moist), fine, loam, sub-angular blocky: moderately firm, moderately plastic, moderately sticky: few roots: many medium to coarse continuous pores: common mica flakes: clear smooth boundary to
149- 200cm	brown (7.5 YR 4/4 moist): fine, loam, sub-angular blocky: moderately firm, moderately plastic, moderately sticky: many, coarse, prominent, reddish brown mottles (5 YR 4/3): common medium continuous pores, few large pores: common mica flakes: depth to ground water below the profile.

Soil Profile: Odoni 3 (ODN3) Sagbama Local Government Area

Parent material: Alluvium

Geology: Upper Delta Plain of the Meander Belts

Geomorphology: Lower slope or levee slope or flood plain of the Nun River

Location on site: Odoni. by Nun River (N 05° 14' 53.3" E 006° 22' 43.4")

Topography: Gently sloping (3-4%)

Drainage: Poorly drain

Depth to water table: None encountered

Depth to impermeable layer: None encountered within profile depth

Erosion: No evidence of erosion

Flooding: Seasonally flooded. but without flood during sampling

Vegetation: Pepper farm with plantain surrounded by grasses (e.g. elephant grass. costus affer. rubber trees

Date sampled: 28/02/2015

Soil depth	Soil Description of the Soil Profile
0 – 5cm	dark brown (7.5 YR 3/2 moist): fine. silt loam. weak sub-angular blocky. slightly firm. slightly plastic. slightly sticky: few. medium. distinct. reddish brown mottles (5 YR 4/4): common mica flakes: few medium pores : many medium to fine roots: diffuse gradual boundary to
5 – 11cm	brown (7.5 YR 4/4 moist): fine. silt loam. weak sub-angular blocky: moderately firm. slightly plastic. slightly sticky: common. medium. distinct. reddish brown mottles (5 YR 5/3): large pores present:: common mica flakes: many medium to fine root: diffuse wavy boundary to
11 – 25cm	brown (7.5 YR 4/4 moist): fine. silt loam. sub-angular blocky: moderately firm. moderately plastic. moderately sticky: common. medium. distinct. light reddish brown mottles (5YR 6/4): many coarse to medium continuous pores: common mica flakes: common medium roots: diffuse gradual boundary to
25 – 41cm	pinkish gray (7.5 YR 6/2 moist): fine. silt loam. sub-angular blocky: moderately firm. moderately plastic. moderately sticky: common. medium. distinct. gray mottles (5 YR 6/1): common mica flakes : many coarse to medium continuous pores: dark brown to black concretions present : few medium roots: clear smooth boundary to
41 – 48cm	brown (7.5 YR 4/4 moist): fine. silty clay loam. sub-angular blocky: moderately firm. moderately plastic. moderately sticky: common medium distinct reddish gray mottles (5 YR 5/2): common mica flakes: common coarse to medium continuous pores: dark brown to black concretions: few roots: clear smooth boundary to
48 – 56cm	brown (7.5 YR 5/4 moist): fine. clay loam. sub-angular blocky: moderately firm .moderately plastic. moderately sticky: many. coarse. prominent. reddish brown mottles (5 YR 4/4): common mica flakes: common coarse to medium continuous pores: dark brown to black concretions present : few roots: clear smooth boundary to

56–122cm	strong brown (7.5 YR 5/6 moist): fine, loam, sub-angular blocky: moderately firm: moderately plastic, moderately sticky: many, coarse, prominent, reddish brown mottles (5 YR 4/4) common mica flakes: common medium to coarse continuous pores: few roots: clear smooth boundary to
122-200cm	strong brown (7.5 YR 4/6 moist): fine, silt loam, sub-angular blocky: moderately firm, moderately plastic, moderately sticky: many, coarse, prominent, yellowish red mottles 5 YR 4/6 common mica flakes: common medium continuous pores: depth to ground water below the profile

Soil Profile: Trofani 1 (TFN1) Sagbama Local Government Area

Parent material: Alluvium
Geology: Upper Delta Plain of the Meander Belts

Geomorphology: Alluvial Plain, levee crest or upper slope of Forcados River

Location on site: Trofani (N 05 18' 01.5" E 006 19' 36.0")

Topography: Nearly level (0-1% slope)

Drainage: Well-drained

Depth to water table: None encountered

Depth to impermeable layer: None encountered within profile depth

Erosion: None encountered

Flooding: No evidence of flooding

Vegetation Land use: Cassava farm, wild oil palm, grassy vegetation.

Date sampled: 26/01/2015

Soil depth	Soil Description of the Soil Profile
0 – 14cm	dark yellowish brown (10 YR 3/4 moist): fine, silt loam, sub-angular blocky: slightly firm, slightly plastic, slightly sticky: many coarse to medium continuous pores: many medium and fine roots: many mica flakes: clear smooth boundary to
14 – 31cm	dark yellowish brown (10 YR 3/4 moist): fine, silt loam, sub-angular blocky: slightly firm, slightly plastic, slightly sticky: many coarse to medium continuous pores: common mica flakes: many medium to fine roots: clear smooth boundary to
31 - 55cm	dark yellowish brown 10 YR 3/4 moist), fine, silt loam, sub-angular blocky: moderately firm, moderately sticky, moderately plastic: many coarse to medium continuous pores: very many mica flakes: common medium

	roots: clear smooth boundary to
55–140cm	dark yellowish brown (10 YR 3/6 moist): fine, silt loam, sub-angular blocky: moderately firm, slightly sticky, slightly plastic: many mica flakes: many coarse to medium continuous pores: clear smooth boundary to
140–150cm	dark grayish brown (10 YR 4/2 moist): fine, silty clay loam, sub-angular blocky: moderately firm, moderately sticky, moderately plastic: common medium distinct dark reddish brown mottles (2.5 YR 3/4): strong gleying: black concretions: common medium to coarse continuous pores: common mica flakes: clear smooth boundary to
150–200cm	dark yellowish brown 10 YR 4/4 moist): fine, silty loam, sub-angular blocky: moderately firm, moderately sticky, moderately plastic: many coarse prominent yellowish red mottles (5 YR 4/6): common medium to coarse continuous pores: common mica flakes: depth to ground water below the profile.

Soil Profile: Trofani 2 (TFN2) Sagbama Local Government Area

Parent material: Recent Alluvial Deposit of Sedimentary origin

Geology: Upper Delta Plain of the Meander Belts

Geomorphologic unit: Alluvial plain, back slope, levee slope or middle slope of Forcados River

Location on site: Trofani (N 05 17' 58.6", E 006 19' 37.1")

Topography: Nearly level (1-3% slope)

Drainage: Imperfectly drain

Depth to water table: None encountered

Depth to impermeable layer: None encountered within profile depth

Erosion: None encountered

Flooding: No evidence of flooding

Vegetation Land use: under oil palm farm with ferns and other vegetation, close to cassava farm

Date sampled: 28/01/2015

Soil depth	Soil Description of the Soil Profile
0 – 11cm	dark brown (7.5 YR 3/3 moist): fine, loamy sand, crumbly structure: very friable, non-sticky, non-plastic: many medium roots: many coarse and medium continuous pores: many mica flakes: clear smooth boundary to

11 – 35cm	dark yellowish brown (10 YR 4/4 moist); fine, silt loam, sub-angular blocky; slightly firm, slightly sticky, slightly plastic; many scattered fine mottles; many large and medium roots; black concretions; many mica flakes; common medium to coarse continuous pores; clear smooth boundary to
35 – 44cm	brown 10YR 5/2 moist); fine, silt clay loam, sub-angular blocky; slightly firm, slightly sticky, slightly plastic; many large and medium roots; common coarse to medium continuous pores; common mica flakes; clear smooth boundary to
44 – 70cm	brown (10 YR 5/3 moist); fine, silt loam, sub-angular blocky; slightly firm, slightly sticky, slightly plastic; common large roots; common coarse continuous pores; common mica flakes; clear smooth boundary to
70 – 126cm	grayish brown (10 YR 5/2 moist); fine, silt loam, sub-angular blocky; slightly firm, slightly sticky, slightly plastic; many, coarse, prominent, dark reddish brown mottles (5 YR 3/3); few large roots; common coarse to medium continuous pores; common mica flakes; clear smooth boundary to
126 – 200cm	light brownish gray (10 YR 6/2 moist); fine, loam, sub-angular blocky; slightly firm, slightly sticky, slightly plastic; many, coarse, prominent, dark reddish brown mottles (5 YR 3/3); few large roots; common mica flakes; depth to ground water below the profile.

Soil Profile: Trofani 3 (TFN3) Sagbama Local Government Area

Parent material: Recent Alluvial Deposit of Sedimentary origin

Geology: Upper Delta Plain of the Meander Belts

Geomorphology: Alluvial fan or recent alluvial deposits on Forcados River (Fadama)

Location on site: Trofani (N 05 17' 58.6", E 006 19' 37.1")

Topography: Undulating (2-5%)

Drainage: Well-drained but seasonally flooded

Depth to water table: None encountered

Depth to impermeable layer: None encountered within profile depth

Erosion: No significant evidence of erosion

Flooding: flooded each year

Vegetation: grassy vegetation with cultivated patches of yam, cassava, okra, pepper, etc.

Date sampled: 30/01/2015

Soil depth	Soil Description of the Soil Profile
0 – 13cm	dark brown (10 YR 3/3 moist); fine. silt loam. massive: slightly firm. slightly sticky. slightly plastic: many medium to fine roots; few medium pores: common mica flakes : clear wavy boundary to
13 – 23cm	dark yellowish brown (10 YR 3/4 moist): fine. silt loam. weak sub-angular blocky: slightly firm. slightly sticky. slightly plastic: many medium to fine roots; many mica flakes: many coarse to medium continuous pores: clear wavy boundary to
23 – 38cm	yellowish brown (10 YR 5/4 moist): fine. silt loam: weak sub-angular blocky: slightly firm. slightly sticky. slightly plastic: many medium to fine roots: many coarse to medium continuous pores; many mica flakes: clear smooth boundary to
38 – 52cm	dark brown (10 YR 3/3 moist): fine. sandy loam. sub-angular blocky: slightly firm. slightly sticky. slightly plastic: many medium distinct dusky red mottles (10R 3/3): few fine to medium roots: many mica flakes: common medium to coarse continuous pores: clear smooth boundary to
52 – 69cm	dark yellowish brown (10 YR 4/6): fine. silt loam: sub-angular blocky: slightly firm. slightly sticky. slightly plastic: common. medium. distinct. dark brown mottles (10 YR 3/3); many brown concretions: few medium roots: many mica flakes: common medium to coarse continuous pores: clear wavy boundary to
69 – 83cm	dark brown (10 YR 3/3 moist): fine. loamy sand: single grain: loose. non-sticky. non-plastic: many mica flakes: many coarse continuous pores: clear wavy boundary to
83 – 200cm	light yellowish brown (10 YR 6/4 moist): fine. sand: single grain: loose. non-sticky. non-plastic: many mica flakes: many coarse continuous pores: depth to ground water below the profile.

Soil Profile: Odi 1 (ODI1) Kolokuma/Opukuma Local Government Area

Parent material: Recent Alluvial Deposit of Sedimentary origin

Geology: Upper Delta Plain of Nun River

Geomorphology: Alluvial plain. Levee crest or Upper slope on the bank of Nun River

Location on site: Odi. bank of Nun River (N 05° 11' 17.4" E 006° 18' 04.6")

Topography: Almost flat (0-1%)

Drainage: Moderately well-drained

Depth to water table: None encountered

Depth to impermeable layer: None encountered within profile depth

Erosion: None encountered

Flooding: No evidence of flooding

Vegetation/Land use: Cassava farm, grassy vegetation, oil palm trees in the wild.

Date sampled: 09/02/2015

Soil depth	Soil Description of the Soil Profile
0 – 26cm	brown (10 YR 4/3, dry) and dark brown (10 YR 3/3, moist): fine, silt loam, crumbly: friable, slightly plastic, slightly sticky: many medium to coarse continuous pores: many mica flakes: many fine roots: clear boundary to
26 – 60cm	dark yellowish brown (10 YR 4/4 moist and dry): fine, silt loam to loam: very weak sub-angular blocky: friable, slightly plastic, slightly sticky: many medium to coarse continuous pores: few large pores: many mica flakes: common medium roots: clear wavy boundary to
60 – 78cm	dark yellowish brown (10 YR 4/4 moist): fine, silt loam to loam, sub-angular blocky: moderately firm, moderately plastic, moderately sticky: few fine mottles: many medium to coarse continuous pores: many mica flakes: common medium roots: clear wavy boundary to
78 – 120cm	dark yellowish brown (10 YR 4/4 moist): fine, silt loam, sub-angular blocky: moderately firm, slightly plastic, slightly sticky: few fine mottles: many medium to coarse continuous pores many mica flakes: few fine roots: clear wavy boundary to
120– 135cm	dark yellowish brown (10 YR 4/4 moist): fine, loam, sub-angular blocky: slightly firm, slightly plastic, slightly sticky: few fine mottles: many medium to coarse continuous pores: many mica flakes: few fine roots: clear wavy boundary to
135 – 163cm	dark yellowish brown (10 YR 4/4 moist): fine, silty clay loam, sub-angular blocky: moderately firm, moderately plastic, moderately sticky: common, medium, distinct brown mottles (7.5 YR 3/4): many medium to coarse continuous pores: many mica flakes: clear wavy boundary to
163 – 186cm	dark yellowish brown (10 YR 4/4 moist): fine, silt loam, sub-angular blocky: moderately firm, moderately plastic, moderately sticky: many coarse, distinct, dark reddish brown mottles 2.5 YR 3/4), many medium to coarse continuous pores: many mica flakes: clear wavy boundary to
186 – 200cm	dark yellowish brown (10 YR 4/4 moist): fine, silt loam, sub-angular blocky: moderately firm, moderately plastic, moderately sticky: many coarse, prominent, reddish brown mottles (5 YR 4/4): common coarse to medium continuous pores: many mica flakes: depth ground water below the profile

Soil Profile: Odi 2 (ODI2), Kolokuma/Opokuma Local Government Area

Parent material: Recent Alluvial deposit of Sedimentary origin

Geology: Upper Delta Plain of the Meander Belts

Geomorphology: Alluvial plain, Levee slope or middle slope of the bank of Nun River

Location on site: Odi, by Nun River (N 05° 11' 17.1", E006° 17' 52.3")

Topography: (1-3%)

Drainage: Imperfectly drain

Depth to water table: Water into the profile at about 200cm

Depth to impermeable layer: None encountered within profile depth

Erosion: No significant evidence of erosion

Flooding: flooded each year during the flood season

Vegetation: cassava/okra intercrop, grassy vegetation

Date sampled: 11/02/2015

Soil depth	Soil Description of the Soil Profile
0 -20cm	dark yellowish brown (10 YR 3/4 moist) fine, silt loam, crumbly: friable, non-plastic, non-sticky: many medium to coarse continuous pores: many medium and fine roots: many mica flakes: gradual smooth boundary to
20 - 40cm	yellowish brown (10 YR 5/4 moist): fine, loam, sub-angular blocky: slightly firm to friable, slightly plastic, slightly sticky: many fine roots: many medium to coarse continuous pores: common mica flakes: clear smooth boundary to
40 – 110cm	brown (10 YR 5/3 moist): fine, silt loam, sub-angular blocky: slightly firm, slightly plastic, slightly sticky: many medium to coarse continuous pores: common medium roots: common mica flakes: clear smooth boundary to
110– 141cm	brown (7.5 YR 5/4 moist) fine, silt loam, weak sub-angular blocky: slightly firm, slightly plastic, slightly sticky: many, coarse, distinct, reddish brown mottles (5 YR 4/4): many medium to coarse continuous pores: few medium roots: common mica flakes: clear smooth boundary to
141 – 180cm	brown (7.5 YR 5/2 moist), fine, silt loam, sub-angular blocky: slightly firm, slightly sticky, slightly plastic: many, coarse, prominent, dark reddish brown mottles (5 YR 3/4): many medium to coarse continuous pores: common mica flakes: smooth boundary to
180 – 200cm	gray (10 YR 5/1 moist): fine, silt loam, sub-angular blocky: slightly firm, slightly plastic, slightly sticky: many, coarse, prominent, dark reddish mottles (5 YR 3/4), many medium continuous pores, few large pores: many mica flakes: many black concretions: depth to ground water below the profile.

Soil Profile: Odi 3 (ODI3) Kolokuma/Opokuma Local Government Area

Parent material: Recent Alluvial Deposit of Sedimentary origin

Geology: Upper Delta Plain of the Meander Belts

Geomorphology: Alluvial plain, Levee slope or lower slope of the Nun River

Location on site: Odi (N 05° 11' 38.7`` " E 006° 17' 47.0")

Topography: (3-5%)

Drainage: Poorly drain

Depth to water table: Water into the profile at about 200cm

Depth to impermeable layer: None encountered within profile depth

Erosion: No significant evidence of erosion

Flooding: flooded each year during the flood season

Vegetation: grassy vegetation with cultivated oil palm trees

Date: 13/02/2015

Soil depth	**Soil Description of the Soil Profile**
0 – 3cm	very dark brown (10 YR 2/2 dry) and black (10 YR 2/1 moist): fine. silt loam. crumbly structure: very friable. non-plastic. non-sticky: many large and fine roots: few medium distinct. reddish brown mottles (5 YR 4/4). many coarse continuous pores: common mica flakes: clear smooth boundary to
3 – 20cm	pale brown (10 YR 6/3 dry) and light yellowish brown (10 YR 6/4 moist): fine. silt loam: weak sub-angular blocky: friable. non-plastic. non- sticky: many fine mottles: many fine. medium and large roots common. medium distinct. reddish brown mottles (5 YR 5/3) many coarse to medium continuous pores: common mica flakes: clear smooth boundary to
20 – 46cm	light brownish gray (10 YR 6/2 dry) and pale brown (10 YR 6/3 moist): fine. silt loam. sub-angular blocky: slightly firm. slightly plastic. slightly sticky: common. medium. distinct. reddish brown mottles. (5 YR 5/4): many medium to coarse continuous pores: many mica flakes: common large roots: clear smooth boundary
46 – 60cm	pale brown (10 YR 6/3 dry) and brown (10 YR 5/3 moist): fine. silt loam. sub-angular blocky: moderately firm. slightly sticky. slightly plastic: common. medium. distinct. yellowish red (5 YR 4/6) mottles: many fine pores: few large roots: common medium to coarse continuous pores: many mica flakes: clear smooth boundary to
60 – 94cm	brown (7.5 YR 4/4 moist): fine. silt loam. sub-angular blocky: moderately firm. moderately plastic. moderately sticky: many. coarse. distinct. reddish brown mottles (5 YR 4/4): few large pores: many mica flakes:: few large roots: common medium to coarse continuous pores: gradual smooth boundary to
94 – 145cm	strong brown (10 YR 4/6 moist): fine. silt loam. sub-angular blocky: moderately firm. moderately sticky. moderately plastic: many coarse distinct mottles (5 YR 4/6): many medium continuous pores. few large pores: many concretions: many mica flakes: gradual smooth boundary to

145 – 158cm	yellowish brown (10 YR 5/4) fine, silt loam, sub-angular blocky; moderately firm, moderately sticky, moderately plastic; many coarse prominent weak red mottles (2.5 YR 5/2); many mica flakes; many fine pores; many dark concretions; common medium continuous pores; gradual smooth boundary to
158 – 200cm	yellowish brown (10 YR 5/4) fine, silt loam, sub-angular blocky; moderately firm, moderately sticky, moderately plastic; many coarse prominent reddish brown mottles (5 YR 5/3); many mica flakes; many medium continuous pores; many dark concretions; depth to ground water below profile

Soil Profile: Koroama 1 (KRM 1) Yenagoa Local Government Area

Parent material: Recent Alluvium of Sedimentary deposits

Geology: Upper Delta Plain of the Meander Belts

Geomorphology: Alluvial plain, Levee crest or Upper slope

Location on site: Koroama, by Taylor Creek (N 05 02' 59.9", E 006 17' 28.8")

Topography: Nearly level (0-1% slope)

Drainage: Moderately well-drained

Depth to water table: None encountered

Depth to impermeable layer: None encountered within profile depth

Erosion: None encountered

Flooding: Not flooded

Vegetation/Land use: oil palm, wild marigold, siam weed, cassava farm.

Date sampled: 12/01/2015

Soil depth	Soil Description of the Soil Profile
0 – 7cm	dark yellowish brown (10 YR 3/4 moist); fine, silt loam, crumbly to very weak sub-angular blocky structure; friable, non-sticky, non-plastic; many fine and medium roots; many medium to coarse continuous pores; many mica flakes; clear smooth boundary to
7 – 43cm	brown (10 YR 4/3 moist); fine, silt loam; sub-angular blocky; slightly firm, slightly sticky, slightly plastic; many medium to coarse pores; many fine, medium and large roots; many mica flakes; clear smooth boundary to
43 – 86cm	dark brown (10 YR 3/2 moist); fine, silt loam, sub-angular blocky; slightly firm, slightly sticky, slightly plastic; black concretions 2.5/N (Gley 1); common large roots; common medium to coarse continuous pores; many mica flakes clear smooth boundary to

86 – 115cm	dark brown (10 YR 3/2 moist); fine, silt loam, sub angular blocky, moderately firm, slightly sticky, slightly plastic; many coarse to medium continuous pores; many mica flakes; few large roots; clear smooth boundary to
115 – 130cm	brown (10 YR 4/2 moist), fine, silt loam, sub-angular blocky; moderately firm, slightly sticky, slightly plastic; many, medium, distinct, brown mottles (7.5 YR 4/4); very few large roots; yellowish red concretions (10 YR 5/6); common mica flakes; common medium continuous pores clear smooth boundary to
130 – 200cm	brown (10 YR 4/3 moist); fine, silt loam, sub-angular blocky; slightly hard when dry, moderately firm, slightly sticky, slightly plastic; many coarse, prominent, dark yellowish brown mottles (10 YR 4/6); common medium continuous pores; many mica flakes; depth to ground water level below profile

Soil Profile: Koroama 2 (KRM 2) Yenagoa Local Government Area

Parent material: Recent Alluvium of Sedimentary deposits

Geology: Upper Delta Plain of the Meander Belts

Geomorphology: Alluvial plain, Levee Slope or Middle slope

Location on site: Koroama, by Taylor Creek (N 05° 02' 59.2", E 006° 17' 26.9")

Topography: Nearly level (1-3% slope)

Drainage: Imperfectly drain

Depth to water table: None encountered

Depth to impermeable layer: None encountered within profile depth

Erosion: None encountered

Flooding: No evidence of flooding

Vegetation/Land use: secondary bush, oil palm, cassava farm, siam weed, wild marigold, gmelina, bush rubber.

Date sampled: 14/01/2015

Soil depth	Soil Description of the Soil Profile
0 – 15cm	very dark grayish brown (10 YR 3/2 moist); fine, silt loam, weak sub-angular blocky structure; slightly firm, slightly sticky, slightly plastic; many medium to fine roots; many coarse to medium continuous pores; few mica flakes; wavy boundary to
15 – 23cm	brown (10 YR 5/3 moist); fine, silt loam; sub-angular blocky; moderately firm, slightly sticky, slightly plastic; many fine mottles; many medium to fine roots; many coarse to medium continuous pores; many mica flakes; clear

	smooth boundary to
23 – 40 cm	brown (10 YR 5/3 moist); fine, silty clay loam; sub-angular blocky; moderately firm, slightly sticky, slightly plastic; many fine mottles; few fine to medium roots; many mica flakes; many medium to coarse continuous pores; clear smooth boundary to
40 – 64 cm	brown (10 YR 4/3 moist); fine, silty clay loam, sub-angular blocky; moderately firm slightly sticky, slightly plastic; many fine mottles; few fine roots; many mica flakes; many medium to large roots; common coarse to medium continuous pore, common medium to large roots; clear smooth boundary to
64 – 78 cm	brown (10 YR 5/3 moist); fine, silt loam, sub-angular blocky; moderately firm, slightly sticky, slightly plastic; many coarse, distinct, dark reddish brown mottles (5YR 3/4); few large roots; many mica flakes; no root activity; common coarse to medium continuous pores; clear smooth boundary to
78 –140 cm	grayish brown (10 YR 5/2 moist); fine, silt loam, sub-angular blocky; moderately firm, slightly sticky, slightly plastic; many coarse, prominent, dark reddish brown mottles (5 YR 3/4); many mica flakes; many coarse to medium continuous pores; clear smooth boundary to
140–194 cm	gray (10 YR 5/1 moist); fine, silt loam; sub-angular blocky; moderately firm, slightly sticky, slightly plastic; many coarse, prominent, very dark brown mottles (7.5 YR 2.5/3); common mica flakes; common coarse to medium continuous pores; depth to ground water level below profile

Soil Profile: Koroama 3 (KRM 3) Yenagoa Local Government Area

Parent material: Recent Alluvial Deposit of Sedimentary origin

Geology: Upper Delta Plain of the Meander Belts

Geomorphology: Alluvial plain, Flood plain or lower slope

Location on site: Koroama, by Taylor Creek (N 05° 02' 58.1", E 006° 17' 14.0")

Topography: Nearly level (3-4% slope)

Drainage: Poorly drain

Depth to water table: None encountered

Depth to impermeable layer: None encountered within profile depth

Erosion: None encountered

Flooding: seasonally flooded

Vegetation/Land use: plantain farm, wild marigold, oil palm, secondary forest

Date sampled: 16/01/2015

Soil depth	Soil Description of the Soil Profile
0 – 12 cm	very dark grayish brown (10 YR 3/2 moist): fine. silt loam: very weak sub-angular blocky: friable. non-sticky. non-plastic: common medium to fine roots: many coarse to medium continuous pores: few mica flakes: many medium to fine roots: wavy boundary to
12 – 39 cm	grayish brown (10 YR 5/2): fine. silty clay loam: sub-angular blocky: moderately firm. moderately sticky. moderately plastic: few. medium. distinct reddish brown mottles (5 YR 4/3): many coarse to medium continuous pores: few mica flakes: many medium to fine roots: wavy boundary to
39 – 59 cm	very dark brown (10 YR 2/2 moist): fine. silt loam. weak sub-angular blocky. slightly firm. slightly sticky. slightly plastic: many medium. distinct. dark reddish brown mottles (5 YR 3/4): many medium to large roots: many medium to coarse continuous pores: few mica flakes: clear boundary to
59 – 96 cm	grayish brown (10 YR 5/2 moist): fine. silty clay loam. sub-angular blocky: moderately firm. moderately sticky. moderately plastic: many coarse. distinct. strong brown mottles (7.5 YR 4/6): few large pores: many medium continuous pores: few mica flakes: common large roots: clear boundary to
96 – 135 cm	grayish brown (10 YR 5/2 moist): fine. silty clay loam: sub-angular blocky: moderately firm. moderately sticky. moderately plastic: many coarse prominent strong brown mottles (7.5 YR 4/6): few mica flakes: many medium to coarse continuous pores: clear boundary to
135 – 190 cm	grayish brown (10 YR 5/2 moist): fine. silty clay loam. sub-angular blocky: moderately firm. moderately sticky. moderately plastic: many coarse. prominent. strong brown mottles (7.5 YR 4/6): few mica flakes: common medium coarse continuous pores: depth to ground water below the profile

Soil Profile: NDU 1 (Niger Delta University Teaching and Research Farm) Southern Ijaw Local Government Area

Parent material: Recent Alluvial Deposit of Sedimentary origin

Geology: Upper Delta Plain of the Meander Belts

Geomorphology: Alluvial plain. Levee Crest or Upper slope

Location on site: Niger Delta University (N 04° 58' 49.1" E 006° 06' 23.7")

Topography: Almost flat (0-1%)

Drainage: Moderately well-drain

Depth to water table: None encountered

Depth to impermeable layer: None encountered within profile depth

Erosion: No evidence of erosion

Flooding: None

Vegetation/Land use: Students experimental plots, plantain farm, sugar cane

Date sampled: 09/03/2015

Soil depth	Soil Description of the Soil Profile
0 – 19 cm	dark brown (10 YR 3/3 moist): fine, silt loam, weak sub-angular blocky structure: slightly firm, slightly sticky, slightly plastic: many mica flakes: many medium to fine roots: many coarse to medium continuous pores: clear smooth boundary to
19 – 39 cm	dark yellowish brown (10 YR 4/4 moist): fine, silty clay loam: sub-angular blocky: moderately firm, slightly sticky, slightly plastic: many coarse to medium continuous pores: many medium to fine roots: many mica flakes: clear smooth boundary to
39 – 71 cm	dark yellowish brown (10 YR 3 4 moist): fine, silty clay loam, sub-angular blocky: moderately firm, slightly sticky, slightly plastic: very few fine mottles: many coarse to medium continuous pores: many mica flakes: common medium to fine roots: few black concretions: clear smooth boundary to
71 – 81 cm	yellowish brown (10 YR 5/4 moist): fine, silty clay loam, sub-angular blocky: moderately firm, slightly sticky, slightly plastic: few fine mottles: few medium roots: many mica flakes: many coarse to medium continuous pores: clear smooth boundary to
81 – 138 cm	brown (10 YR 5/3 moist): fine, silt loam: weak sub-angular blocky: slightly firm, slightly sticky, slightly plastic: many coarse, distinct, reddishbrown mottles (5 YR 4/4): many mica flakes: common coarse to medium continuous pores: clear smooth boundary to
138 – 195 cm	light brownish gray (10 YR 6/2 moist): fine, silt loam, weak sub-angular blocky: slightly firm, slightly sticky, slightly plastic: many coarse, prominent, reddish brown mottles (5 YR 4/4): many mica flakes: common medium to coarse continuous pores: depth to ground water below the profile

Soil Profile: NDU 2 (Niger Delta University Teaching and Research Farm) Southern Ijaw Local Government Area.

Parent material: Recent Alluvial Deposit of Sedimentary origin

Geology: Upper Delta Plain of the Meander Belts

Geomorphology: Alluvial plain, Levee Crest or Upper slope

Location on site: Niger Delta University (N 04° 58' 49.9", E 006° 06' 17.5")

Topography: Almost flat (1-3%)

Drainage: Imperfectly drain

Depth to water table: None encountered

Depth to impermeable layer: None encountered within profile depth

Erosion: No evidence of erosion

Flooding: None

Vegetation: Close to student experimental cassava farm. Musanga species near the profile.

Date sampled: 11/03/2015

Soil depth	**Soil Description of the Soil Profile**
0 – 12cm	dark yellowish brown (10 YR 4/4 moist): fine. silty clay loam. sub-angular blocky structure: moderately firm. moderately sticky. moderately plastic: many medium to coarse continuous pores: many medium to fine roots: few mica flakes: clear smooth boundary to
12 – 26 cm	dark yellowish brown (10 YR 4/4 moist): fine. silty clay loam. sub-angular blocky: moderately firm. moderately sticky. moderately plastic: many fine mottles: common coarse to medium continuous pores: many medium to fine roots: few mica flakes: clear smooth boundary to
26 – 36 cm	brown (10 YR 5/3 moist): fine. silty clay loam. sub-angular blocky: moderately firm. moderately sticky. moderately plastic: many fine mottles: few medium roots: few mica flakes: few large pore. many medium to coarse continuous pores: clear smooth boundary to
36 – 53 cm	brown (10 YR 3/4 moist): fine. silty clay loam. sub-angular blocky: moderately firm. moderately sticky. moderately plastic: very few medium roots: few mica flakes: medium to coarse continuous pores: clear smooth boundary to
53 – 116 cm	yellowish brown (10 YR 5/4 moist): fine. clay loam. sub-angular blocky: moderately firm. moderately sticky. moderately plastic: many coarse. prominent. reddish brown mottles (5 YR 4/3): many medium to coarse continuous pores: many mica flakes: clear smooth boundary to
116– 190 cm	light brownish gray (10 YR 6/2 moist): fine. loam. sub-angular blocky: moderately firm. slightly sticky. slightly plastic: many coarse. prominent. dark brown mottles (7.5 YR 3/4): many medium to coarse continuous pores: many mica flakes: depth to ground water below the profile

Soil Profile: NDU 3 (Niger Delta University Teaching and Research Farm) Southern Ijaw Local Government Area

Parent material: Recent Alluvial Deposits of Sedimentary origin

Geology: Upper Delta Plain of the Meander Belts

Geomorphology: Alluvial plain. Flood plain or lower slope

Location on site: Niger Delta University. (N 04 58' 50.5". E 006 06' 15.7")

Topography: Gently sloping (3-4%)

Drainage: Imperfectly drain

Depth to water table: Ground water encountered in the profile

Depth to impermeable layer: None encountered within profile depth

Erosion: No evidence of erosion

Flooding: seasonally flooded

Vegetation: grassy

Date sampled: 14/03/2015

Soil depth	Soil Description of the Soil Profile
0 – 5 cm	dark brown (10 YR 3/3 moist): fine. silt loam. weak sub-angular blocky structure: friable. slightly sticky. slightly plastic. many medium to fine roots. many coarse to medium continuous pores. common mica flakes. clear smooth boundary to
5 – 13 cm	dark gray (10 YR 4/1 moist): fine. silt loam. weak sub-angular blocky: friable. slightly sticky. slightly plastic: many coarse. distinct. reddish brown mottles 5 YR 5/3) common medium to fine roots. many coarse to medium fine continuous pores. common mica flakes. clear smooth boundary to
13 – 20 cm	dark yellowish brown (10 YR 4/4 moist). fine. silt loam. weak sub-angular blocky: friable. slightly sticky. slightly plastic: many coarse. prominent. reddish brown mottles (5 YR 5/4): few medium roots. many mica flakes. common medium to fine continuous pores: clear smooth boundary to
20 – 75 cm	yellowish brown (10 YR 5/4 moist): fine. silt loam. weak sub-angular blocky: friable. slightly sticky. slightly plastic. many coarse. prominent. reddish brown mottles (5 YR 4/3): many mica flakes. common medium to fine continuous pores. water into profile
75 – 140 cm	yellowish brown (10 YR 5/4 moist): fine. silt loam. weak sub-angular blocky: friable. slightly sticky. slightly plastic. many coarse. prominent. pinkish gray mottles (5 YR 6/2): many mica flakes. common medium to fine pores. water into profile
140– 196 cm	pale brown (10 YR 6/3 moist): fine. silt loam. weak sub-angular blocky: friable. slightly sticky. slightly plastic. many coarse. prominent. gray mottles (5 YR 6/1): many mica flakes. common medium to fine pores. water into profile

Annenxure 2: Summary of Physical, Chemical and Micronutrient Characteristics of ELM1 Soil from Elemebiri in Bayelsa State, Southern Nigeria

	Surface 40 cm		Subsurface	
Parameters	**Range**	**Mean**	**Range**	**Mean**
Sand (%)	15-23	19	14-24	18
Silt (%)	54-67	61	56-73	65
Clay (%)	10-31	20	10-30	17
Silt/Clay Ratio	1.7-6.7	3.9	1.9-7.0	4.7
pH-H_2O	5.46-5.77	5.62	5.72-6.55	5.94
pH-$CaCl_2$	5.17-5.36	5.26	4.94-5.37	5.21
ΔpH	0.21-0.60	0.36	0.49-1.18	0.73
Organic C (%)	1.52-2.25	2.00	0.70-1.50	1.04
Organic Matter (%)	2.62-3.88	3.46	1.21-2.59	1.80
Total N (%)	0.08-0.25	0.15	0.02-0.09	0.06
C:N Ratio	9-20	16	12-21	17
Avail. P (Mg kg^{-1})	9-18	14	3-10	6
Exch. Bases (cmol/kg)				
Ca^{2+}	0.74-1.26	0.93	0.71-1.22	0.93
Mg^{2+}	0.43-0.64	0.55	0.10-1.22	0.49
K^{+}	0.53-1.65	0.91	0.18-0.42	0.60
Na^{+}	0.06-0.09	0.08	0.07-0.08	0.07
TEB	1.80-4.14	3.12	1.59-2.74	2.09
Exch. Acidity (cmol/kg)	1.50-2.50	2.16	1.40-2.40	1.88
Exch. Al (cmol/kg)	0.8-1.1	1.0	0.7-1.8	1.1
ECEC (cmol/kg)	3.99-5.62	4.60	3.99-4.74	3.97
Al Sat. (%)	14-28	22	15.46	29
PBS-ECEC (%)	43-62	55	41-59	53
ECe (dS/M)	0.06-0.21	0.12	0.08-0.23	0.15
Micronutrients (mg/kg)				
Fe	48 – 57	52	41 – 68	58
Mn	1.80 – 3.05	2.58	1.30 – 1.91	1.51
Zn	9.61 – 15.57	13.15	6.70 – 12.94	8.76
Cu	3.00 – 3.20	3.07	1.55 – 3.60	2.66

Annenxure 3: Summary of Physical, Chemical and Micronutrient Characteristics of ELM2 Soil from Elemebiri in Bayelsa State, Southern Nigeria

	Surface 40 cm		Subsurface	
Parameters	**Range**	**Mean**	**Range**	**Mean**
Sand (%)	18-31	23	12-28	21
Silt (%)	57-68	64	58-72	65
Clay (%)	12-16	14	12-18	15
Silt/Clay Ratio	4.1-5.2	4.7	3.6-5.3	4.4
pH-H_2O	5.44-6.61	5.96	5.74-6.18	6.04
pH-$CaCl_2$	5.20-5.37	5.23	5.17-5.32	5.23
ΔpH	0.09-1.24	0.67	0.54-1.01	0.81
Organic C (%)	0.16-1.03	0.42	0.11-0.16	0.13
Organic Matter (%)	0.27-1.77	0.71	0.19-0.28	0.23
Total N (%)	0.01-0.09	0.04	0.01-0.03	0.02
C:N Ratio	8-21	13	5-11	7
Avail. P ($MgKg^{-1}$)	10-17	14	6-8	7
Exch. Bases (cmol/kg)				
Ca^{2+}	0.80-1.95	1.10	0.63-0.90	0.81
Mg^{2+}	0.09-0.79	0.43	0.13-0.48	0.35
K^+	0.43-0.66	0.57	0.18-0.70	0.40
Na^+	0.03-0.13	0.07	0.04-0.08	0.06
TEB	1.54-2.57	2.17	1.29-2.16	1.61
Exch. Acidity (cmol/kg)	0.90-2.7	1.85	0.70-2.30	1.55
Exch. Al (cmol/kg)	0.6-1.2	0.9	0.5-1.3	0.9
ECEC (cmol/kg)	2.44-5.07	4.02	2.21-3.77	3.16
Al Sat. (%)	16-28	23	23-34	29
PBS-ECEC (%)	47-63	55	39-68	52
ECe (dS/M)	0.01-0.31	0.12	0.06-0.12	0.11
Micronutrients (mg/kg)				
Fe	41 – 65	58	42 – 55	50
Mn	1.69 – 3.56	2.54	1.60 – 1.94	1.77
Zn	9.54 – 16.17	13.13	8.66 – 16.56	11.84
Cu	2.30 – 3.65	3.03	1.25 – 4.70	2.96

Annenxure 4: Summary of Physical, Chemical and Micronutrient Characteristics of ELM3 Soil from Elemebiri in Bayelsa State, Southern Nigeria

	Surface 40 cm		Subsurface	
Parameters	**Range**	**Mean**	**Range**	**Mean**
Sand (%)	68-78	73	66-88	74
Silt (%)	18-28	23	10-21	18
Clay (%)	4-4	4	2-15	8
Silt/Clay Ratio	4.5-7.0	5.8	1.3-10.0	4.0
p*H*-H_2O	5.52-7.00	6.22	5.31-5.98	5.74
pH-$CaCl_2$	5.30-5.42	5.34	5.19-5.64	5.35
ΔpH	0.10-1.70	0.88	0.04-0.68	0.43
Organic C (%)	0.78-0.84	0.81	0.53-0.59	0.56
Organic Matter (%)	1.35-1.45	1.40	0.91-1.02	0.97
Total N (%)	0.03-0.06	0.04	0.02-0.07	0.04
C:N Ratio	13-28	21	8-27	15
Avail. P (Mg Kg^{-1})	9-18	14	5-10	7
Exch. Bases (cmol/kg)				
Ca^{2+}	0.72-0.84	0.76	0.56-1.28	0.93
Mg^{2+}	0.45-0.97	0.73	0.08-0.74	0.31
K^{+}	0.18-0.58	0.40	0.12-1.81	0.61
Na^{+}	0.06-0.08	0.07	0.03-0.08	0.07
TEB	1.70-2.47	1.96	0.99-3.91	1.91
Exch. Acidity (cmol/kg)	1.20-1.90	1.43	0.50-3.40	1.78
Exch. Al (cmol/kg)	0.7-1.2	1.1	0.3-1.9	1.0
ECEC (cmol/kg)	2.91-4.37	3.40	1.49-6.11	3.69
Al Sat. (%)	24-34	28	16-34	26
PBS-ECEC (%)	57-59	58	40-66	55
ECe (dS/M)	0.04-0.07	0.06	0.04-0.22	0.10
Micronutrients (mg/kg)				
Fe	42 – 62	52	42 – 65	65
Mn	2.22 – 4.25	3.16	1.56 – 2.41	1.87
Zn	4.09 – 11.34	7.39	3.48 – 17.98	10.05
Cu	1.90 – 4.80	2.98	2.50 – 5.30	4.01

Annenxure 5: Summary of Physical, Chemical and Micronutrient Characteristics of ODN1 Soil from Odoni in Bayelsa State, Southern Nigeria

	Surface 40 cm		Subsurface	
Parameters	**Range**	**Mean**	**Range**	**Mean**
Sand (%)	22-25	24	29-41	33
Silt (%)	65	65	52-55	53
Clay (%)	12-13	13	6-18	14
Silt/Clay Ratio	5-5.4	5.2	2.9-8.8	4.73
$pH\text{-}H_2O$	5.75-5.76	5.76	5.33-6.48	6.04
$pH\text{-}CaCl_2$	5.17-5.33	5.25	5.17-5.72	5.37
ΔpH	0.42-0.43	0.43	0.16-1.02	0.67
Organic C (%)	0.58-1.07	0.83	0.01-0.41	0.19
ORGANIC Matter (%)	1.00-1.84	1.42	0.02-0.71	0.32
Total N (%)	0.05	0.05	0.01-0.04	0.02
C:N Ratio	12-21	17	10-12	11
Avail. P (Mg K^{-1})	12-15	14	3-9	7
	Exch. Bases (cmol/kg)			
Ca^{2}	0.75-1.25	1.00	0.72-0.91	0.81
Mg^{2+}	0.58-0.99	0.79	0.15-0.93	0.43
K	0.24-0.53	0.39	0.17-1.12	0.56
Na	0.07-0.09	0.08	0.03-0.09	0.07
TEB	2.05-2.45	2.25	1.07-2.99	1.87
Exch. Acidity (cmol/kg)	1.9-2.2	2.1	1.1-2.8	1.9
Exch. Al (cmol/kg)	1.0-1.4	1.2	0.7-1.8	1.2
ECEC (cmol/kg)	4.25-4.35	4.30	2.47-4.75	3.72
Al Sat. (%)	23-33	28	17-45	33
PBS-ECEC (%)	52-56	54	41-73	66
EC (ds/M)	0.12-0.19	0.16	0.00-0.17	0.11
	Micronutrients (mg/kg)			
Fe	36 – 46	41	47 – 95	67
Mn	1.62 – 2.80	2.21	0.53 – 1.21	0.93
Zn	15.20 18.00	16.60	4.99 – 11.67	9.33
Cu	2.05 – 3.65	2.85	0.95 – 5.95	3.78

Annenxure 6: Summary of Physical, Chemical and Micronutrient Characteristics of ODN2 Soil from Odoni in Bayelsa State, Southern Nigeria

	Surface 40 cm		Subsurface	
Parameters	**Range**	**Mean**	**Range**	**Mean**
Sand (%)	21-35	29	27-48	39
Silt (%)	53-60	56	38-58	47
Clay (%)	12-19	15	12-15	14
Silt/Clay Ratio	3.2-4.4	3.8	2.7-4.4	3.5
pH-H_2O	5.38-6.70	5.91	6.11-6.41	6.27
pH-$CaCl_2$	5.18-5.32	5.24	5.27-6.19	5.54
ΔpH	0.20-1.38	0.67	0.22-1.10	0.74
Organic C (%)	0.20-2.13	1.22	0.37-0.73	0.61
Organic Matter (%)	0.35-3.68	2.10	0.63-1.26	1.04
Total N (%)	0.04-0.21	0.11	0.03-0.06	0.05
C:N Ratio	5-15	10	11-12	12
Avail. P (Mg Kg^{-1})	8-16	13	2-4	3
Exch. Bases (cmol/kg)				
Ca^{2+}	0.70-0.79	0.74	0.74-0.83	0.78
Mg^{2}	0.28-0.86	0.53	0.38-0.89	0.57
K	0.10-0.48	0.33	0.15-0.82	0.43
Na	0.07-0.08	0.07	0.05-0.08	0.07
TEB	1.47-1.81	1.68	1.55-2.02	1.83
Exch. Acidity (cmol/kg)	1.5-2.9	2.2	1.4-6.2	2.83
Exch. Al (cmol/kg)	0.9-1.9	1.2	0.7-3.6	1.6
ECEC (cmol/kg)	2.97-4.71	3.88	3.42-8.06	4.66
Al Sat. (%)	30-40	37	20-45	30
PBS-ECEC (%)	38-49	44	23-59	45
ECe (ds/M)	0.12-0.14	0.13	0.06-020	0.10
Micronutrients (mg/kg)				
Fe	41 63	49	26 – 55	43
Mn	1.51 – 3.72	2.98	1.11- 3.80	1.99
Zn	8.12 – 18.99	13.19	6.61 – 17.19	11.57
Cu	3.00 – 4.35	3.62	2.30 – 5.10	3.34

Annenxure 7: Summary of Physical, Chemical and Micronutrient Characteristics of ODN3 Soil from Odoni in Bayelsa State, Southern Nigeria

	Surface 40 cm		Subsurface	
Parameters	**Range**	**Mean**	**Range**	**Mean**
Sand (%)	19-25	22	21-33	26
Silt (%)	53-65	61	48-51	49
Clay (%)	12-22	18	19-29	25
Silt/Clay Ratio	2.4-5.4	3.7	1.7-2.5	2.1
pH-H_2O	5.67-6.45	6.04	5.91-6.62	6.30
pH-$CaCl_2$	5.18-5.51	5.34	5.27-5.70	5.41
ΔpH	0.30-0.94	0.70	0.55-1.30	0.88
Organic C (%)	0.31-2.33	1.36	0.31-0.99	0.71
Organic Matter (%)	0.53-4.02	2.35	0.53-1.70	1.22
Total N (%)	0.03-0.20	0.12	0.03-0.09	0.06
C:N Ratio	12	12	10-11	11
Avail. P (Mg Kg^{-1})	14-22	17	1-5	3
Exch. Bases (cmol/kg)				
Ca^{2+}	0.69-1.95	1.15	0.73-1.22	0.97
Mg^{2+}	0.32-0.70	0.49	0.39-0.92	0.53
K^{+}	0.18-0.68	0.53	0.58-2.13	1.20
Na^{+}	0.04-0.13	0.08	0.07-0.80	0.07
TEB	1.36-3.39	2.97	1.97-4.34	2.79
Exch. Acidity (cmol/kg)	1.6-2.3	1.9	2.0-3.4	2.5
Exch. Al (cmol/kg)	0.8-1.5	1.1	1.2-2.0	1.5
ECEC (cmol/kg)	3.66-4.99	4.15	4.07-6.84	5.29
Al Sat. (%)	16-41	28	23-35	29
PBS-ECEC (%)	37-68	53	40-63	52
ECe (dS/M)	0-0.67	0.20	0-0.25	0.08
Micronutrient (mg/kg)				
Fe	35 – 74	58	39 – 74	53
Mn	1.14 – 3.10	2.12	1.58 – 2.86	2.20
Zn	4.45 – 11.80	7.32	4.10 – 9.88	7.79
Cu	2.40 – 4.10	3.38	2.50 – 4.10	3.03

Annenxure 8: Summary of Physical, Chemical and Micronutrient Characteristics of TFN1 Soil from Trofani in Bayelsa State, Southern Nigeria

	Surface 40 cm		Subsurface	
Parameters	**Range**	**Mean**	**Range**	**Mean**
Sand (%)	21	21	11-39	20
Silt (%)	60-62	61	50-66	61
Clay (%)	17-19	18	11-29	20
Silt/Clay Ratio	3.2-36	3.4	2.1-4.5	3.4
pH-H$_2$O	5.64-5.75	5.70	5.30-5.95	5.75
pH-CaCl$_2$	5.12-5.25	5.19	5.09-5.39	5.23
Δ*pH*	0.50-0.52	0.51	0.21-0.74	0.52
Organic C (%)	0.45-1.60	1.03	0.21-1.04	0.54
Organic Matter C (%)	0.78-2.76	1.77	0.37-1.80	0.94
Total N (%)	0.06-0.13	0.10	0.02-0.04	0.03
C:N Ratio	8-12	10	8-26	16
Avail. P (MgKg^{-1})	8-12	10	4-16	9
Exch. Bases (cmol/kg)				
Ca^{2+}	0.75-0.78	0.77	0.56-0.78	0.72
Mg^{2+}	0.12-0.42	0.27	0.20-0.98	0.72
K^{+}	0.15-0.65	0.35	0.16-0.62	0.43
Na^{+}	0.07	0.07	0.03-0.07	0.06
TEB	1.09-1.92	1.51	0.97-2.07	1.61
Exch. Acidity (cmol/kg)	1.70-1.80	1.75	1.90-5.40	3.10
Exch. Al (cmol/kg)	1.0-1.4	1.2	0.8-2.4	1.4
ECEC (cmol/kg)	2.89-3.62	3.26	3.66-6.37	4.71
Al Sat. (%)	35-39	37	18-38	29
PBS-ECEC (%)	38-53	46	15-48	37
EC(ds/M)	0.07-0.09	0.08	0.04-0.11	0.06
Micronutrients (mg/kg)				
Fe	49 – 54	52	34 – 79	67
Mn	2.39 – 3.42	2.91	0.49 –0. 86	0.56
Zn	5.41 – 15.86	10.64	6.52 – 14.26	9.88
Cu	2.40 – 2.80	2.60	2.55 – 5.70	3.86

Annenxure 9: Summary of Physical, Chemical and Micronutrient Characteristics of TFN2 Soil from Trofani in Bayelsa State, Southern Nigeria

	Surface 40 cm		Subsurface	
Parameters	**Range**	**Mean**	**Range**	**Mean**
Sand (%)	15-79	36	17-41	30
Silt (%)	17-60	45	49-60	56
Clay (%)	4-28	19	10-23	15
Silt/Clay Ratio	2.0-4.3	2.9	2.6-5.3	4.3
pH-H_2O	5.98-6.16	6.10	6.15-6.80	6.40
pH-$CaCl_2$	5.06-5.35	5.19	4.90-5.25	5.07
ΔpH	0.81-1.09	0.90	1.09-1.55	1.38
Organic C (%)	0.35-1.28	0.74	0.19-0.31	0.24
Organic Matter (%)	0.60-2.20	1.27	0.32-0.54	0.41
Total N (%)	0.05-0.06	0.06	0.02-0.03	0.03
C:N Ratio	12-21	17	10-12	11
Avail. P (Mg Kg^{-1})	10-17	14	2-15	7
Exch. Bases (cmol/kg)				
Ca^{2+}	0.75-1.83	1.27	0.78-1.83	1.17
Mg^{2+}	0.12-0.89	0.44	0.40-0.66	0.51
K	0.14-0.53	0.37	0.28-1.88	0.81
Na	0.07-0.08	0.08	0.05-0.07	0.06
TEB	1.09-2.91	2.05	1.74-3.24	2.56
Exch. Acidity (cmol/kg)	1.80-3.30	2.57	0.80-1.80	1.20
Exch. Al (cmol/kg)	1-1.9	1.5	0.5-1.1	0.7
ECEC (cmol/kg)	2.89-6.29	4.62	2.79-5.04	3.76
Al Sat. (%)	31-35	33	14-23	19
PBS- ECEC (%)	38-47	43	64-77	68
EC (ds/M)	0.01-0.09	0.04	0-0.03	0.01
Micronutrients (mg/kg)				
Fe	40 – 61	47	39 – 60	48
Mn	0.65 – 1.53	0.97	0.34 – 0.80	0.53
Zn	6.33 – 11.84	8.99	6.43 – 8.74	7.69
Cu	0.75 – 3.10	2.15	2.40 – 5.30	4.17

Annenxure 10: Summary of Physical, Chemical and Micronutrient Characteristics of TFN3 Soil from Trofani in Bayelsa State, Southern Nigeria

	Surface 40 cm		Subsurface	
Parameters	**Range**	**Mean**	**Range**	**Mean**
Sand (%)	68-71	70	54-91	71
Silt (%)	25-27	26	8-36	22
Clay (%)	2-7	4	1-12	8
Silt/Clay Ratio	3.6-14.0	8.0	1.4-8.0	4.0
pH-H_2O	5.55-5.98	5.76	5.79-6.11	5.97
pH-$CaCl_2$	4.98-5.24	5.13	5.15-5.33	5.26
ΔpH	0.50-0.82	0.63	0.51-0.96	0.73
Organic C (%)	0.55-1.20	0.82	0.08-0.68	0.35
Organic Matter (%)	0.94-2.07	1.42	0.14-1.18	0.60
Total N (%)	0.05-0.10	0.07	0.01-0.06	0.03
C:N Ratio	11-12	12	8-11	10
Avail. P (Mg Kg^{-1})	3-15	9	4-10	7
Exch. Bases (cmol/kg)				
Ca^{2+}	0.75-1.24	0.93	0.74-0.95	0.80
Mg^{2}	0.34-0.93	0.65	0.06-1.01	0.49
K^{+}	0.46-0.94	0.64	0.19-0.88	0.55
Na	0.07-0.09	0.08	0.07-0.08	0.07
TEB	2.06-2.72	2.29	1.10-2.67	1.91
Exch. Acidity (cmol/kg)	1.60-1.80	1.70	1.40-4.60	2.43
Exch. Al (cmol/kg)	0.9-1.2	1.0	0.7-2.2	1.2
ECEC (cmol/kg)	3.66-4.52	3.99	3.05-5.70	4.34
Al Sat. (%)	26-27	26	20-39	26
PBS-ECEC (%)	55-60	57	19-57	47
ECe (ds/M)	0-0.05	0.02	0-0.13	0.03
Micronutrients (kg/kg)				
Fe	49 – 92	65	30 – 83	64
Mn	1.20 - 3.80	2.42	0.92 – 1.29	1.09
Zn	7.20 – 11.34	9.36	0.87 – 18.52	11.07
Cu	4.10 – 5.30	4.83	0.85 – 3.90	2.78

Annenxure 11: Summary of Physical, Chemical and Micronutrient Characteristics of ODI1 Soil from Odi in Bayelsa State, Southern Nigeria

	Surface 40 cm		Subsurface	
Parameters	**Range**	**Mean**	**Range**	**Mean**
Sand (%)	31	31	11-41	30
Silt (%)	56	56	41-67	57
Clay (%)	13	13	12-22	17
Silt/Clay Ratio	4.3	4.3	2.1-5.3	3.63
pH-H_2O	6.30	6.30	5.60-6.40	6.00
pH-$CaCl_2$	5.24	5.24	5.07-5.55	5.30
ΔpH	1.06	1.06	0.38-1.17	0.70
Organic C (%)	0.95	0.95	0.11-0.93	0.34
Organic Matter (%)	1.64	1.64	0.19-1.60	0.59
Total N (%)	0.04	0.04	0.01-0.04	0.02
C:N Ratio	24	24	6-28	15
Avail. P (Mg Kg^{-1})	13	13	6-19	11
Exch. Bases (cmol/kg)				
Ca^{2+}	0.77	0.77	0.63-0.75	0.71
Mg^{2+}	0.28	0.28	0.23-1.26	2.72
K	1.51	1.51	0.11-1.44	0.59
Na	0.07	0.07	0.03-0.07	0.05
TEB	2.63	2.63	1.14-2.96	1.90
Exch. Acidity (cmol/kg)	1.8	1.8	1.50-2.50	1.81
Exch. Al (cmol/kg)	1	1	0.8-1.2	0.9
ECEC (cmol/kg)	4.43	4.43	2.74-4.56	3.72
Al Sat. (%)	23	23	20-34	26
PBS-ECEC (%)	59	59	36-65	50
ECe (ds/M)	0.08	0.08	0.06-0.26	0.15
Micronutrients (mg/kg)				
Fe	41	41	37 – 89	68
Mn	3.05	3.05	1.17 – 3.23	2.01
Zn	18.00	18.00	4.53 – 12.38	8.83
Cu	3.65	3.65	2.20 – 4.10	3.11

Annenxure 12: Summary of Physical, Chemical and Micronutrient Characteristics of ODI2 Soil from Odi in Bayelsa State, Southern Nigeria

	Surface 40 cm		Subsurface	
Parameters	**Range**	**Mean**	**Range**	**Mean**
Sand (%)	41-42	42	15-35	26
Silt (%)	45-47	46	51-69	60
Clay (%)	11-14	13	12-18	16
Silt/Clay Ratio	3.2-4.3	3.8	3.4-4.8	4.02
pH-H_2O	5.70-6.08	5.89	6.00-6.10	6.03
pH-$CaCl_2$	4.78-5.31	5.05	5.13-5.47	5.34
ΔpH	0.39-1.30	0.85	0.55-0.97	0.70
Organic C (%)	0.46-1.58	1.02	0.11-0.20	0.17
Organic Matter (%)	0.80-2.72	1.76	0.19-035	0.29
Total N (%)	0.04-0.14	0.09	0.01-0.02	0.02
C:N Ratio	11-12	12	10-17	12
Avail. P (Mg Kg^{-1})	16-19	18	6-13	9
Exch. Bases (cmol/kg)				
Ca^{2+}	0.74-0.78	0.76	0.44-1.13	0.76
Mg^{2+}	0.22-0.25	0.24	0.48-1.12	0.78
K^{+}	0.73-0.77	0.75	0.10-1.44	0.70
Na^{+}	0.07-0.08	0.08	0.06-0.08	0.07
TEB	1.81-1.83	1.82	1.48-3.77	2.30
Exch. Acidity (cmol/kg)	1.7-2.50	2.10	0.90-2.70	1.90
Exch. Al (cmol/kg)	0.9-1.3	1.1	0.4-1.4	1.0
ECEC (cmol/kg)	3.53-4.31	3.92	2.38-5.87	4.20
Al Sat. (%)	25-30	28	17-30	23
PBS-ECEC (%)	42-52	47	42-64	55
ECe (ds/M)	0.02-0.05	0.04	0.04-0.22	0.10
Micronutrients (mg/kg)				
Fe	70 -99	85	59 – 86	74
Mn	2.66 – 4.23	3.45	1.59 – 2.44	2.02
Zn	3.24 – 4.21	3.73	7.38 – 9.86	8.33
Cu	2.70 – 5.20	3.95	3.10 – 5.55	3.86

Annenxure 13: Summary of Physical, Chemical and Micronutrient Characteristics of ODI3 Soil from Odi in Bayelsa State, Southern Nigeria

	Surface 40 cm		Subsurface	
Parameters	**Range**	**Mean**	**Range**	**Mean**
Sand (%)	21-35	28	15-37	22
Silt (%)	57-63	59	53-65	63
Clay (%)	8-16	13	10-20	15
Silt/Clay Ratio	3.9-7.1	5.0	3.3-5.3	4.3
pH-H_2O	5.67-6.30	5.95	5.90-6.20	6.03
pH-$CaCl_2$	5.37-5.40	5.39	5.11-5.32	5.22
ΔpH	0.30-0.90	0.70	0.67-0.97	0.83
Organic C (%)	0.38-5.25	2.27	0.21-0.34	0.25
Organic Matter (%)	0.65-9.05	3.92	0.36-0.58	0.43
Total N (%)	0.03-0.45	0.18	0.02-0.03	0.02
C:N Ratio	12-24	16	11-13	12
Avail. P (Mg Kg^{-1})	7-21	12	2-12	7
Exch. Bases (cmol/kg)				
Ca^{2+}	0.71-0.83	0.77	0.65-0.85	0.75
Mg^{2}	0.17-0.52	0.31	0.02-0.87	0.30
K	0.19-0.23	0.20	0.11-0.73	0.50
Na	0.07-0.08	0.07	0.04-0.08	0.07
TEB	1.22-1.62	1.36	0.82-2.25	1.61
Exch. Acidity (cmol/kg)	2.0-2.8	2.4	1.8-5.0	2.6
Exch. Al (cmol/kg)	1.0-1.7	1.3	0.9-3.0	1.3
ECEC (cmol/kg)	3.22-4.24	3.76	3.32-5.82	4.17
Al Sat. (%)	31-38	35	20-51	30
PBS-ECEC (%)	34-38	36	14-51	41
ECe (ds/M)	0.07-0.33	0.17	0.0-0.16	0.10
Micronutrients (mg/kg)				
Fe	44 – 79	62	35 – 65	48
Mn	1.60 – 2.80	2.14	0.84 – 2.42	1.48
Zn	5.69 – 15.70	9.68	7.65 – 9.73	8.76
Cu	2.50 – 6.30	4.40	2.80 – 3.90	3.32

Annenxure 14: Summary of Physical, Chemical and Micronutrient Characteristics of KRM1 Soil from Koroama in Bayelsa State, Southern Nigeria

	Surface 40 cm		Subsurface	
Parameters	**Range**	**Mean**	**Range**	**Mean**
Sand (%)	20-24	22	16-21	18
Silt (%)	61-64	63	60-69	64
Clay (%)	14-15	15	15-19	18
Silt/Clay Ratio	4.1-4.6	4.4	3.2-4.6	3.7
pH-H_2O	5.48-5.79	5.64	5.77-6.18	5.98
pH-$CaCl_2$	5.02-5.30	5.16	5.05-5.55	5.37
ΔpH	0.18-0.77	0.48	0.33-0.73	0.62
Organic C (%)	1.76-1.84	1.80	0.37-1.03	0.75
Organic Matter (%)	3.03-3.18	3.15	0.64-1.78	1.29
Total N (%)	0.1-0.11	0.11	0.02-0.05	0.04
C:N Ratio	17-18	18	19-21	20
Avail. P (Mg Kg^{-1})	20-21	21	5-14	9
Exch. Bases (cmol/kg)				
Ca^{2+}	0.75-1.35	1.05	0.30-0.85	0.65
Mg^{2+}	0.02-0.15	0.09	0.37-1.02	0.52
K	0.33-0.73	0.53	0.16-1.15	0.66
Na^{+}	0.07-0.12	0.1	0.03-0.08	0.06
TEB	1.57-1.95	1.76	1.93-2.29	2.00
Exch. Acidity (cmol/kg)	1.3-1.5	1.4	1.0-4.9	2.83
Exch Al (cmol/kg)	0.7	0.7	0.6-2.4	1.5
ECEC (cmol/kg)	2.87-3.58	3.16	2.93-6.43	4.83
Al Sat. (%)	20-24	22	20-37	29
PBS-ECEC (%)	55-57	56	24-66	46
ECe (ds/M)	0.09-0.30	0.20	0-0.23	0.09
Micronutrients (mg/kg)				
Fe	42 – 53	48	32 – 59	40
Mn	2.00 – 3.20	2.60	1.64 – 2.89	2.16
Zn	7.21 – 7.65	7.43	3.47 – 7.85	5.33
Cu	2.30 2.40	2.35	0.80 – 3.10	2.35

Annenxure 15: Summary of Physical, Chemical and Micronutrient Characteristics of KRM2 Soil from Koroama in Bayelsa State, Southern Nigeria

	Surface 40 cm		Subsurface	
Parameters	**Range**	**Mean**	**Range**	**Mean**
Sand (%)	19-27	23	18-19	18
Silt (%)	53-67	61	53-70	65
Clay (%)	9-28	16	12-29	17
Silt/Clay Ratio	1.9-7.4	5.4	1.8-5.8	4.4
pH-H_2O	5.55-6.39	6.01	6.15-6.49	6.28
pH-$CaCl_2$	4.27-5.00	4.64	5.04-5.52	5.36
ΔpH	0.89-1.83	1.37	0.63-1.45	0.94
Organic C (%)	0.43-1.30	0.76	0.230.45	0.36
Organic Matter (%)	0.74-2.24	1.32	0.40-0.78	0.63
Total N (%)	0.03-0.06	0.04	0.02-0.03	0.03
C:N Ratio	14-22	18	12-17	15
Avail. P (Mg Kg^{-1})	16-22	19	4-15	9
Exch. Bases (cmol/kg)				
Ca^{2}	0.81-0.93	0.88	0.60-1.53	0.91
Mg^{2+}	0.07-0.82	0.41	0.35-1.24	0.79
K	0.09-0.41	0.24	0.12-0.27	0.21
Na	0.04-0.08	0.06	0.04-0.11	0.07
TEB	1.14-2.04	1.53	1.11-3.03	1.47
Exch. Acidity (cmol/kg)	1.7-5.4	3.37	0.7-2.1	1.5
Exch. Al (cmol/kg)	0.8-3.8	2.0	0.3-09	0.7
ECEC (cmol/kg)	2.84-6.80	4.89	2.71-5.13	3.47
Al Sat. (%)	28-59	38	10-30	22
PBS-ECEC (%)	21-40	34	41-77	56
ECe (ds/M)	0.02-0.09	0.07	0.09-0.21	0.15
Micronutrients (mg/kg)				
Fe	31 – 95	63	62 – 94	76
Mn	1.80 – 2.02	1.91	1.40 – 1.86	1.65
Zn	7.31 – 10.76	8.83	6.75 – 12.05	9.01
Cu	1.70 – 4.70	2.15	2.95 – 6.95	4.03

Annenxure 16: Summary of Physical, Chemical and Micronutrient Characteristics of KRM3 Soil from Koroama in Bayelsa State, Southern Nigeria

	Surface 40 cm		**Subsurface**	
Parameters	**Range**	**Mean**	**Range**	**Mean**
Sand (%)	10-30	25	16-18	15
Silt (%)	60-64	62	54-67	61
Clay (%)	9-16	13	16-30	29
Silt/Clay Ratio	4.0-6	5.4	1.8-2.3	2.1
pH-H_2O	5.67-6.09	5.88	5.72-6.35	6.11
pH-$CaCl_2$	5.51-5.52	5.52	4.15-5.40	5.07
ΔpH	0.16-0.57	0.37	0.32-2.09	1.04
Organic C (%)	0.31-1.29	0.80	0.14-0.45	0.29
Organic Matter (%)	0.54-2.22	1.38	0.20-0.77	0.49
Total N (%)	0.02-0.06	0.04	0.01-0.02	0.02
C:N Ratio	16-22	19	14-23	19
Avail. P (Mg Kg^{-1})	18-20	19	6-14	10
Exch. Bases (cmol/kg)				
Ca^{2+}	0.75-0.86	0.81	0.70-2.05	1.28
Mg^{2+}	0.09-0.53	0.31	0.53-1.12	0.76
K^+	0.12-0.24	0.18	0.18-0.52	0.35
Na^+	0.05-0.07	0.06	0.04-0.08	0.07
TEB	1.03-1.68	1.36	1.71-3.32	2.45
Exch. Acidity (cmol/kg)	1.7-1.8	1.8	1.0-2.1	1.8
Exch. Al (cmol/kg)	0.7	0.7	0.5-1.0	0.8
ECEC (cmol/kg)	2.83-3.38	3.11	3.96-4.52	4.20
Al Sat. (%)	21-25	23	11-25	19
PBS-ECEC (%)	36-50	43	40-78	58
ECe (ds/M)	0.08-0.32	0.20	0-0.07	0.03
Micronutrients (mg/kg)				
Fe	42 – 65	54	42 – 66	59
Mn	1.20 – 1.33	1.27	0.97 – 1.30	1.12
Zn	6.54 – 8.55	7.55	4.45 – 12.05	8.56
Cu	2.60 – 4.30	3.45	2.80 – 7.05	4.21

Annenxure 17: Summary of Physical, Chemical and Micronutrient Characteristics of NDU1 Soil from Niger Delta University Wilberforce Island in Bayelsa State, Southern Nigeria

	Surface 40 cm		Subsurface	
Parameters	**Range**	**Mean**	**Range**	**Mean**
Sand (%)	10-20	15	13-17	15
Silt (%)	61-73	67	59-72	64
Clay (%)	7-29	18	10-30	21
Silt/Clay Ratio	2.1-10.4	6.3	2.0-7.2	3.9
pH-H_2O	5.58-5.69	5.64	5.92-6.32	6.13
pH-$CaCl_2$	4.53-5.45	4.99	4.28-5.49	4.79
ΔpH	0.13-1.16	0.65	0.43-1.99	1.34
Organic C (%)	1.48-1.51	1.50	0.29-0.50	0.38
Organic Matter (%)	2.56-2.60	2.58	0.50-0.87	0.66
Total N (%)	0.06	0.06	0.02-0.03	0.03
C:N Ratio	25	25	14-17	16
Avail. P (Mg Kg^{-1})	5-11	8	0.6-1	1
Exch. bases (cmol/kg)				
Ca^{2+}	0.75-1.25	1.00	0.70-1.10	0.90
Mg^{2+}	0.99-1.63	1.31	0.10-1.35	0.77
K	0.16-0.35	0.26	0.09-0.43	0.27
Na^+	0.05-0.09	0.07	0.04-0.09	0.06
TEB	2.14-3.13	2.64	0.93-2.48	2.00
Exch. Acidity (cmol/kg)	2.3-4.0	3.2	1.1-3.3	2.0
Exc. Al (cmol/kg)	1.0-2.3	1.8	0.6-1.8	1.1
ECEC (cmol/kg)	4.44-7.14	5.79	2.03-5.78	4.00
Al Sat. (%)	23-32	28	18-31	26
PBS-ECEC (%)	44-48	46	43-63	50
ECe (ds/M)	0.08-0.29	0.19	0.09-0.21	0.14
Micronutrients (mg/kg)				
Fe	61 – 64	63	57 – 78	68
Mn	1.49 – 1.56	1.53	1.41 – 2.14	1.86
Zn	1.97 – 7.68	4.83	3.85 – 8.85	5.36
Cu	2.50 – 3.80	3.15	3.20 – 4.30	3.75

Annenxure 18: Summary of Physical, Chemical and Micronutrient Characteristics of NDU2 Soil from Niger Delta University Wilberforce Island in Bayelsa State, Southern Nigeria

	Surface 40 cm		Subsurface	
Parameters	**Range**	**Mean**	**Range**	**Mean**
Sand (%)	13-22	18	15-19	17
Silt (%)	59-61	60	57-70	61
Clay (%)	18-28	22	14-28	22
Silt/ Clay Ratio	2.1-3.3	2.9	1.9-5.0	3.0
pH-H_2O	5.64-6.07	5.88	6.01-6.15	6.08
pH-$CaCl_2$	5.40-5.49	5.45	4.22-5.50	4.88
ΔpH	0.19-0.66	0.43	0.57-1.93	1.20
Organic C (%)	0.93-2.06	1.41	0.23-0.59	0.46
Organic Matter (%)	1.61-3.56	2.44	0.40-1.01	0.79
Total N (%)	0.05-0.10	0.07	0.01-0.03	0.02
C:N Ratio	19-21	20	18-23	20
Avail. P (Mg Kg^{-1})	1-2	2	1-3	2
Exch. Bases (cmol/kg)				
Ca^{2+}	0.57-1.25	0.63	0.58-0.75	0.67
Mg^{2+}	0.12-0.55	0.37	0.51-0.90	0.64
K^+	0.24-0.43	0.36	0.15-0.32	0.21
Na	0.04-0.09	0.06	0.04-0.07	0.06
TEB	1.45-1.81	1.65	1.54-1.70	1.61
Exch. Acidity (cmol/kg)	1.8-3.4	2.7	0.9-4.5	3.07
Exch. Al (cmol/kg)	0.7-2.0	1.5	0.4-2.4	1.6
ECEC (cmol/kg)	3.50-5.21	4.35	2.48-6.20	4.67
Al Sat. (%)	20-44	34	16-39	31
PBS-ECEC (%)	33-49	39	27-64	40
ECe (ds/M)	0.02-0.11	0.07	0-0.07	0.03
Micronutrients (mg/kg)				
Fe	48 – 67	60	60 – 83	73
Mn	1.10 – 1.90	1.57	1.30 – 2.51	1.70
Zn	6.53 – 14.42	11.01	3.00 – 8.02	6.27
Cu	1.60 – 4.20	2.77	2.90 – 3.70	3.33

Annenxure 19: Summary of Physical, Chemical and Micronutrient Characteristics of NDU3 Soil from Niger Delta University Wilberforce Island in Bayelsa State, Southern Nigeria

	Surface 40 cm		**Subsurface**	
Parameters	**Range**	**Mean**	**Range**	**Mean**
Sand (%)	16-17	16	14-15	15
Silt (%)	69	69	66-69	67
Clay (%)	14-15	15	16-19	18
Silt/Clay Ratio	4.6-4.9	4.7	3.5-4.3	3.8
pH-H_2O	5.42-5.90	5.68	6.03-6.14	6.09
pH-$CaCl_2$	5.20-5.53	5.39	5.25-5.55	5.42
Δ*pH*	0.22-0.37	0.29	0.58-0.75	0.64
Organic C (%)	1.23-2.81	2.22	0.59-0.92	0.75
Organic Matter (%)	2.12-4.84	3.82	1.02-1.58	1.29
Total N (%)	0.06-0.22	0.14	0.03-0.04	0.04
C:N Ratio	13-22	18	19-23	21
Avail. P (Mg Kg^{-1})	0.9-3	2	3-4	4
Exch. Bases (cmol/kg)				
Ca^{2+}	0.50-0.69	0.63	0.75-0.92	0.85
Mg^{2+}	0.10-0.39	0.29	0.13-0.32	0.22
K	0.15-0.44	0.29	0.44-0.60	0.53
Na	0.03-0.05	0.04	0.05-0.08	0.06
TEB	0.97-1.57	1.25	1.53-1.90	1.66
Exch. Acidity (cmol/kg)	1.5-2.3	1.8	1.7-1.8	1.7
Exch Al (cmol/kg)	0.8-1.0	0.9	0.7-0.8	0.8
ECEC (cmol/kg)	2.90-3.27	3.08	3.23-3.70	3.39
Al Sat. (%)	26-31	28	22-25	23
PBS-ECEC (%)	30-51	41	47-51	49
ECe (ds/M)	0.09-0.43	0.21	0.11-0.13	0.12
Micronutrients (mg/kg)				
Fe	34 – 99	59	81 – 88	85
Mn	1.20 – 1.51	1.37	2.51 - 2.80	2.67
Zn	6.51 – 13.91	9.31	9.00 – 9.74	9.29
Cu	2.60 – 5.70	4.10	3.60 – 3.80	3.70

Annenxure 20: Summary of criteria for Land Capability Classification (Adopted from Ogunkunle and Bbabalola, 1986).

Limitation	Arable Crops				Non-Arable Crops			
	I	II	III	IV	V	VI	VII	VIII
Slope angle (degrees)	0-2	3-4	4-5	5-10	10-20	20-35	›35	
Wetness	nil	Nil	Slight	slight	mod	mod	severe	Severe
Effective Depth (cm)	150	100	60	30	20	20	30	
Texture	Scl/c	Sl/c	Sl/c	Ls/c	Ls/heavy c	Ls/heavy c	Ls/heavy c	Ls/heavy c
ECEC-subsoil Cmol/kg	15	10-15	5-10	2-5	2-5	1-2	0-1	2-5

*Flooding f0- no flooding, f1- flooding for less than 1month, f2- flooding for 1-2months, f3- flooding for 3-6months, f4- flooding for more than 6months

Annexure 21: Evaluation of capability index for different groups of crops (Van Ranst and Verdoodt, 2005)

Capability Classes	Cocoa (Exacting)	Cotton (Moderately exacting)	Rubber (Less exacting)
Excellent	›90	›85	›75
High	70-90	65-85	50-75
Good	50-70	45-65	35-50
moderate	35-50	30-45	25-35
Low	25-35	15-30	10-25
Not capable	‹25	‹15	‹10

Annexure 22: Definition of Land Capability Classes (Van Ranst and Verdoodt, 2005)

capability		Crop group		
Classes	index	Exacting	Moderately exacting	Less exacting
I	›90	Excellent	Excellent	Excellent
II	70-90	High	Excellent-high	Excellent
III	50-70	Good	High-good	High
IV	35-50	Moderate	Good-moderate	Good
V	25-35	Low	Moderate-low	Moderate
VI	‹25	Not capable	Low-uncapable	Low-uncapable

Annexure 23: Ratings for Profile Development (Van Ranst and Verdoodt, 2005)

	Profile development	Rating
1	Absence of diagnostic subsurface horizons (A-C profiles, or profiles with a cambic or argillic horizon but with a CEC ≥24cmol(+) kg^{-1} clay	100
2	Cambic or argillic horizon with a CEC ‹24 24cmol(+) kg^{-1} clay and a Munshell chroma (moist) ≤4	95
3	Argillic horizon with a good structure, a CEC‹24 cmol(+) kg^{-1} clay, a Munshell chroma (moist) ›4 and ›50% clay cutans on ped faces	90
4	Argillic horizon with a good structure, a CEC‹24 cmol(+) kg^{-1} clay, a Munshell chroma (moist) ›4 and ‹50 clay on ped faces	85
5	Oxic horizon with some (good) structure and some patchy clay skins	80
6	Oxic horizon with weak structure and almost without patchy clay skins	75
7	Oxic horizon with a very weak structure but having a net negative charge	65
8	Oxic horizon with a very weak structure, a bleached A2(E) horizon and/or a positive charge	55

Annexure 24: Rating for soil texture of the fine earth (Van Ranst and Verdoodt, 2005)

Textural class USDA triangle	Rating						
	≤15 vol% coarse fragments	›15 vol% coarse fragments					
		Rock fragments		Laterite gravel		Quartz	
		Gavely[1]	Very gravely[2]	gravely	Very gravely	Gravely	Very gravely
Clay ›75%	75	85	60	80	60	-	-
Clay 60-75%	90	100	65	95	60	-	-
C ‹60%, SiC	100	90	75	85	60	-	-
SiCL	95	85	70	80	60	70	50
CL	90	80	65	75	55	65	50
SiL, Si	85	75	65	70	50	60	50
SC	80	70	60	65	50	55	50
L	75	70	60	65	50	55	50
SCL	70	65	55	60	50	50	45
SL	60	55	50	50	45	45	40
LS	50	45	40	40	35	35	30
S	40	35	30	30	25	25	20

[1] › 15 and ≤35 volume percent (vol%) coarse fragments (CF)

[2] ›35 and ≤75 volume percent (vol%) coarse fragments (CF)

Annexure 25: Ratings for soil depth (Van Ranst and Verdoodt, 2005)

Depth (cm)	Rating	
	annuals	Perennials
≥120	100	100
80-120	100	85
50-80	85	70
20-50	70	50
≤20	50	30

Annexure 26: Rating of colour/drainage class (Van Ranst and Verdoodt, 2005)

	Moist colour	Mottling (cm)	drainage	Rating	
				Annuals	Perennials
1	Red-%YR and redder	No	Well	100	100
2	Yellow-yellower than 5YR	›120	Well	95	95
3	-	80-120	Moderate	90	80
4	-	40-80	Imperfect	75	60
5	-	0-40	Poor	60	40
6	Reduced horizon in upper part		Very poor	50	25

Annexure 27: Rating of pH and base saturation (Van Ranst and Verdoodt, 2005)

B horizon		A horizon		Rating
pH	BS (%)	pH	BS (%)	
≥5.8	≥50	≥5.8	≥50	100
‹5.8	‹50	≥5.8	≥50	95
		5.2-5.8	35-50	90
		4.6-5.2	15-35	75
		‹4.6	‹15	60

Annexure 28: Ratings for the development of the topsoil (Van Ranst and Verdoodt, 2005)

Thickness classes (cm) of the dark coloured topsoil			Rating
Savannah	Forest	Cultivated	
-	›10	-*	125
›20	5-10	-	120
10-20	-	›20	110
5-10	2-5	10-20	100
2-5 (continuous)	-	5-10	80
2-5 (continuous	-	‹5	60
‹2	-	-	40

Annexure 29: Capability Classification of ELM1 Soil Mapping Unit

Factor	Parameter	Value	Rating	
			Annuals	Perennials
A	Profile development	ABC-profile	95	95
B	Texture		95	95
	Ap	Silt loam-no gravel		
	Ap2	Silt loam-no gravel		
	B1	Silty clay loam-no gravel		
	B2	Silty clay loam-no gravel		
	C1	Silt loam-no gravel		
	C2	Silt loam-no gravel		
	C3	Silt loam-no gravel		
	C4	Silt loam-no gravel		
C	Soil depth cm	200+	100	100
D	Drainage	Mottling 80-120cm	90	80
E	pH		98	98
	Ap	5.46		
	Ap2	5.62		
	B1	5.77		
	B2	5.73		
F	Development of topsoil		120	120
	-land use	Grassy vegetation		
	-value/chroma	A≤ 3/2		
	-thickness	›20		
Cs			97	85
Class			I	II

Annexure 30: Capability Classification of ELM2 Soil Mapping Unit

Factor	Parameter	Value	Rating	
			Annuals	Perennials
A	Profile development	ABC-profile	95	95
B	Texture		75	75
	Ap	Silt loam-no gravel		
	Ap2	Silt loam-no gravel		
	B1	Silt loam-no gravel		
	B2	Silt loam-no gravel		
	B3	Silt loam-no gravel		
	C1	Silt loam-no gravel		
	C2	Silt loam-no gravel		
	C3	Silt loam-no gravel		
C	Soil depth cm	190+	100	100
D	Drainage	Mottling 40-80cm	75	60
E	pH		95	95
	Ap	5.44		
	Ap2	5.74		
	B1	6.61		
	B2	6.04		
	B3	6.07		
F	Development of topsoil		110	110
	-land use	Plantain farm		
	-value/chroma	A≤3/3		
	-thickness	‹20		
Cs			56	45
Class			III	IV

Annexure 31: Capability Classification of ELM3 Soil Mapping Unit

Factor	Parameter	Value	Rating	
			Annuals	Perennials
A	Profile development	A-C profile	100	100
B	Texture		52	52
	A	Loamy sand-no gravel		
	Ap1	Loamy sand-no gravel		
	Ap2	Sandy loam-no gravel		
	C1	Loamy sand-no gravel		
	C2	Loamy sand-no gravel		
	C3	Sandy loam-no gravel		
	C4	Sandy loam-no gravel		
	C5	Sandy loam-no gravel		
C	Soil depth cm	200+	100	100
D	Drainage	-	100	100
E	pH		95	95
	A	5.52		
	Ap1	7.00		
	Ap2	6.15		
F	Development of topsoil		120	120
	-land use	Grassy vegetation		
	-value/chroma	A-3/6		
	-thickness (cm)	>20		
Cs			59	59
Class			III	III

Annexure 32: Capability Classification of ODN1 Soil Mapping Unit

Factor	Parameter	Value	Rating	
			Annuals	Perennials
A	Profile development	ABC-profile	95	95
B	Texture		85	85
	Ap	Silt loam-no gravel		
	Ap2	Silt loam-no gravel		
	B1	Silt loam-no gravel		
	B2	Silt loam-no gravel		
	B3	Silt loam-no gravel		
	C	Silt loam-no gravel		
C	Soil depth cm	200+	100	100
D	Drainage	Mottling 80-120cm	90	80
E	pH		95	95
	Ap	5.76		
	Ap2	5.75		
	B1	6.01		
F	Development of topsoil		120	120
	-land use	Plantain farm		
	-value/chroma	A- 2/2		
	-thickness	›20		
Cs			83	74
Class			II	II

Annexure 33: Capability Classification of ODN2 Soil Mapping Unit

Factor	Parameter	Value	Rating	
			Annuals	Perennials
A	Profile development	ABC-profile	95	95
B	Texture		85	85
	Ap	Silt loam-no gravel		
	Ap2	Silt loam-no gravel		
	B1	Silt loam-no gravel		
	B2	Silt loam-no gravel		
	BC	Silt loam-no gravel		
	C1	loam-no gravel		
	C2	loam-no gravel		
C	Soil depth cm	200+	100	100
D	Drainage	Mottling 40-80cm	75	60
E	pH		93	93
	Ap	5.64		
	Ap2	6.70		
	B1	5.38		
	B2	6.11		
F	Development of topsoil		120	120
	-land use	Grassy vegetation		
	-value/chroma	A- ¾		
	-thickness	›20		
Cs			68	54
Class			III	III

Annexure 34: Capability Classification of ODN3 Soil Mapping Unit

Factor	Parameter	Value	Rating	
			Annuals	Perennials
A	Profile development	ABC-profile	95	95
B	Texture		88	88
	A	Silt loam-no gravel		
	Ap1	Silt loam-no gravel		
	Ap2	Silt loam-no gravel		
	B1	Silt loam-no gravel		
	B2	Silty clay loam-no gravel		
	B3	Silty clay loam-no gravel		
	C1	loam-no gravel		
	C2	loam-no gravel		
C	Soil depth cm	200+	100	100
D	Drainage	Mottling 0-40cm	60	40
E	pH	5.67	95	95
	Ap	6.45		
	Ap2	5.97		
	B1	6.07		
	B2	6.45		
	B3	5.91		
F	Development of topsoil		120	120
	-land use	Grassy vegetation		
	-value/chroma	A- 3/2		
	-thickness	›20		
Cs			57	38
Class			III	IV

Annexure 35: Capability Classification of TFN1 Soil Mapping Unit

Factor	Parameter	Value	Rating	
			Annuals	Perennials
A	Profile development	ABC-profile	95	95
B	Texture		85	85
	Ap	Silt loam-no gravel		
	A	Silt loam-no gravel		
	B1	Silt loam-no gravel		
	B2	Silt loam-no gravel		
	B3	Silty clay loam-no gravel		
	C	Silt loam-no gravel		
C	Soil depth cm	200+	100	100
D	Drainage	Mottling 80-120cm	95	95
E	pH		93	93
	Ap	5.64		
	A	5.75		
	B1	5.88		
F	Development of topsoil		120	120
	-land use	Grassy vegetation		
	-value/chroma	A-3/4		
	-thickness	›20		
Cs			86	86
Class			II	II

Annexure 36: Capability Classification of TFN2 Soil Mapping Unit

Factor	Parameter	Value	Rating	
			Annuals	Perennials
A	Profile development	ABC-profile	95	95
B	Texture		79	79
	Ap	Loamy sand-no gravel		
	A2p	Silt loam-no gravel		
	B1	Silty clay loam-no gravel		
	B2	Silt loam-no gravel		
	C1	Silt loam-no gravel		
	C2	Loam-no gravel		
C	Soil depth cm	200+	100	100
D	Drainage	Mottling 40-80cm	75	60
E	pH		93	93
	Ap	6.16		
	A2p	6.15		
	B1	5.98		
	B2	6.80		
F	Development of topsoil		120	120
	-land use	Oil palm farm		
	-value/chroma	A- 3/3		
	-thickness (cm)	›20		
Cs			63	51
Class			III	III

Annexure 37: Capability Classification of TFN3 Soil Mapping Unit

Factor	Parameter	Value	Rating	
			Annuals	Perennials
A	Profile development	A-C profile	100	100
B	Texture		60	60
	A	Sandy loam-no gravel		
	Ap1	Sandy loam-no gravel		
	Ap2	Sandy loam-no gravel		
	C1	Sandy loam-no gravel		
	C2	Sandy loam-no gravel		
	C3	Sandy loam-no gravel		
	C4	Sand-no gravel		
C	Soil depth cm	200+	100	100
D	Drainage	Mottling -	100	100
E	pH		90	90
	A	5.74		
	Ap1	5.98		
	Ap2	5.55		
F	Development of topsoil		120	120
	-land use	Grassy vegetation		
	-value/chroma	A 3/3		
	-thickness	›20		
Cs			60	60
Class			III	III

Annexure 38: Capability Classification of ODI1 Soil Mapping Unit

Factor	Parameter	Value	Rating	
			Annuals	Perennials
A	Profile development	ABC-profile	95	95
B	Texture		78	78
	Ap	Silt loam-no gravel		
	A	Loam-no gravel		
	B1	Loam-no gravel		
	B2	Silt loam-no gravel		
	B3	Loam-no gravel		
	C1	Silt loam -no gravel		
	C2	Silt loam -no gravel		
	C3	Silt loam -no gravel		
C	Soil depth cm	200+	100	100
D	Drainage	Mottling 80-120cm	90	80
E	pH		90	90
	Ap	6.30		
	A	6.03		
	B1	6.40		
F	Development of topsoil		120	120
	-land use	Secondary forest		
	-value/chroma	A-3/3		
	-thickness	›20		
Cs			72	64
Class			II	III

Annexure 39: Capability Classification of ODI2 Soil Mapping Unit

Factor	Parameter	Value	Rating	
			Annuals	Perennials
A	Profile development	ABC-profile	95	95
B	Texture		75	75
	Ap	Loam-no gravel		
	A	Loam-no gravel		
	B1	Silt loam-no gravel		
	B2	Silt loam-no gravel		
	B3	Silt loam -no gravel		
	C	Silt loam-no gravel		
C	Soil depth cm	200+	100	100
D	Drainage	Mottling 40-80cm	75	60
E	pH		90	90
	Ap	5.70		
	A	6.08		
F	Development of topsoil		120	120
	-land use	Grassy vegetation		
	-value/chroma	A-3/4		
	-thickness	›20		
Cs			58	46
Class			III	IV

Annexure 40: Capability Classification of ODI3 Soil Mapping Unit

Factor	Parameter	Value	Rating	
			Annuals	Perennials
A	Profile development	ABC-profile	95	95
B	Texture		85	85
	Ah	Silt loam-no gravel		
	Ap1	Silt loam -no gravel		
	Ap2	Silt loam-no gravel		
	B1	Silt loam-no gravel		
	B2	Silt loam-no gravel		
	B3	Silt loam-no gravel		
	C1	Silt loam-no gravel		
	C2	Silt loam-no gravel		
C	Soil depth cm	200+	100	100
D	Drainage	Mottling 0-40cm	60	40
E	pH		90	90
	Ah	5.67		
	Ap1	5.89		
	Ap2	6.30		
	B1	6.20		
	B2	6.04		
F			120	120
	-land use	Oil palm farm		
	-value/chroma	A-2/2		
	-thickness	›20		
Cs			52	35
Class			III	IV

Annexure 41: Capability Classification of KRM1 Soil Mapping Unit

Factor	Parameter	Value	Rating	
			Annuals	Perennials
A	Profile development	ABC-profile	95	95
B	Texture		85	85
	A1	Silt loam-no gravel		
	A2	Silt loam-no gravel		
	B1	Silt loam-no gravel		
	B2	Silt loam-no gravel		
	BC	Silt loam-no gravel		
	C	Silt loam-no gravel		
C	Soil depth cm	200+	100	100
D	Drainage	Mottling 80-120cm	90	80
E	pH		90	90
	A1	5.79		
	A2	5.48		
	B1	6.12		
F	Development of topsoil		120	120
	-land use	Fallowed cassava farm		
	-value/chroma	A-3/4		
	-thickness	›20		
Cs			78	70
Class			II	II

Annexure 42: Capability Classification of KRM2 Soil Mapping Unit

Factor	Parameter	Value	Rating	
			Annuals	Perennials
A	Profile development	ABC-profile	95	95
B	Texture		90	90
	Ap	Silt loam-no gravel		
	Ap2	Silt loam-no gravel		
	B1	Silty clay loam-no gravel		
	B2	Silty clay loam-no gravel		
	B3	Silt loam-no gravel		
	C1	Silt loam-no gravel		
	C2	Silt loam-no gravel		
C	Soil depth cm	200+	100	100
D	Drainage	Mottling 40-80cm	75	60
E	pH		90	90
	Ap	5.55		
	Ap2	6.39		
	B1	6.10		
	B2	6.38		
	B3	6.49		
F	Development of topsoil		120	120
	-land use	Secondary bush		
	-value/chroma	A-3/2		
	-thickness	›20		
Cs			69	55
Class			III	III

Annexure 43: Capability Classification of KRM3 Soil Mapping Unit

Factor	Parameter	Value	Rating	
			Annuals	Perennials
A	Profile development	ABC-profile	95	95
B	Texture		91	91
	Ap	Silt loam-no gravel		
	Ap2	Silt loam-no gravel		
	B1	Silty clay loam-no gravel		
	B2	Silty clay loam-no gravel		
	B3	Silty clay loam-no gravel		
	C	Silt loam-no gravel		
C	Soil depth cm	200+	100	100
D	Drainage	Mottling 0-40cm	60	40
E	pH		90	90
	Ap	5.67		
	Ap2	6.09		
	B1	6.24		
	B2	5.72		
F	Development of topsoil		120	120
	-land use	Old plantain farm		
	-value/chroma	A-3/2		
	-thickness	›20		
Cs			56	37
Class			III	IV

Annexure 44: Capability Classification of NDU1 Soil Mapping Unit

Factor	Parameter	Value	Rating	
			Annuals	Perennials
A	Profile development	ABC-profile	95	95
B	Texture		93	93
	Ap	Silt loam-no gravel		
	B1	Silty clay loam-no gravel		
	B2	Silty clay loam-no gravel		
	B3	Silty clay loam-no gravel		
	C1	Silt loam-no gravel		
	C2	Silt loam-no gravel		
C	Soil depth cm	200+	100	100
D	Drainage	Mottling 80-120cm	90	80
E	pH		90	90
	Ap	5.58		
	B1	5.69		
	B2	6.07		
	B3	5.92		
F	Development of topsoil		120	120
	-land use	Fallowed farmland		
	-value/chroma	A-3/3		
	-thickness	‹20		
Cs			86	76
Class			II	II

Annexure 45: Capability Classification of NDU2 Soil Mapping Unit

Factor	Parameter	Value	Rating	
			Annuals	Perennials
A	Profile development	ABC-profile	95	95
B	Texture		90	90
	Ap	Silt loam-no gravel		
	Ap2	Silt loam-no gravel		
	B1	Silty clay loam-no gravel		
	B2	Silty clay loam-no gravel		
	B3	Silt loam-no gravel		
	C	Silt loam-no gravel		
C	Soil depth cm	200+	100	100
D	Drainage	Mottling 40-80cm	75	60
E	pH		90	90
	Ap	5.64		
	Ap2	5.92		
	B1	6.06		
	B2	6.01		
F	Development of topsoil		120	120
	-land use	Fallowed farmland		
	-value/chroma	A-4/4		
	-thickness	›20		
Cs			69	55
Class			III	III

Annexure 46: Capability Classification of NDU3 Soil Mapping Unit

Factor	Parameter	Value	Rating	
			Annuals	Perennials
A	Profile development	ABC-profile	95	95
B	Texture		85	85
	A1	Silt loam-no gravel		
	A2	Silt loam-no gravel		
	AB	Silt loam-no gravel		
	B1	Silt loam-no gravel		
	B2	Silt loam-no gravel		
	C	Silt loam-no gravel		
C	Soil depth cm	200+	100	100
D	Drainage	Mottling 0-40cm	60	40
E	pH		90	90
	A1	5.42		
	A2	5.72		
	AB	5.90		
	B1	6.03		
F	Development of topsoil		120	120
	-land use	Grass land		
	-value/chroma	A-3/3/		
	-thickness	‹20		
Cs			52	35
Class			III	IV